European Commission
European Climate, Infrastructure and Environment Executive Agency (CINEA)

Connecting Europe Facility

ASR-2022-2015-EU-TM-0316-S-Models for Economic Hydrogen Refuelling Infrastructure

D3.1 - Analysis of economic data

Public report

1. INFORMATION ON THE ACTION

Grant Agreement Nº	INEA/CEF/TRAN/M2015/1142684
Action number	2015-EU-TM-0316-S
Action title	Models for Economic Hydrogen Refuelling Infrastructure
PCI (for energy and synergy only)	

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Content

1 Summary

The MEHRLIN (Models for Economic Hydrogen Refuelling Infrastructure) project aims to promote, deploy, and commercialize hydrogen as an alternative fuel, hence contributing to the European alternative fuel implementation strategy. This project's activities include studies based on real life-pilot deployments at seven locations: Bolzano (Italy), Wermelskirchen and Hürth (Cologne, Germany), Wuppertal (Germany), Heinenoord-South Rotterdam (Netherlands), Birmingham and London (United Kingdom).

In this report, a generalised business case of a hydrogen refuelling station is built based on a single Hydrogen Refuelling Station's (HRS) economic performance after 12-18 months with real operation. The business case is modelled over 5 years. Due to the heterogeneity of the seven HRS, two general business cases were derived and described: "Case 1500" and "Case 500".

The "Case 1500" results as a viable Business Case under certain circumstances. The purchase price and the margin of 30% on the raw costs play a central role. With maximum utilization of the plant, a sufficient dynamic of the case can be achieved to create the prerequisite of bankability. However, due to the lack of experience and values of the sector, bank loans would only be granted with additional guarantees (corporate guarantee or government guarantee).

The "Case 500" achieves break-even in terms of earnings but does not meet the requirements for bankability according to the modelling because the cash flow is too low to be able to service the debts. Nevertheless, this case has its justification since public transport operators often want to enter the technology on this scale. In this case, the financing is borne by the public sector.

Due to the after-effects of the energy crisis, a positive case is currently only possible with hydrogen as a by-product of the chlor-alkali industry. However, when electricity costs normalize, onsite production or the supply of green hydrogen from large energy parks may become profitable again. Innovative approaches can come into play, such as self-consumption of energy for electrolysis from energy production sites and avoidance of system costs and grid fees of the power grid, remunerable smart-grid functions, use of flexibility on the spot market, and use of surplus electricity.

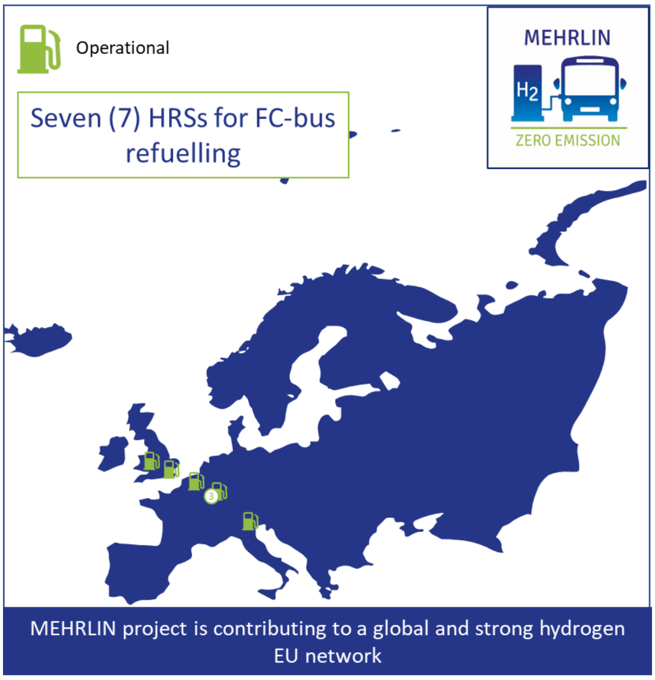
In general, it must be required that HRS operate at maximum capacity, that the appropriate technical maturity are in place (availability and reliability >99%), that effective operation and maintenance contracts are in place, and that contracting with suppliers and customers are driven towards long-term contracts to cover the greatest risks.

One of the most significant risks to the business case relates to the constant offtake of hydrogen. This is associated with the acquisition of a correspondingly large fleet of Fuel Cell (FC) -buses and vehicles. This is usually a lengthy process due to the associated obligation to tender in the public sector and is associated with various risks. Since these vehicles currently still have significantly higher investment costs than conventional vehicles, this hurdle can only be overcome with public funding for the purchase of the vehicle fleets.

