D4.8 - Fuel cell bus rollout in Sweden. Developing pathways to post-JIVE deployment in Scandinavia

Best Practice Tool for Sweden with reference to the broader Norther European context

ZERO EMISSION

JIVEs / MEHRLIN projects



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Clean Hydrogen Partnership

Co-funded by the European Union

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Dissemination status: Final

Dissemination level: Public

Date: 01/04/2024

Approval process

Steps	**Status**
Work Package Leader	Approved
Coordinator	Approved
Clean Hydrogen Partnership	Pending/approved

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Fuel cell bus rollout in Sweden. Developing pathways to post-JIVE deployment in Scandinavia.

The aim of this study is to identify the obstacles that prevented the rollout of buses in any Swedish city and to compile these findings into recommendations for a successful future implementation. This study is primarily based on interviews with stakeholders involved in initial discussions and processes that began positively but ultimately led to no buses being deployed in Sweden as part of the project.

Due to the significant financial commitment required for a minimum of five buses in the JIVE 2 project, Sandviken opted to purchase two buses independently. Some challenges were encountered in reaching interviewees who have since left their positions since the JIVE 2 discussions took place. As a result, the study focuses on the available interviewees from Gävleborg and western Sweden, along with representatives from the bus manufacturer Solaris and Hydrogen Sweden.

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Executive summary

What Has Happened So Far

The rollout of fuel cell buses in Sweden has encountered significant barriers, resulting in no deployment under the JIVE 2 project in any Swedish cities. An exception to this was Sandviken, which independently acquired two buses after opting not to commit to the purchase of the minimum of five buses required by the project. This decision underscores the financial and logistical challenges that have substantially impacted the broader adoption of fuel cell technology in public transport.

Issues primarily stemmed from several challenges encountered during the initial planning and discussion phases. These included difficulties in securing commitments from regions, who operate mass transit in Sweden. Furthermore, the prevailing economic considerations, coupled with existing technological and infrastructure readiness, favoured more established alternatives like biogas buses, which already had a developed supply and refuelling infrastructure. Since all buses across the approached regions are procured under public procurement regulations, cost was a major focus. In the JIVE 2 project, the primary challenge was getting the concerned regions to trial new technologies.

Biogas, sourced from local facilities and primarily produced by municipalities, better aligned with the regions' existing knowledge and experience in transportation and fuels, particularly given the focus on CO2 rather than air quality. This alignment made biogas a less risky and more readily implementable solution compared to hydrogen buses, which necessitated substantial initial investments in new infrastructure and maintenance facilities.

Current State in Sweden

Sweden's bus fleet is undergoing a gradual transition towards electrification, prominently featuring battery electric vehicles (BEVs), supported by Sweden's nearly entirely fossil-free electricity grid.

The grid, primarily powered by hydro, nuclear, and wind energy, provides a clean electricity supply that enhances the environmental benefits of electric buses. The bus suppliers taking part in public procurement processes do not have to account for charging infrastructure when offering BEVs, making it a cost-effective alternative as they do not have to take grid deficiencies into account.

However, the regions must take this issue into consideration. This may involve upgrading power grids to accommodate the increased load from bus depots or public charging stations, adding significant hidden expenses to the transition to electric buses. These costs are often not reflected in the initial vehicle procurement expenses but are crucial for the operational feasibility of BEVs in public transportation networks. With hydrogen fuel cell buses, hydrogen can be stored to put less stress on the grid on high load hours.

The presence of ambitious hydrogen projects, like HYBRIT (Hydrogen Breakthrough Ironmaking Technology) and H2 Green Steel, further illustrates the potential for integrating public transportation needs with industrial hydrogen use. These projects not only aim to reduce carbon emissions in steel production—one of the most energy-intensive industries—but also offer a blueprint for how large-scale hydrogen use can be implemented in other sectors, including public transport.

Despite these advancements, the shift from traditional diesel to hydrogen fuel cell buses has encountered significant challenges. The transition involves not just replacing old buses with new ones but also entails comprehensive changes in infrastructure, such as building new hydrogen refuelling stations (HRS), training staff for both handling gas and high voltage electricity, and ensuring public and regulatory acceptance.

Effective project management and strategic planning are crucial to address these challenges. The complexity of the project management involves synchronizing the technological, financial, and operational aspects of introducing new types of buses into the existing fleet, requiring meticulous attention to detail and robust stakeholder engagement to ensure smooth implementation.

Future Recommendations

To ensure a more successful rollout of fuel cell buses in Sweden, several strategic actions are recommended:

- **Enhanced Infrastructure Development:**
    - Prioritize the expansion of HRS to support the operational needs of fuel cell buses.
    - Leverage synergies with large-scale hydrogen projects for integrated hydrogen infrastructure development.
- **Policy Adjustments and Incentives:**
    - Adjust policies in a way that makes hydrogen fuel cell buses a good complement to BEVs and biogas buses, recognizing the nearly fossil-free nature of Sweden's electricity grid which enhances the sustainability of electrolytic hydrogen.
    - Implement financial incentives and subsidies that specifically support the higher initial costs and infrastructure needs of hydrogen buses.
- **Focused Education and Communication:**
    - Develop targeted educational campaigns to raise awareness about the benefits of hydrogen fuel technology, addressing misconceptions about safety and efficiency.
    - Communicate the environmental advantages of hydrogen buses over biogas, especially in terms of zero tailpipe emissions and higher energy efficiency.
- **Strengthened Public-Private Partnerships:**
    - Foster collaborations between municipalities, bus manufacturers, energy providers, and technology firms to share knowledge, risks, and rewards.
    - Engage in pilot projects that allow for real-world testing of fuel cell buses, generating data to inform larger-scale deployments.
- **Improved Procurement Strategies:**
    - Standardize and streamline procurement processes to reduce complexities and encourage more bids from bus manufacturers.

- Link bus procurement strategies with the development of hydrogen refuelling infrastructure to ensure coordinated growth.

By addressing these areas, Sweden can enhance its public transportation network's sustainability and efficiency, aligning with its environmental goals and to better align with the EU strategy in the adoption of clean transportation technologies.

Fuel cell buses competitive advantage over alternative drivetrain technologies.

There are several aspects of advantages with fuel cell buses compared to biogas buses:

- Enhanced passenger comfort due to a smoother ride
- Easier for driver to operate
- No particle matter or NOx from the tail pipe
- Higher energy efficiency

Comfortable and easy to drive

A fuel cell bus, with its electric drivetrain, offers a driving and riding experience very similar to that of a battery electric bus, whereas a biogas bus, with its combustion engine, feels more like a diesel bus. The electric drivetrain operates without gears, providing smoother acceleration and deceleration, aided by regenerative braking. This not only enhances passenger comfort but also reduces the risk of standing passengers losing balance. Additionally, the low noise levels—both outside the bus as it arrives and inside during travel—further improve passenger wellbeing. This is a key factor in encouraging people to shift from private cars to public transport.

Local emissions

While combustion in the engine of a biogas bus produces both particles and NOx, the levels of these emissions are significantly lower than those from diesel buses. Importantly, neither emissions are generated in the fuel cell or elsewhere in the vehicle. The only byproduct is pure water. Local emissions can have several consequences. When examining NOx, the following impacts are particularly significant:

- NOx emissions contribute to the formation of ground-level ozone and fine particulate matter (PM2.5), both of which are harmful to human health. Exposure to these pollutants can lead to respiratory problems, heart disease, and can exacerbate conditions such as asthma and bronchitis. Reducing NOx emissions helps lower the concentrations of these harmful pollutants, thereby reducing health risks to city inhabitants.
- NOx plays a significant role in the formation of acid rain, which can damage forests, soils, and aquatic systems. It also contributes to the eutrophication of water bodies, leading to the depletion of oxygen in rivers and lakes and harming aquatic life. Lowering NOx levels helps protect ecosystems and maintain biodiversity.
- Some forms of NOx, particularly nitrous oxide (N2O), are potent greenhouse gases with a much higher global warming potential than carbon dioxide (CO2). Reducing NOx emissions can contribute to efforts to mitigate climate change by decreasing the concentration of these gases in the atmosphere.
- NOx contributes to the formation of smog, which can significantly reduce visibility in urban areas. This not only affects the quality of life by obscuring the skyline and landscape but can also have safety implications for transportation.
- Cities need to lower NOx levels to comply with regulations and avoid potential penalties. This also includes meeting international agreements and commitments aimed at reducing air pollution and protecting the climate.

- According to data from the Swedish Environmental Protection Agency, road traffic in Sweden generated in 2023 particulate matter (PM2.5) emissions of 2,290 tons and NOX emissions of 33,050 tons, of which approximately 5% was allocated to emissions from buses. Based on the 'Handbook On The External Costs of Transport' issued by the European Commission in 2019, the assessed total societal costs of this pollution in Sweden correspond annually to approximately €28 million.

Energy efficiency

Fuel cells convert hydrogen directly into electricity, water, and heat through an electrochemical process without combustion. This process is inherently more efficient than the combustion process used in biogas engines. Fuel cells can achieve energy conversion efficiencies of 50-60%. In contrast, internal combustion engines (ICEs), including those powered by biogas, typically have lower efficiencies, often around 25-35%.

Fuel cell electric buses often incorporate electric drivetrains that can use regenerative braking to recapture energy that would otherwise be lost in a conventional braking system. This energy is then stored in batteries and can be used to power the bus, further improving overall efficiency. Especially for city buses this is important as the distance between stops is short, leading to frequent acceleration and deceleration.

Range, refuelling time and flexibility compared to BEV

It also provides advantages to electric buses:

- Longer range making it easier to plan different routes and more flexible to re-route when vehicle malfunction or road blocking events take place.
- Faster refuelling than recharging, resulting in higher number of vehicles being served from a given infrastructure facility.
  The possibility to produce hydrogen from electrolysers when electricity prices are low and the grid allows it, compared to fast charging, especially on grid peak hours which coincides with peaks in public transportation travels.

On a single refuelling, FCEVs have a longer driving range compared to their BEV counterparts. This longer range allows transit authorities to plan a diverse array of routes without the constraints imposed by the need for frequent recharging stops. Buses can cover longer distances, serve more remote areas, and operate for extended hours, catering to a wider demographic and geographic area. This flexibility is critical for cities looking to expand their public transportation networks efficiently and inclusively.

The unpredictability of daily operations due to vehicle malfunctions, accidents, or sudden road closures demands a transit fleet that can adapt quickly. FCEVs, with their longer range, provide this adaptability. In the event of a road being blocked or a vehicle malfunction, the ability to reroute buses without worrying about the immediate availability of charging stations is a logistical advantage. This ensures that the public transportation service remains reliable and timely, even in the face of unforeseen disruptions.

The requirement for fewer refuelling points due to the extended range of FCEVs eases the pressure on infrastructure development. While BEVs necessitate a dense network of charging stations to support their operation across a city, FCEVs can operate with a sparser network of

hydrogen refuelling stations. This characteristic can lead to cost savings in infrastructure development and faster deployment of alternative fuel buses across new areas.

As traffic intensity is at its highest in the morning and afternoon, it much coincides with electric grid peak hours. Having a large proportion of BEVs in the public transportation fleet hence further stresses the grid, if fast charging at end stations is applied. This could be countered by using overnight charging when the grid is less constrained; however, this requires more batteries in the buses making them heavier and more energy consuming.

Hydrogen on the other hand can be produced when electricity prices are low and the grid is less utilised (and used later), reducing investment needs in the grid and utilising intermittent renewable energy such as solar and wind better.

Innovative ways for local sites to finance and deploy FC Buses.

By creatively leveraging the local advantages with fuel cell buses and exploring innovative strategies, local sites can overcome the initial barriers to adopting FC buses by creating value in other sector than public transportation. These approaches not only make the projects financially viable but also enhance their contribution to local sustainability, resilience, and community well-being. As the technology and regulatory landscape evolve, these innovative strategies will play a crucial role in transitioning to cleaner, more sustainable transportation solutions.

Utilizing by-products from electrolysis

The electrolysis of water produces hydrogen and oxygen. The oxygen by-product can be sold to industries such as healthcare, welding, and aquaculture, providing an additional revenue stream to offset the costs of hydrogen production.

The regulatory process for manufacturing and distributing medical oxygen involves obtaining permits from the regulating body, with associated costs for manufacturing and registration. Most producers of medical oxygen employ air separation technology, requiring stringent purification processes.

While medical oxygen may not yield the highest returns per unit, its widespread use makes it an interesting option for energy storage concepts. There's potential synergy with hydrogen production at hospitals, providing redundancy for electricity supply and enabling hydrogen-powered vehicles.

To ensure continuous oxygen deliveries from electrolysis, surplus hydrogen must be managed effectively. Options include selling excess hydrogen to the natural gas network or using it for heating purposes. Although integrating hydrogen into existing natural gas networks presents technical challenges, it's feasible up to certain concentrations.