2 The MEHRLIN project

2.1 Introduction

The MEHRLIN (Models for Economic Hydrogen Refuelling Infrastructure) project aims to promote, deploy, and commercialize hydrogen as an alternative fuel, hence contributing to the European alternative fuel implementation strategy. This project's activities include studies based on real life-pilot deployments at seven locations: Bolzano (Italy), Hürth and Wermelskirchen (Cologne, Germany), Wuppertal (Germany), Heinenoord-South Rotterdam (Netherlands), London and Birmingham (United Kingdom):



- Five (5) HRSs are owned by public transport companies or their affiliates and are servicing their own fleets.
- Two (2) HRSs are owned and operated by private companies and are selling the hydrogen to public transport operators.
- The locations are deploying 10 to 20 FC-buses per fleet.
- All locations aim to increase their FC-bus fleets in the coming years.
- All locations are receiving funding support by the European Commission trough CINEA (European Climate, Infrastructure and Environment Executive Agency) within the Connecting Europe Facility programme.
- All locations are using also regional and/or national funding schemes to support their project.

To achieve this overall objective, five activities will be implemented: the first activity is to build a hydrogen refuelling station (HRS) in these locations to refuel hydrogen powered fuel cell buses and potentially utility vehicles. Consequentially, the second activity's objective is to operate these HRS and to test - under real-life conditions - their technical and economic performance under high load and in daily operation. The third objective is to produce an adequate amount of data which allows the monitoring and analysis of each HRS' economic and technical performance, each station will operate for a period of at least 12-18 months. The last two activities concern dissemination and project management.

MEHRLIN and JIVE – creating synergies between EU funded projects. A captive fleet of 124 FC-buses for urban use will be refuelled at these stations, deployed within the JIVE 1 (735528 – JIVE – H2020-JTI-FCH-2016-1) and JIVE 2 (779563 – JIVE 2 – H2020-JTI-FCH-2017-1) projects which have been funded by the Fuel Cells and Hydrogen Joint Undertaking (FCH-JU). These three projects (JIVE 1, JIVE 2 and MEHRLIN) run in parallel and create synergies, as all projects involved benefit from a lively exchange of experiences and data sets.

2.2 Hydrogen Source and Delivery

The locations in the MEHRLIN project used the following hydrogen sources being delivered in different way:

- Electrolysis with certified green energy: 2 locations
- Electrolysis with energy from biomass waste: 1 location
- Electrolysis chlor-alkali (by product): 3 locations
- Methane steam reforming: 1 location

Delivery of hydrogen:

- Onsite production: 1 location
- Trailer delivery: 6 locations
  - from 200 kg to 958 kg per trailer
  - from 200 bar to 350 bar onsite
  - from 0,5 km to 450 km distance

2.3 Technology in operation

Six different technology manufacturers delivered the hydrogen stations to the seven locations with different characteristics, ranging from:

- Dispensing capacity:
  - from 250 kg/d to 2000 kg/day
  - from 50 kg/hour to 120 kg/hour
- Nozzles
  - 1 nozzle at 350 bar: 2 locations
  - 2 nozzles at 350 bar: 5 locations
  - 1 nozzle at 700 bar (additional): 1 location
- H2 Storage capacity onsite
  - fixed storage: from 160 kg to 484 kg
  - mobile storage: from 200 kg to 1900 kg
  - total capacity: from 200 kg to 2176 kg

3 Starting point

3.1 Real-world Assessment

Since MEHRLIN and JIVE represent pioneer projects in the sector, and the operational phase begun with the first expansion phase of the European hydrogen buses fleet, only 10 to 20 vehicles have been in operation at each site, hence lowering the current HRS operations to between 10% and 20% of their maximum capacity. This of course had a large impact on the economic results of the first 18 months of operations and didn't enable a positive business case. It is important to specify that this is expected to change with the planned scale-up of fleets and infrastructures at all sites.

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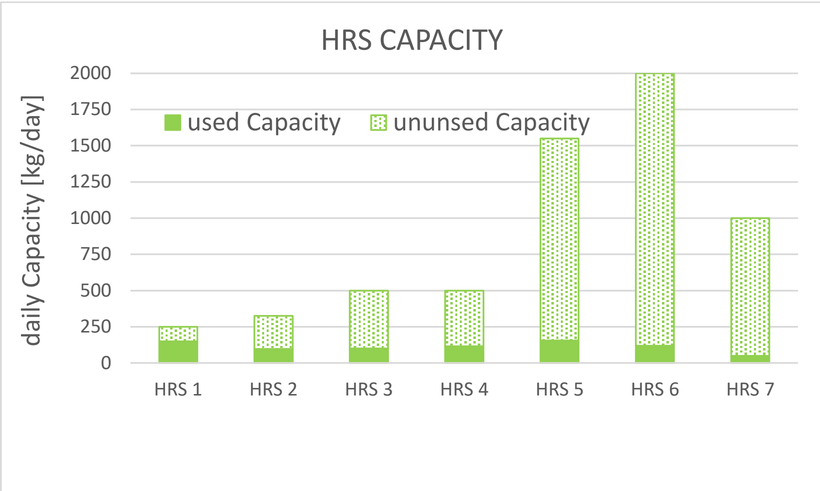