Electrolysis and fuel cell operations generate heat, which can be captured and used for local heating needs, such as district heating systems, greenhouses, or industrial processes. This not

only provides a source of revenue or cost savings but also improves overall energy efficiency. Electrolysers typically operate around 80 centigrade, making it a good fit for district heating, but it could also be used for heating sports centres or swimming pools, something that many municipalities own.

Deploying FC buses as mobile generators

FC buses can be equipped with power export capabilities, allowing them to serve as mobile generators during emergencies or in remote areas lacking infrastructure. In times of crisis, i.e., natural disasters or war, these buses can provide critical power to evacuation centres, hospitals, and relief operations.

Similarly, FC buses can supply electricity for public events, construction sites, or temporary installations where grid power is unavailable or insufficient. This application showcases the versatility of FC buses and can generate rental income or public relations benefits.

Why fuel cell buses have not yet been deployed in the area.

The deployment of Fuel Cell Buses (FCBs) in Sweden encounters several challenges across multiple fronts, from fuel availability and economic considerations to policy alignment and operational uncertainties. Insights gathered from interviews with stakeholders from Buss i Väst, Region Gävleborg, Solaris, and Hydrogen Sweden illuminate these challenges and offer a comprehensive understanding of the barriers to FCB adoption in the area.

Infrastructure and Fuel Availability

Challenges:

Fuel Supply: Hydrogen supply remains a critical challenge, with significant shortfalls in infrastructure development. Solaris noted the curiosity and interest from politicians and operators, but emphasized that decisions on hydrogen supply, crucial for securing clients, are yet to be made.

Hydrogen Refuelling Stations (HRS): Region Gävleborg faced issues with HRS capacities and technical limitations, which have led to operational challenges and scepticism about FC technology's reliability. Hydrogen Sweden also highlighted the scarcity of HRS as a major obstacle to market uptake.

Economic Considerations

Challenges:

High Costs: Both the purchase price and operating costs of FCBs are currently high due to low volumes and technological maturity, making them less economically viable compared to biogas buses.

Financial Support and Subsidies: Although subsidies are available, they are not considered on par with the levels provided in other countries, such as Germany. This disparity affects the attractiveness of investing in FCBs.

Policy and Market Dynamics

Challenges:

Policy Alignment: There's a strong regional focus on electrification and biogas, with hydrogen not being prioritized in recent years due to the absence of infrastructure and higher initial costs.

Market Readiness: The availability of FCBs and the readiness of the market to adopt this technology are concerns. Suppliers are cautious, and the range of offers is limited, impacting the feasibility of transitioning to hydrogen-powered public transport.

Operational and Technical Uncertainties

Challenges:

Reliability and Maintenance: The guaranteed vehicle availability or uptime is yet to be addressed, with Buss i Väst citing uncertainties preventing them from presenting a viable case to their stakeholders. Solaris has not encountered significant problems with FCB operation as long as service and handling are correctly managed.

Safety and Regulations: Concerns about safety, handling, and regulatory compliance also stand out as significant challenges, needing more clarity and information to reassure operators and authorities.

Strategic Recommendations

To overcome these challenges and foster a conducive environment for the deployment of FCBs in Sweden, a multifaceted approach is required:

1. **Infrastructure Investment:** Accelerate the development of HRS infrastructure through public-private partnerships, government investment, and European Union funding. There has been a lot of funding made available nationally over the last two years in Sweden, focused on trucks mainly, but this should be possible to leverage for buses as well.
2. **Economic Incentives:** Implement more aggressive financial incentives, including subsidies and tax benefits, to lower the total cost of ownership for FCBs.
3. **Policy Support:** Advocate for inclusive policies that equally support hydrogen technologies alongside electrification and biogas, emphasizing the unique benefits of FCBs in achieving emission reduction targets.
4. **Market Engagement:** Encourage bus manufacturers and suppliers to increase their offerings and support for FCBs, ensuring a competitive market that drives innovation and reduces costs.
5. **Education and Awareness:** Launch educational campaigns targeting policy-makers, operators, and the public to increase awareness about the benefits of hydrogen fuel technology, safety, and operational efficiency.

By addressing these areas, Sweden can pave the way for a successful transition to a cleaner, more sustainable public transportation system that includes FCBs as a viable alternative to traditional fossil fuels and complements existing biogas and electric solutions.

Communication strategy

- *Use of the evidence-base to develop a communication strategy that will present FC buses as a viable alternative/complement to biogas and diesel.*

A robust communication strategy is essential to position fuel cell (FC) buses as a competitive, viable, and sustainable solution in public transportation. The following approach highlights critical aspects for crafting an effective strategy:

1. **Identify Competitive Advantages**
   FC buses have a strong competitive edge in specific transport applications. They excel in long-distance urban and intercity routes due to their extended range and rapid refuelling capabilities compared to battery-electric buses. Their operation in regions with stringent emissions regulations or where biogas infrastructure is limited offers another strategic advantage. Additionally, FC buses provide reliable performance in extreme weather conditions, where other drivetrain technologies may falter.

2. **Define Target Groups**
   Key target groups for communication activities include public transport authorities, policymakers, fleet operators, environmental organizations, and local communities. Each group has distinct priorities: policymakers focus on emissions reduction, operators seek cost efficiency, and communities value cleaner air and quieter urban environments.

3. **Utilize Evidence-Based Communication**
   Using data-driven insights is vital to demonstrate how FC buses compare to biogas and diesel in terms of lifecycle costs, environmental benefits, and operational performance. Case studies from regions with successful FC bus deployments can be leveraged to highlight real-world feasibility.

4. **Develop Relevant Communication Messages**
   Tailored messaging should address the concerns of each group. For policymakers, emphasize emissions reduction and alignment with green policies. Fleet operators should see the cost savings from long-term efficiency and fuel diversification. For communities, focus on health and quality-of-life improvements.

5. **Address Financing and Practical Deployment**
   Practical deployment requires addressing financing models and subsidies. Messaging should emphasize partnerships with government and private sectors to lower costs. Highlight grants, public-private partnerships, and scalable deployment strategies to reduce perceived financial and operational risks.

Through these tailored messages and strategies, FC buses can be effectively positioned as a viable alternative to incumbent technologies, fostering adoption and enhancing their role in the future of sustainable transport.