Figure 1: Dispensing capacity in kg hydrogen per day of the HRS (entire bar) and the actual utilisation rate (full green section of the bar)

In parallel with fleet expansion, key technical factors such as the technical availability and reliability of the refuelling systems must also be improved. This is because when the facilities are operating at full capacity, the current performance data would lead to flow restrictions and thus revenue losses. The refuelling speed, on the other hand, already reached very good results, significantly exceeding the target of 10 minutes per refuelling time.

3.2 Modelling

All stations showed a negative result over the observation period (12-18 months) with the very low utilisation factor of the existing capacity (see Figure 2) being a key contributing factor. Therefore, based on the data collected, modelling was carried out with the revenues from hydrogen sales and from subsidy income, and with the realised cost structure (cost of sales and general structural costs). In the modelling, a sales price of 30% margin was calculated, which is added to the purchase price or the production costs for hydrogen. This value is assumed to be constant in the presentation and corresponds on average to the consolidated data sets from the locations investigated.

The overall result in the single Business Models improves by maximising the sites' capacities, even if this does not lead to a positive result for all plants: Figure 3 shows that plant utilisation alone is not sufficient to achieve a positive result. The results at maximum capacity, however, are very divergent indicating the influence of another technical variable.

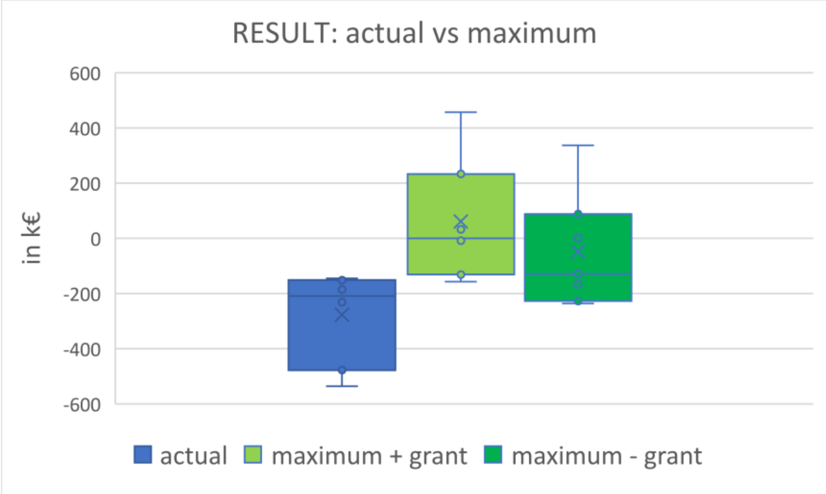


Figure 2: Averaged results of all plants together in comparison at currently low (blue) utilization after 12-18 month of operation and simulated maximum possible utilisation (green). In light green the averaged result with the subsidies, in dark green without subsidies.

In addition to the station's utilisation rate, the plant size or capacity has a decisive influence on their result and economic viability. Only when a critical size is reached does the business model become self-sustaining or positive. In the simulation model, a refuelling station receiving subsidies can only achieve an economically positive result from a critical size of over 500 kg/day at maximum utilisation (Figure 3- light green line). Without subsidies (in dark green), this critical limit shifts upwards, and a positive result can be reached only from a plant capacity of about 750 kg/day.