The reasons for policy preference for biogas

This chapter will explain the reasons behind the policy preference for biogas as an alternative to diesel buses. This preference is driven by several key factors, including environmental, economic, technological, and infrastructural considerations.

Environmental Benefits

Biogas buses offer a significant reduction in greenhouse gas emissions compared to traditional diesel buses. This aligns with Sweden's environmental goals and commitments to the Paris Agreement on climate change. While not entirely emission-free, biogas represents a substantial improvement in terms of air quality by reducing pollutants such as NOx and particulate matter compared to diesel.

Economic and Technological Maturity

Biogas technology is relatively mature and has been integrated into Sweden's public transportation systems for years. This maturity has led to the development of a robust infrastructure for biogas production and distribution, making it a more immediately viable option than newer technologies like FCBs, which are still confronting high initial costs and infrastructure development challenges.

Policy Support and Subsidies

Biogas has received strong policy support at both local and national levels, driven in part by Sweden's abundant biomass resources and its leadership in waste-to-energy technologies. Subsidies and incentives for biogas production and usage have made it economically attractive for public transportation authorities and bus operators. This support has helped bridge the cost gap between biogas and diesel buses, facilitating the transition away from fossil fuels.

Infrastructure Development

The existing infrastructure for biogas production and refuelling is a significant factor in its policy preference. Sweden's investment in biogas plants and refuelling stations has created a relatively seamless transition for public transportation systems from diesel to biogas. The lack of comparable infrastructure for hydrogen presents a barrier to the immediate adoption of FCBs.

Energy Security and Local Production

Biogas production from local waste and biomass sources contributes to energy security and supports Sweden's circular economy objectives. This local production capability reduces dependency on imported fuels and promotes sustainable waste management practices. The preference for biogas is partly rooted in these broader strategic considerations, which are not as immediately applicable to hydrogen due to current limitations in green hydrogen production capacity.

Community and Political Factors

Community support and political backing have also played a role in the preference for biogas. Local initiatives and projects that showcase the benefits of biogas buses have garnered positive

public and political attention, reinforcing the choice of biogas over newer alternatives like FCBs. The established success and visibility of biogas projects contribute to ongoing policy support.

In summary, the preference for biogas as an alternative to diesel buses is underpinned by its environmental benefits, economic and technological maturity, strong policy support, developed infrastructure, contributions to energy security, and local production capabilities. While emerging technologies like FCBs offer promising future alternatives, the current policy preference for biogas reflects a pragmatic approach based on existing capabilities and priorities in Sweden's journey toward sustainable public transportation.

Strategies for smoothing procurement processes

This chapter will focus on development of strategies for smoothing procurement processes for sites wanting to introduce FC Buses to their fleets.

Developing Comprehensive Tender Documents

Strategy: Develop tender documents that provide detailed and prescriptive technical specifications for fuel cell buses (FCBs) while maintaining enough flexibility to encourage innovation from suppliers. Specifications should cover vehicle performance, reliability, environmental impact, and compatibility with existing or planned HRS infrastructure.

Implementation:

- Include criteria for energy efficiency, operational range, refuelling time, and vehicle lifespan.
- Specify requirements for onboard safety systems and hydrogen leak detection. This can probably be handled by pointing at existing standards.
- Demand clarity on maintenance support and warranty conditions.
- Encourage suppliers to propose solutions for training local staff in FCB operation and maintenance.
- Include provisions for data sharing on vehicle performance and operational metrics to facilitate continuous improvement.

Facilitating Supplier Information Exchange

Strategy: Establish a platform for information exchange between potential suppliers and transit authorities. This platform can serve as a repository for sharing developments in FCB technology, infrastructure solutions, and best practices from other regions.

Implementation:

- Host informational workshops and webinars with FCB manufacturers, HRS providers, and technology experts.
- Create an online portal where suppliers can update their product specifications, case studies, and contact information.
- Encourage suppliers to present case studies of successful FCB deployments, focusing on challenges overcome and lessons learned.

Linking Bus Procurement with HRS Development

Strategy: Synchronize the procurement of FCBs with the development of HRS infrastructure to ensure that refuelling capacity is available when buses are ready to be deployed. This requires close coordination between bus operators, municipalities, energy companies, and infrastructure providers.

Implementation:

- Include requirements in the tender documents for bus suppliers to coordinate with HRS providers, ensuring compatibility between buses and refuelling infrastructure.

- Explore joint procurement initiatives for FCBs and HRS development to leverage economies of scale and negotiate better terms.
- Consider public-private partnerships (PPPs) to finance and develop HRS infrastructure, with commitments from transit authorities to use the stations for their fleets.

Leveraging Pilot Projects

Strategy: Implement pilot projects as part of the procurement process. Pilot projects allow transit authorities to test FCBs under real-world conditions, assess their performance, and make informed decisions about larger-scale deployments.

Implementation:

- Select a small number of routes for initial FCB deployment to evaluate vehicle performance, passenger feedback, and operational impact.
- Use pilot projects as a benchmark for refining procurement specifications for future tenders.
- Document and share experiences from pilot projects with potential suppliers and other stakeholders to give input to broader deployment strategies.

Standardizing Procurement Processes

Strategy: Develop standardized procurement templates and processes for FCBs and related infrastructure to reduce complexity and uncertainty for both transit authorities and suppliers.

Implementation:

- Collaborate with industry associations, regulatory bodies, and other transit authorities to develop standardized tender documents and contracts.
- Incorporate flexibility to adapt to technological advancements and regulatory changes.
- Promote transparency in the evaluation criteria and selection process to build trust with suppliers and stakeholders.

Establishing Multi-Stakeholder Platforms

Strategy: Create a platform that brings together all relevant stakeholders, including transit authorities, municipal governments, energy providers, and technology suppliers, to facilitate the integrated planning and deployment of FCBs and HRS.

Implementation:

- Organize regular meetings and workshops to align on goals, timelines, and responsibilities.
- Use the platform to address regulatory hurdles, share funding opportunities, and coordinate on public awareness campaigns.

By adopting these strategies, transit authorities can streamline the procurement process for introducing FCBs into their fleets, addressing technical, logistical, and financial challenges while promoting collaboration and innovation among all stakeholders involved.

Policy Recommendation Report: Advancing Fuel Cell Buses (FCBs) as a Sustainable Public Transportation Solution

This part of the report outlines strategic recommendations for policymakers to support the adoption of Fuel Cell Buses (FCBs) as a viable and competitive alternative to traditional and biogas-powered public transportation systems. Drawing upon insights from technical documents, stakeholder interviews, and a comprehensive analysis of the challenges and benefits associated with FCBs, it advocates for enhanced policy frameworks, financial incentives, and infrastructure development initiatives. The goal is to accelerate the transition towards a more sustainable, efficient, and environmentally friendly public transportation network.