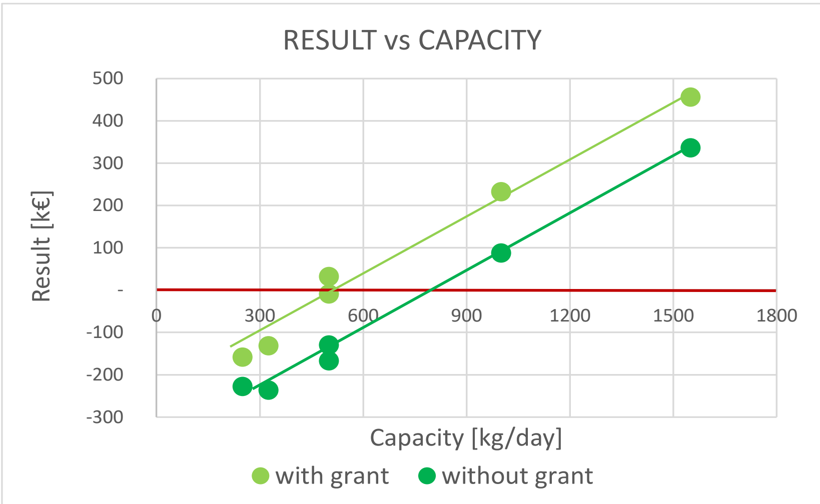


Figure 3: Economy of scale for hydrogen refuelling stations: Positive results are only achieved above a critical size and refuelling capacity of 500 kg/day (with public subsidies) or 750 kg/day (without subsidies).

The calculations of the business cases of the individual sites and the simulations and modelling, and consequently the derivation of the general business case, were carried out with data preceding the energy crisis period in order to preserve comparability and to keep the complexity as low as possible and the conclusions consistent.

4 Generalised Business Model

Generally valid business cases are derived from the aggregated results of the individual locations. Due to the different sizes and business models, two general cases are derived that reflect the results of the seven HRSs as representatively as possible.

4.1 Business Model „Case 1500“

4.1.1 Technical Performance

The hydrogen refuelling facilities in the project are used to refuel bus fleets, both own FC-buses in operation and third-party bus fleets. A smooth refuelling operation is a prerequisite for a maximum possible flow and therefore turnover of hydrogen and the achievement of a positive business case. In addition to buses for public transport, these filling stations can also refuel other fuel cell vehicles, such as municipal vehicles and heavy-duty vehicles with 350 bar technology.

The refuelling station of the "Case 1500" has a standard refuelling capacity of 1500 kg/day and can thus refuel up to 100 buses per day. After 12 months of operation, the facility has an average utilisation of 10%. The low utilisation of the plant at the beginning of its operation subsequently has an impact on the economics of the plant, as we will see in the chapter for Economic Performance (4.1.2), and must be successively increased to maximum utilisation. This will be done by scaling up the bus fleet (see Table 1).

A key indicator is the technical availability of the plants. The project has defined 99% availability as a target. High availability is important for customers, e.g. for smooth bus operation. As a consequence, this key figure also influences the maximum possible utilisation and therefore the economy of the plant. The average availability of the plant is currently 95% and must therefore be trimmed towards 99% with the help of improvement measures. This difference would mean a 4% loss in turnover at full operation.

Another technical parameter is the refuelling speed. In combination with availability and reliability, this has an effect on the number of buses that can be refuelled per day. The target value specified by the manufacturers of the systems, which must be adhered to so that the nominal value of the daily capacity of the systems can also be achieved, is less than 10 min. per refuelling process. The value determined for this indicator is 7 min. per refuelling operation on average and is significantly better than the target and standard specification. In this aspect, the technical maturity of the system is given and therefore does not represent a restriction of flow and turnover.

4.1.2 Economic Performance

4.1.2.1 Investment and Operation

The refuelling system "Case 1500" has an investment sum of around 4.5 million euros, with the EU providing an investment contribution of 0.6 million euros and the national/regional authority an investment contribution of 1 million euros. The plant is depreciated on a straight-line basis over 10 years. In addition, the EU authority provides support of 0.26 million euros to cushion the operating costs of the plant. The owner of the plant finances the remaining sums of the investment and operation with equity.

Table 1: Initial data of the business model "Case 1500" for calculating the economic performance, with information on the purchase and sales price of hydrogen. In this analysis, hydrogen is supplied as a by-product of the chlor-alkali industry.

H2-Source	**H2 colour**	**Delivery**	**Distance**
By-Product	chlor-alkali	Trailer 350bar	150km
HRS type	**Capacity**	**Storage**	**No. Nozzles**
350bar	1 500 kg/d	1 500kg	2
Investment HRS	**depreciation (annual)**	**financing**	**loan**
€ 4 556 603	10%	n.a.	n.a.
Funding EU	**Funding national**	**Funding regional**	**Equity**
€ 864 218	1 000 000	n.a.	€ 2 692 385
FC-Buses	**scale-up 1**	**scale-up 2**	**scale-up 3**
10	40	75	100

Hydrogen	
Purchasing price	**Sales price**
€6.50/kg	**€8.45/kg**

In the first year of operation, 10 FC buses are refuelled daily with an average of 15 kg of hydrogen per day and bus. The buses consume an average of 6.7 kg/100 km of hydrogen and cover a daily distance of around 224 km. The bus fleet will be successively expanded over the next few years up to the maximum utilisation of the refuelling facility (see Table 1) and thus up to the maximum flow and revenue (see Figure 4). The majority of the revenue comes from hydrogen sales; just under 0.2 million euros per year is revenue from subsidies in the first five years.

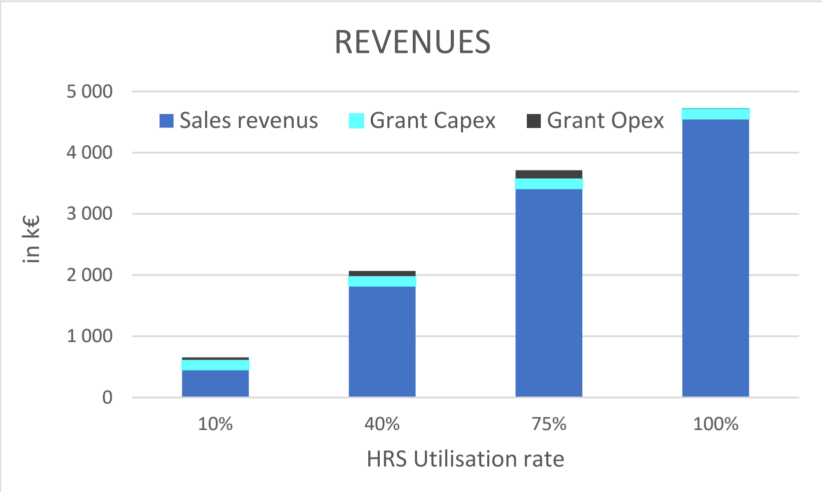


Figure 4: Revenues from hydrogen sales and subsidies: Revenue growth in line with increasing hydrogen sales parallel to the expansion of the bus fleet.

The goods receipt of hydrogen can take place in different ways. In the most advantageous variant, the hydrogen is delivered as a by-product of the chlor-alkali industry via trailers. The sales price for hydrogen is made up of the purchase price with a 30% mark-up.

On the expenditure side, a distinction can be made between the acquisition costs for hydrogen (cost of sales) and the operational costs. The cost of hydrogen increases in proportion to the throughput and parallel to the fleet build-up, up to 80% of the total costs at full capacity (see Figure 5). In operational costs, variable and fixed costs can be described. The variable costs change with the upscaling and utilisation of the plant, such as the electricity costs to operate the plant, the personnel costs for operation and maintenance and the costs for consumables. All other costs are fixed costs that remain constant and therefore decrease in percentage in relation to the increase in turnover in the scale-up, thus enabling the effect of an economic upscaling of the result in parallel with the technical flow. The main share of these costs is taken up by the depreciation costs for the plant (see Figure 6).

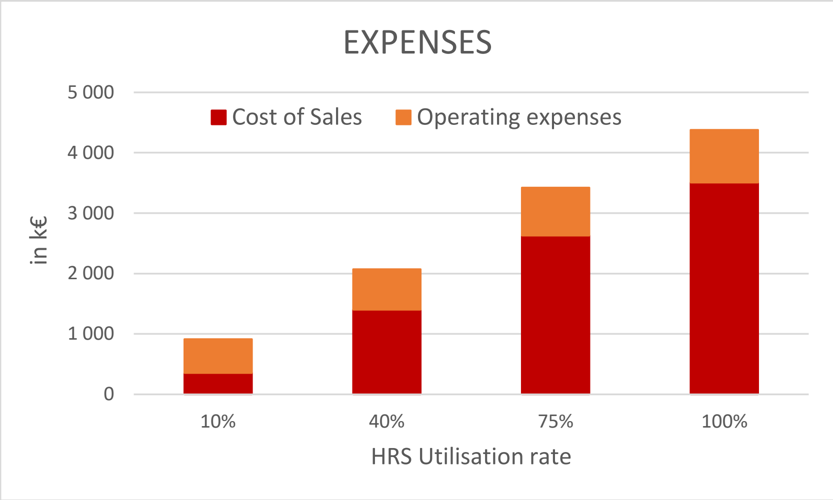


Figure 5: Consideration of the expenses of "Case 1500" with the main categories of costs for the purchase of goods (hydrogen) and operating costs depending on hydrogen sales in parallel with the expansion of the bus fleet.