Introduction

The global push towards sustainability and reduction of carbon emissions has positioned FCBs as a promising alternative to diesel and biogas buses. FCBs offer zero tailpipe emissions, high energy efficiency, and the potential for leveraging renewable energy sources for hydrogen production. However, their widespread adoption is hindered by challenges including high initial costs, lack of refuelling infrastructure, and technological maturity concerns. Addressing these barriers requires a cohesive policy strategy that supports technological development, infrastructure expansion, and market readiness for FCBs.

Policy Recommendations

1. **Enhance Funding and Financial Incentives**

   Implement subsidies for FCB procurement and operation, mirroring those provided for biogas and electric buses, to make FCBs economically competitive.

   Offer tax incentives and grants for the development of hydrogen refuelling infrastructure, encouraging private investment in this critical area.

2. **Develop Strategic Public-Private Partnerships (PPPs)**

   Promote collaborations between public transit authorities, energy companies, vehicle manufacturers, and technology firms to share the financial and operational risks associated with FCB deployment and HRS development.

3. **Support Research and Development (R&D)**

   Increase funding for R&D activities focused on improving the efficiency, reliability, and cost-effectiveness of FCB technology and green hydrogen production methods.

4. **Implement Pilot Projects and Demonstrations**

   Sponsor pilot projects across diverse geographic and operational settings to gather data on FCB performance, passenger feedback, and real-world challenges, guiding future deployments.

5. **Educate and Engage Stakeholders**

Launch awareness campaigns targeting policymakers, transit operators, and the public to highlight the benefits of FCBs, counter myths about hydrogen safety, and demonstrate the technology's alignment with sustainability goals.

FCBs stand at the forefront of the evolution towards sustainable public transportation. With their environmental benefits and dynamic compatibility with renewable energy sources, FCBs offer a pathway to achieving carbon neutrality in the public transit sector. However, realizing their full potential requires a joint effort from policymakers, industry stakeholders, and the community. By implementing the recommended policies, governments can unlock the transformative potential of FCBs, contributing to a cleaner, greener, and more sustainable future.

As we embark on the path to a more sustainable and environmentally friendly public transportation future, the role of policymakers is crucial. Fuel Cell Buses (FCBs) present an innovative solution that aligns with our collective goals of reducing greenhouse gas emissions, improving air quality, and reducing noise. By embracing FCB technology and supporting the development of the necessary infrastructure and market conditions, we can achieve significant environmental and public health benefits. We urge policymakers to consider these recommendations as a blueprint for action, demonstrating leadership in the transition to sustainable transportation solutions.

Appendix

Gävleborg

The following is based on an interview with Anders Lundell at Region Gävleborg. Gävleborg is a region north of Stockholm where Sandviken and Gävle have shown most interest in fuel cell buses. Sandviken became part of the JIVE 2 project but later withdrew because of the five bus commitment requirement. They still decided to proceed with two buses, although outside the JIVE 2 project.

Fuel Availability at Region Gävleborg

A principal decision was made to return the funds and instead purchase two buses fully funded from our own budget, rather than the originally planned five buses with JIVE co-funding.The biogas buses in Gävle, previously HVO buses, had been a part of our operations for some time. At the latest procurement process we expected to receive offers for biogas buses, but the new operators have fully transitioned to BEV (Battery Electric Vehicles). It appears that Gävle city will also become fully BEV, operating several BEV lines. In Sandviken, the operation includes BEV and two FC (Fuel Cell) buses. The operator X-trafik has been clear in their intention to test various technologies to compare their performance. There's a move away from biogas, despite having a reliable supply of biogas sufficient for public transport, should there be a desire to use it, thanks to local production. The main issues with hydrogen and BEVs lie in the electrical grid's capacity, limiting depot charging and the use of electrolysers. Hydrogen has a particular advantage in being able to adapt production to the electrical grid's demands. However, the technology for storage and distribution needs development. Self-sufficiency and robustness are high priorities. Alleima and Ovako also require more electricity to expand the supply in the grid for both themselves and the transportation sector. There is relatively extensive charging infrastructure for light vehicles, and it's beginning to appear for heavy vehicles. By 2028, we expect to see more heavy-duty vehicles as Volvo starts to offer them. Unfortunate experiences have made it easy to think that FC technology doesn't work. There were numerous cancellations of BEV trips in January 2024 when the network capacity was insufficient to fully charge the buses overnight.

Air Quality Considerations at Region Gävleborg

We have not examined this aspect sufficiently. We have considered biogas to be fossil-free, but we have not progressed to the point where an emission-free bus or fuel cell bus would be deemed superior. This topic has only been raised in a few contexts. The air quality in the area is not poor enough to serve as a driving factor.

Climate Impact and Strategies at Region Gävleborg

Our approach hasn't been profoundly deep, but we have had a strong ambition to become fossil-free, aggressively adopting HVO and biogas. Electricity has emerged more as an

opportunity within procurements, largely driven by suppliers. We demanded fossil-free solutions but remained technology-neutral. HVO was quite expensive for a period. The E16 electric road has been at the forefront, achieving a lot in this space, though it hasn't translated significantly into mass air quality improvements. A political shift occurred in the midst of this, leading to a more short-term outlook now.

Subsidies and Financial Support at Region Gävleborg

We applied for, received, and then returned the subsidies because the decision was made to only purchase two buses. We had to return the funds. The main reason to return the funds was the five bus commitment, but it is uncertain if any money was saved by opting out and reducing the number of buses. The subsidy per bus was reduced after we joined the project, and by the time it came to placing orders, the original offer per bus had been decreased. For the project support would ideally be provided for at least 5, preferably 10, buses per city.

Offers from Bus Suppliers to Region Gävleborg

We made early visits to various suppliers, including Solaris, and explored options with around 10-11 potential suppliers. Solaris had already delivered buses to Riga, which we reviewed. One of the operators, who already had a contract, placed an order with Solaris, so we did not need to conduct a procurement process for this. It was included within the scope of the traffic contract and was primarily relevant.

Delivery Time and Uncertainties for Bus Procurement at Region Gävleborg

There were no issues; we were not in a hurry. It was acceptable to place orders first and have a bit of a delay. There was time to test and operate the buses before they were required to run according to the timetable. It was a cautious trial.