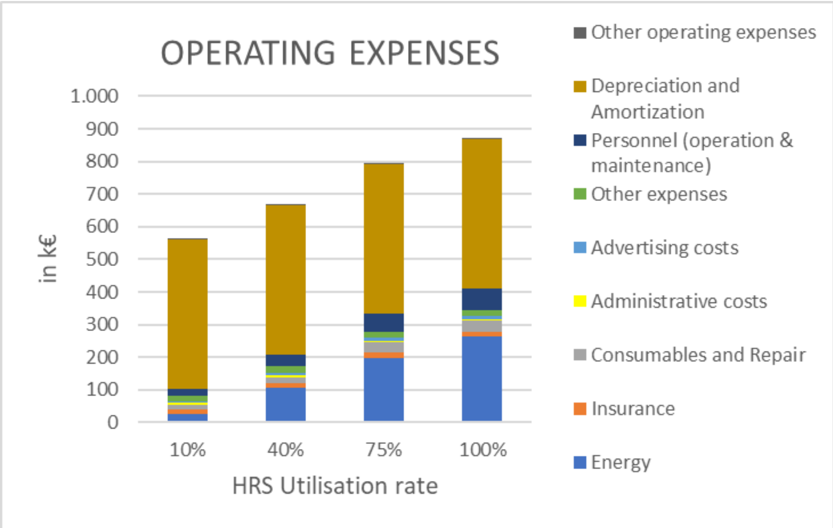


Figure 6: Operational costs of "Case 1500" depending on hydrogen sales and fleet expansion. An increase is only observed in the cost types energy for operation, consumables & repair and personnel costs for the operation and maintenance of the plant. All other cost types remain independent of the utilisation of the plant.

4.1.2.2 Result

The result after one year of operation is negative due to the low utilisation of the plant of 10%. For the simulation of future business years, an annual result is first calculated under the assumption of maximum utilisation of the facility. To reach maximum utilisation, the bus fleet is expanded from 10 buses to 100 buses within five years. A constant margin of 30% on the purchase price is still calculated for the hydrogen sales price. With the increase in hydrogen purchase due to the fleet expansion, the turnover increases accordingly. The result of the upscaling is shown in Figure 7: the plant breaks even in the third year and then achieves a positive result in the fourth year at maximum capacity utilisation.

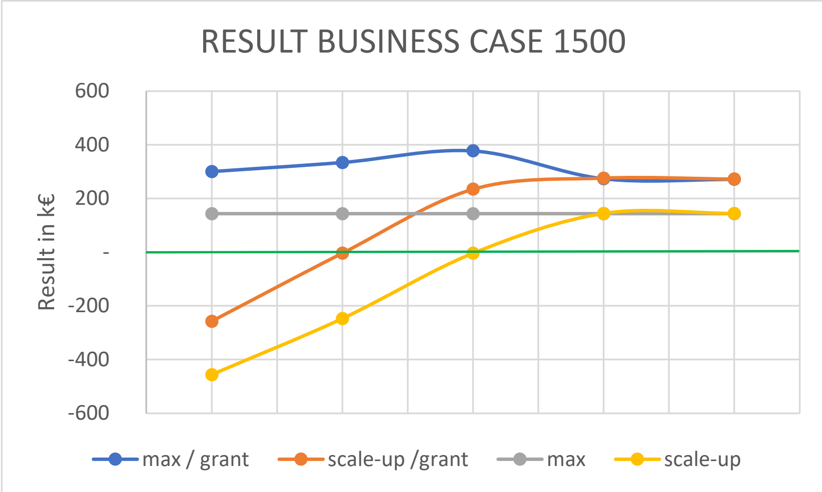
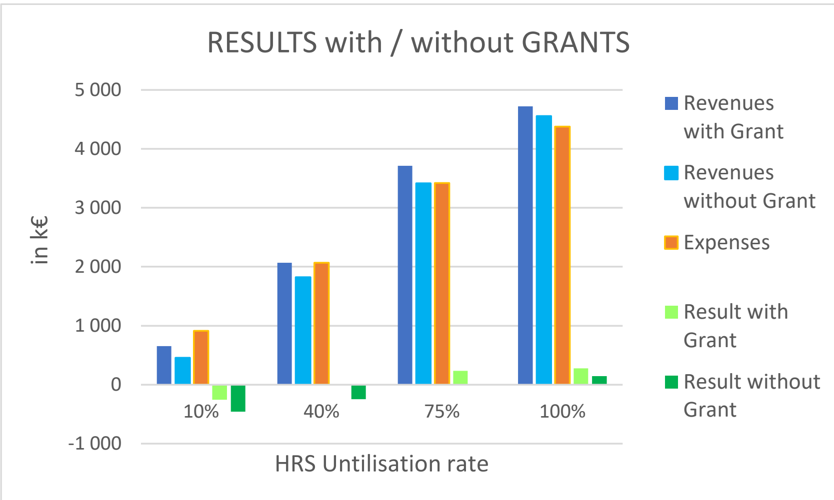


Figure 7: Simulated results of the operation of the hydrogen refuelling system at maximum utilisation and depending on the upscaling of the bus fleet and thus the increase in turnover up to the maximum utilisation of the system. Comparison of the results with and without support from public funding (grant).

4.1.2.3 Comparison with and without funding

The investment of the plant of the "Case 1500" business model is financed with equity capital, supported by investment contributions. The operation is also supported by subsidies in the first few years. Due to the public subsidy, there is initially no need for external financing. The MEHRLIN project is intended to serve as a pilot project for the subsequent roll-out of hydrogen refuelling systems. However, this roll-out should be possible without public subsidies, with the help of traditional financing options such as bank loans. Therefore, the aim of this study is to present the same business case without subsidies and then to examine the bankability.

Instead of subsidies, debt financing should be used to finance the investment and scale-up of the plant to profitable operation. By deducting the periodically allocated subsidies, the income is reduced while the cost structure remains the same. As a result, the result and the return on sales ROS are reduced (see Figure 8). The return on sales ROS (in relation to the annual result) at full load is 5.8% and falls to 3.2% without subsidies (see Figure 8).



Return on Sales (ROS)				
HRS Utilisation rate	10%	40%	75%	100%
ROS with Grant	-39.4%	-0.2%	6.3%	5.8%
ROS without Grant	-100.2%	-13.6%	-0.1%	3.2%

Figure 8: Comparison of the business case with and without subsidies: Expenses remain the same, while revenues, results and return on sales (ROS) are reduced without subsidies.

4.1.3 Customer Perspective

4.1.3.1 Comparison with diesel operation

The bus operator purchases the hydrogen at the pump in the given case (delivery of hydrogen as a by-product from the chlor-alkali industry) for 8.45 €/kg. On average, the FC buses consume 6.7 kg of hydrogen per 100 km travelled. This results in fuel costs of 56.6 €/100 km. As a comparison, diesel buses cost 54 €/100 km to operate, assuming that a diesel bus fills up with 45 l/100 km of diesel at a price of 1.2 €/l at the pump. The fuel costs for FC buses in this case are therefore insignificantly higher than for diesel buses. The prerequisite for achieving this simulated business case with the associated sales price is, in addition to the price level indicated, the operation of the hydrogen refuelling system at full load.

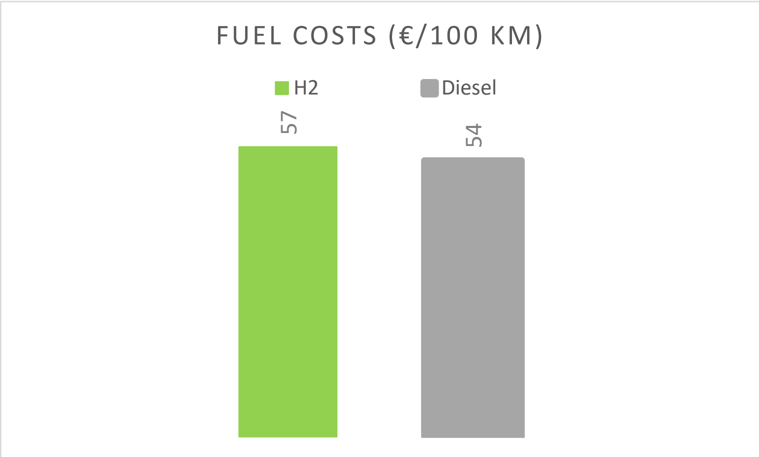


Figure 9: Business model "Case 1500" and fuel costs derived from it for FC buses in comparison with the operation of diesel buses.

4.1.3.2 Simulating different price levels

The assumed business case is based on the supply of hydrogen as a by-product from industry. Since this hydrogen can be purchased cheaply, the price level is very low compared to hydrogen produced via electrolysis from renewable energy sources. In the pre-crisis period, hydrogen could be produced on-site at similar costs and was comparable in price level. The energy crisis, however, has greatly increased this price level due to the link to the electricity market. Consequently, results from simulations with different price levels are presented to illustrate the effects of price increases and different price levels.

The simulations are carried out with the same business model and structure. Only the purchase price of hydrogen was changed. The sales price results from the purchase price with a certain margin: this margin is chosen so that the return on sales is still positive, resulting in the best possible sales price. The price reference is the purchase of hydrogen from the chlor-alkali industry with 6.5 €/kg and 30% margin.

Table 2: Simulations with the business model "Case 1500": the effect of purchase price and sales price on fuel costs. Diesel operation with 54 €/100 km serves as a reference.