Operating Costs and Uncertainties at Region Gävleborg

There wasn't much information available; we wanted to compare and investigate. We understood that the costs would be higher but saw an important value in being early adopters.

Fuel Availability/HRS and Uncertainties at Region Gävleborg

When the station was constructed on Sandvik's request, they received support to build a dual-pressure system. A 700 bar was installed, and a 350 dispenser was placed later shown to be more of a mock-up that never was operationalized. Everyone believed it was built to specifications. AGA changed project managers 3-4 times before completion. AGA's stance has shifted over time. The whole setup, including the hardened surfaces, was made for buses in daily use, but according to AGA the station was only intended for testing a few buses, not for operational use in traffic. X-trafik received certification from the region that it was a dual-pressure system, designed to deliver large quantities of hydrogen via pipeline. Documents exist

showing AGA's demands on Sandviken's municipality and Sandvik for a consumption commitment, with a minimum consumption of a certain volume, equivalent to the annual volume for about 3 city buses. There was a compensation cost involved, equivalent to the consumption of 16-20 personal cars, driving annually around 15,000 km/year, demanding significant usage, not aligned with the retrofit. Since 2016, there have been questions about a cascade system. The formation of Alleima, that was previously an integral part of Sandvik, paused Sandvik's external relations work, and the desire to confront AGA Linde was limited. Requirements were pushed to operationalize the station before AGA sold it to Hynion, but to no avail. The compressor function could handle two buses consecutively, with a large buffer tank to prevent pressure drops towards Sandvik, so the larger amount of hydrogen needed in each fuelling was never a problem. AGA had no local involvement. A pipeline existed but was bypassed in favour of cylinders to avoid the needed connection. It's unclear if the pipeline was ever used or if cylinder transport was solely relied upon. At most, 17-18 vehicles used the station. There was reluctance to provide parts and software for station expansion. One fuel cell bus is operational, intended to run in parallel with electric buses, but sent away for necessary service to Solaris. Transdev, owning the buses, uncertain of the fuel cell buses future.

Guaranteed Vehicle Availability (Uptime) at Region Gävleborg

The vehicles were operated in parallel with the diesel-driven fleet, with the intention to run them for a couple of years without a dedicated timetable. However, this plan was compromised due to issues with the HRS. They should now be operating according to the timetable, but the challenges have primarily been with the HRS and the delivery of gas.

Risk of Committing to Potentially Unsustainable Technologies at Region Gävleborg

There was no concern about this, as it was part of an early trial operation. Signals from private sector actors indicated a continuation with Fuel Cells (FC).

Western Sweden

The following is based on an interview with Christer Pettersson at the mass transit operator Buss i Väst. Buss I Väst is a mass transit operator in several of the Swedish regions, but for this study focus was on southwestern Sweden where several cities were interested in joining JIVE 2, but none ultimately decided to do so.

Fuel Supply and Sustainability

The procurement and utilization of biogas present a relatively straightforward scenario, albeit complicated by its price volatility. However, there have been no significant obstacles. In contrast, the adoption of hydrogen as an alternative fuel has been hindered primarily due to infrastructural deficiencies. The responsibility for driving hydrogen adoption does not solely lie with us but is significantly influenced by regional mandates and requirements. A notable challenge has been a general lack of awareness regarding the cost implications associated with hydrogen, especially when compared to biogas. Initial cost estimations from suppliers were excessively high, approximately five times greater than expected, although these were adjusted upon clarification. Our initial plan to integrate five hydrogen buses evolved following discussions with Västtrafik and the hydrogen supplier, who then stipulated a minimum requirement of twenty-five buses, thereby altering the initial conditions. Our operations are governed by procured traffic agreements, and any modifications or enhancements, such as fleet updates, necessitate comprehensive financial analysis and justifications. The regional willingness to incur additional expenses is contingent upon the perceived value and benefits of such investments. Currently, the focus is on achieving a minimal integration of five hydrogen buses. The critical factors influencing the adoption of hydrogen buses include infrastructure development and the cost implications of hydrogen. Our strategic direction aligns with regional environmental policies, which advocate for the electrification of class 1 buses, biogas utilization across the region, and the adoption of RME HVO for rural transportation. Recent shifts in policy have demonstrated a more restrictive stance on biogas and an increased emphasis on electric solutions. Hydrogen has not been a focus in the past year, primarily due to the absence of refuelling infrastructure, which is critical for operational efficiency and financial viability.

Air Quality and Environmental Impact

The organization places significant emphasis on mitigating traffic congestion and reducing noise pollution, recognizing these factors as crucial to improving air quality. Efforts are underway to enhance the environmental sustainability of our operations, with a particular focus on integrating vehicles that meet stringent emission standards. This initiative is aligned with broader environmental objectives, aiming to contribute positively to climate change mitigation by reducing greenhouse gas emissions. Our strategy encompasses the adoption of cleaner fuel alternatives and the implementation of technologies that support energy efficiency and lower carbon footprints.

Financial Support and Subsidies

Government subsidies and financial support play a pivotal role in offsetting the initial costs associated with adopting cleaner and more sustainable bus technologies. Such financial incentives are critical in bridging the cost gap between conventional diesel buses and their

greener counterparts, including electric and hydrogen fuel cell buses. "Buss i Väst" actively engages with regional and national funding programs to leverage these subsidies, which not only help in procuring environmentally friendly buses but also in developing the necessary infrastructure, such as charging and refuelling stations. These subsidies are essential for accelerating the transition towards a more sustainable public transport system.

Collaboration with Bus Suppliers

Collaborative engagements with bus suppliers are fundamental to our strategy for incorporating advanced technologies within our fleet. Through constructive dialogue and negotiations, we have been able to explore various options and secure favourable terms that align with our operational requirements and environmental goals. Suppliers play a crucial role in providing technical expertise and support, enabling us to evaluate the feasibility and performance of different bus models. These partnerships are invaluable in ensuring that we can access the latest innovations and solutions that contribute to our vision of a cleaner, more efficient public transportation system.

Availability and Acquisition of Fuel Cell Buses (FCBs)

The market for fuel cell buses is perceived as evolving, with increasing interest and inquiries about their availability and procurement. We have received several offers from suppliers, indicating a growing readiness to meet the demand for such vehicles. However, the decision to acquire fuel cell buses is contingent upon various factors, including cost-effectiveness, operational feasibility, and alignment with our environmental objectives. While the interest in fuel cell technology is evident, the actual acquisition process involves careful consideration of these factors to ensure that any addition to our fleet supports our sustainability goals and operational needs.

Operating Costs and Uncertainties

An ongoing requirement had been a maintenance contract, which we did not secure. The consumption versus price presented an uncertain aspect from the hydrogen supplier's perspective. If biogas costs 15 SEK, the equivalent for hydrogen was initially around 80-90 SEK per unit. However, they later reduced this rate, which introduced some uncertainty. They probably viewed it more as a project.

Fuel Availability/HRS (Hydrogen Refuelling Stations) and Uncertainties

Redundancy is incredibly important. We are in procurement processes for locations like Gothenburg and Alingsås, among others. For instance, if we operate in Alingsås, the bus cannot be expected to refuel in Gothenburg. Ideally, the refuelling should be at, or at least near, the depot. A critical factor is determining the volume of sales needed for profitability. For example, if we have 50 buses in Skövde and 30 of them are hydrogen-powered, with each requiring 6000 kg of hydrogen, we then calculate the necessary quantity. Refuelling time is also a significant consideration—will it take 5 minutes or half an hour? For biogas, it's about 10-15 minutes per bus, and we must consider whether this will be done during the night or the day. Another uncertainty is the cost of setting up such a facility. Initially, it was probably the small quantity that presented a challenge.

Guaranteed Vehicle Availability (Uptime)

We have not reached that stage; we were unable to present anything to Västtrafik as the hydrogen supplier withdrew. There were too many uncertainties for us.

Challenges of Fuel Cell Buses (FCB) Compared to Biogas Buses

The uncertainties for myself and others are too significant. We need more information about safety, handling, bus parking regulations, and so on. Electric buses are currently drawing attention due to fire risks. Issues like evacuation hatches are also a concern.

Making Fuel Cell Buses Competitive

In cases where a procurement includes specific requirements, we comply with those. However, if we have the option to choose between electric, biogas, or hydrogen buses, we typically opt for the most cost-effective solution (considering hydrogen price, maintenance, and other costs). There could also be additional points awarded for new technology or drivetrains. The decision is often in the hands of the procurers (regional authorities for public transport, while municipalities procure school transport). Biogas was included as an evaluation clause with an additional cost of 100,000 SEK, but it became common. For HVO or RME, we are allowed to use fossil-free options. There are still some municipalities that permit MK1 diesel, or a mix of 30% of any choice, with the remainder being fossil-free. Most indications suggest a preference for HVO or another type of fossil-free diesel.

Expectations for Biogas Buses Today

The expectations for fuel cell buses and biogas buses are the same as for conventional buses.

Advantages of Fuel Cell Buses Over Biogas Buses

We have too little experience to say for certain. The difference in biogas buses now compared to 10 years ago is substantial—they have been refined, they had issues with oil getting into the gas, but they perform better now. Life cycle cost for a bus that runs 60-70,000 kilometres per year is another consideration; for example, 2.50 SEK/km. The bus is 10-30 öre more expensive per kilometre for maintenance and service contracts, in addition to the purchase cost. For battery electric vehicles (BEVs), these costs have halved compared to when they were first introduced. Battery warranties are important. Warranties are crucial for fuel cells and more. It's important that service contracts can be offered by the seller of the bus. Service contracts are offered by the seller. They have their own authorized workshops. While we have our own workshops, service contracts become important with new technology.

Attitudes Towards Renewable Fuels and the Adoption of FCBs

Västtrafik is keen on ensuring that there are multiple suppliers for vehicles, infrastructure, and procurements that initially allocate a depot with 25-30 buses. Suppliers are interested in being

able to sell more than just public transport solutions—they aim to cater to trucks, personal vehicles, etc., as well.

Solaris

The following is based on an interview with David Tyrenius at the bus manufacturer Solaris that produce and sell diesel/HVO buses, biogas buses and fuel cell buses. They have offered fuel cell buses in many of the cities that were in discussions about JIVE 2 buses, so their experience is from all of Sweden.

Fuel Availability

We see no obstacles in our ability to supply anyone, but hydrogen supply is challenging, for example, with Transdev. We delivered in Sandviken in October 2021. There's enormous curiosity; all politicians find it exciting, as do the operators, but it's up to the politicians to decide on the hydrogen supply. There's a significant shortfall there; we could probably sell a lot if the hydrogen supply was guaranteed. It must be secured before clients can be signed. The process is faster elsewhere in Europe, where politicians are bolder. There are uncertainties, sometimes about safety, often from a lack of knowledge. We sold electric buses to Gävle and Vy Buss, but there were problems with ABB chargers and compatibility.

Air Quality and Vehicle Choice

Politicians are interested in zero emissions, but economically, FCEVs can't be justified over biogas buses. The bus itself is significantly cheaper. There's also a considerable cost difference in terms of service. However, there are advantages; for instance, an electric bus covering the same distance requires huge battery packs, which take hours to charge and affect the bus's weight and space, reducing the number of seats. Hydrogen buses can be refuelled in under 10 minutes, which isn't possible with an electric bus. Yet, biogas buses are an excellent product. In Sweden, substantial investments have been made in biogas, necessitating the purchase of new biogas buses to justify these investments. Biogas is almost not sold in Europe, where HVO diesel, electric, and increasingly FC are the norms. Still, there are discussions with customers who need to justify biogas investments, often choosing electric and biogas, with now 98-99% electric. There are virtually no processes on FC. Zero emission is the predominant requirement, meaning 100% battery operation, with a certain percentage of the bus fleet being electric by a specific year, and later 100%. Customers 99% of the time consider TCO—bus price, financing cost, charging/fuel. Fuel is expensive, surpassing charging costs. Maintenance-wise, an electric bus is more complex than hydrogen Ballard FC, with relatively high maintenance costs, where the calculation falls short for customers. Benchmarking diesel, biogas, HVO, and electric buses, FC remains the most expensive option for now.

Purchase Price Considerations

Buses, maintenance, and refuelling are most expensive with FC (Fuel Cell). Even with subsidies, it remained costly as the buses also need to be operated. Markets in other regions are bolder, and it's unclear why. The former Eastern bloc has heavily invested in BEV (Battery Electric Vehicles). Italy, Germany, the Czech Republic, and Romania have much larger scales of operation. Poland as well. Sweden is catching up quickly and is set to deliver a large number of electric buses this year, becoming one of the biggest in Europe for electric buses. The interest is extremely high. Not many produce FC buses, both 12 and 18 meters, complementing BEV for long distances and full passenger loads.

Operating Costs and Uncertainties

Electricity prices and power are cheap in Sweden, and biogas is also inexpensive. Both these can be used for hydrogen production, but processes for this is often not in place. Therefore, it is easier for the customer to use the fuels readily available for biogas buses and battery electric buses.

Guaranteed Vehicle Availability (Uptime)

We have been operating extensively in Hamburg and Riga for many years, but the latest generation has been in operation since 2021, including in Bolzano. We have not heard of any problems, as long as service and handling are correct. They are expected to perform as well as any regular or electric bus.

Risk of Committing to Unsustainable Technologies

No concerns have been experienced. We deliver quickly. Ballard is also very fast in their responses. However, it is expensive. Vy Buss expressed concerns about after-market costs.

Performance for Biogas Buses

Similarly, everything has worked well. We have never encountered problems with it. The pandemic posed some challenges, but now everything is functioning well again, including production at the factory. We only use subcontractors within Europe, which was completely halted during the pandemic. Previously, we bought cable ducts from China, but now we purchase them from the Czech Republic.

Challenges of Fuel Cell Buses Compared to Biogas Buses

The challenges are of a different nature. We have our own workshop in Gävle where we service and maintain vehicles, but the facilities need to be adapted to comply with safety regulations (fire, explosion risk). Around 2020, hydrogen was regulated similarly to biogas, which requires attention but is not problematic. The infrastructure poses the main challenge. The user must perceive the benefits of FC (payload, not having to charge or considering power efficiency) as sufficiently significant.

Making Fuel Cell Buses Competitive

Price and infrastructure are the main pain points for fuel cell buses that needs to be handled.

Hydrogen Sweden.

Conclusions from Interview with Björn Aronsson at Hydrogen Sweden.

Fuel Availability

There is a lack of knowledge about where hydrogen is produced today and where one can purchase it if one were to invest.

Air Quality

Air quality is a clear issue in many cities across our country, including small cities. However, the problem is seldom discussed, and the perception is that solutions lie in electrifying transportation and, in some cases, banning studded tires.

Climate Impact

The climate impact is significant, yet public entities are adept at finding excuses not to let climate impact heavily dictate the choice of vehicles ultimately purchased.

Support Funds

There are support funds available through various national and EU programs. Initially, these funds were considered generous, but they are not on par with the level of support provided by Germany today.

Offers from Bus Suppliers

There is a noticeable lack of proposals from bus suppliers, who mostly highlight existing technology.

Availability of Fuel Cell Buses (FCB)

FCBs are available, but one needs to actively search for them.

Purchase Price

The purchase price is currently too high due to low volumes.

Delivery Time (and Uncertainties)

There are long lead times for delivery.

Operating Costs (and Uncertainties)

Too high operating costs have been quoted, scaring off customers and signalling that the **technology is not mature.**

Fuel Supply/HRS (and Uncertainties)

There are far too few Hydrogen Refuelling Stations (HRS) for market uptake to accelerate.

Guaranteed Availability for Vehicles (Uptime)

Too frequent service and maintenance offerings for vehicles could limit uptime.

Risk of Investing Incorrectly (What is it Based On?)

There is limited knowledge about this risk in our market today.

Performance for Biogas Buses

There have been significant technical challenges with some biogas buses, but patience has been maintained since often the municipalities themselves have invested in biogas production.

Challenges for FCB Compared to Biogas Buses

The price of the buses and the availability of refuelling stations. The political backing is also significantly stronger for biogas buses.

What Would Make Fuel Cell Buses Competitive?

Focusing more on emissions in urban environments, noise, and making long-term forecasts for alternative fuel futures.

Expectations for a Biogas Bus Today (Performance, Reliability, Refuelling, etc.)

How did it happen that biogas was chosen in your region? What are the driving forces (and who are the people behind them)? What motivates them? Can the same drivers be a driving force for FCB? How is it easiest to initiate a discussion with these organizations/people? Often, there has been political backing and motivation behind it.

Are Biogas Buses More Expensive to Operate Than Diesel Buses? How Much, if So, and Where (CAPEX, OPEX, Specific Items)?

Operation has been more expensive in several regions, but the region or city has stepped in and covered the extra costs. The same approach is now being applied to Battery Electric Buses and is fully reasonable to do the same for FCBs.

What Financing Opportunities Do You See for FCB?

Climate premiums and the Climate Leap (Klimatklivet) can support infrastructure investments.

How Do You View the Political Leadership for Infrastructure Development for Biogas and Hydrogen?

Biogas has received clear political support, first locally then regionally and lately, even stronger nationally. Hydrogen has politically been limited to a few locations, lacking clear national political support.

What Stakeholders Exist for Hydrogen in Your Area, and What Expansion Plans Are There?

This varies significantly between different locations.

We've Picked Up on an Attitude Towards Renewable Fuels That It's Biogas or Nothing, How Do You See This? HVO etc. Prices, When is Diesel Chosen? What Could Simplify a Spread to Also Include FCB?

In some cities and regions, this has been the case. Now, in several instances, it has shifted to BEV buses or nothing.

How Do Your Procurement Documents Handle the Purchase of an HRS? Is Further Procurement Documentation Needed for Such? Do You Share Documentation With Other Public Organizations?

There is essentially a framework in the Adda coordination for making procurements, but otherwise, there is a significant lack of expertise among procurers regarding FCBs.

What Do You See as the Differences Between Procuring a Hydrogen Bus and a Biogas Bus? Any Specific Difficulties With Hydrogen Buses? What Would Help?

A lack of knowledge about hydrogen buses.

How Does Your Specification Look in the Procurement of These Vehicles? Technology Neutrality? Are FCBs Too Expensive?

It is often expressed that technology neutrality applies, but when politically supporting the extra costs for certain technology choices, in practice, there is no technology neutrality.

Would Any Change in This Make It More Profitable to Purchase FCB? Distribution of Purchase Price/Operating Cost, for Example?

Treating hydrogen buses the same way biogas buses or battery buses have been treated.

Project coordination:

ERM

Project dissemination:

Hydrogen Europe

The **JIVE and JIVE2 projects** have received funding from the Clean Hydrogen Partnership (formerly known as FCH JU) under Grant Agreement No 735582 and 779563.

This Joint Undertaking receives support from the **European Union's Horizon 2020** research and innovation programme, Hydrogen Europe and Hydrogen Europe Research.

The **MEHRLIN project** is co-financed by the **European Union's Connecting Europe Facility.**

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Clean Hydrogen Partnership

Co-funded by the European Union