Purchase price	***Sales margin***	***ROS***	***Fuel costs***
€/kg	% margin	%	€/100 km
5	28	1,1	43
6,5	30	5,8	56,6
11,0	14	1,4	84,0
17,0	0,9	0,9	124

Due to the high throughput of hydrogen with the plant, very low returns on sales can be chosen to make the business case positive. This allows the sales price to be optimised. The results show a high price sensitivity, which has a strong impact on the fuel costs per 100 km (additional costs compared to diesel operation).

4.2 Business Model "Case 500"

4.2.1 Technical Performance

The refuelling station of the "Case 500" has a standard refuelling capacity of 500 kg/day and can thus refuel up to 32 buses per day. After 12-18 months of operation, the facility has an average utilisation of 19%. The low utilisation of the plant at the beginning of its operation subsequently has an impact on the economics of the plant, as we will see in the chapter Economic Performance (4.2.2) and must be successively increased to maximum utilisation. This will be done by scaling up the bus fleet (see Table 3).

4.2.2 Economic Performance

4.2.2.1 Investment and Operation

The refuelling system "Case 500" has an investment sum of around 2.9 million euros, with the EU providing an investment contribution of 0.6 million euros and the national/regional authority an investment contribution of 1.35 million euros. The plant will be depreciated on a straight-line basis over 10 years. In addition, the EU authority provides support of 0.26 million euros to cushion the operating costs of the plant. The owner of the plant finances the remaining sums of the investment and operation with equity.

Table 3: Starting data of the business model "Case 500" for calculating the economic performance, with information on the purchase and sales price of hydrogen. In this analysis, hydrogen is supplied as a by-product of the chlor-alkali industry..

H2-Source	***H2 colour***	***Delivery***	***Distance***
By-Product	chlor-alkali	Trailer 350bar	150km
HRS type	***Capacity***	***Storage***	***No. Nozzles***
350bar	500 kg/d	800kg	2
Investment HRS	***depreciation (annual)***	***financing***	***loan***
€ 2 920 930	10%	n.a.	n.a.
Funding EU	***Funding national***	***Funding regional***	***Equity***
€ 764 218	1 350 000	n.a.	€ 806 712
FC-Buses	***scale-up 1***	***scale-up 2***	***scale-up 3***
8	18	28	32

Hydrogen	
Purchasing price	***Sales price***
€6.56/kg	***€8.53/kg***

In the first year of operation, 8 FC buses are refuelled daily with an average of 15 kg of hydrogen per day and bus. The buses consume an average of 8.5 kg/100 km of hydrogen. The bus fleet will be successively expanded over the next few years until the refuelling facility is used to its maximum capacity, maximising the maximum flow rate and revenue (see Figure 10). The majority of the revenue comes from hydrogen sales, and just under 0.25 million euros per year are income from subsidies in the first years.

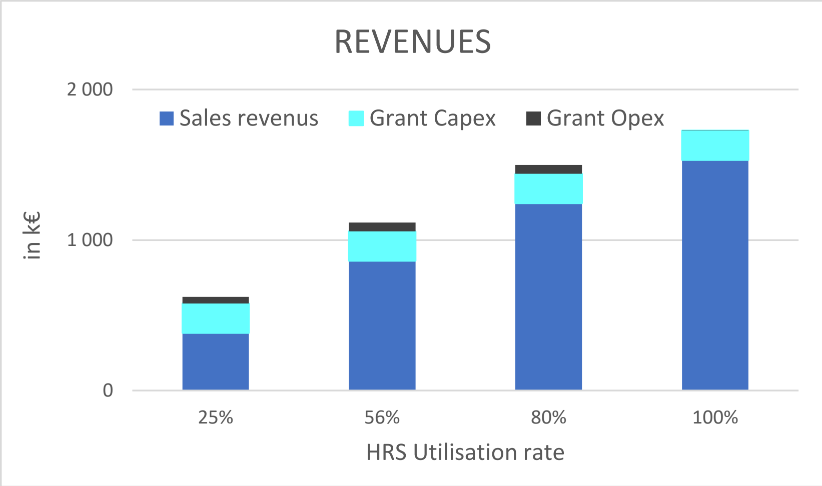


Figure 10: Revenues from hydrogen sales and proceeds from subsidies: Revenue growth in line with increasing hydrogen sales parallel to the expansion of the bus fleet.

Hydrogen can be delivered in different ways. In the most advantageous variant, the hydrogen is delivered as a by-product of the chlor-alkali industry via trailers. The sales price for hydrogen is made up of the purchase price with a 30% mark-up.

On the expenditure side, a distinction can be made between the acquisition costs for hydrogen (cost of sales) and the operational costs. The costs for hydrogen increase in proportion to the throughput and parallel to the fleet build-up, up to 70% of the total costs at full capacity (see Figure 11). For operational costs, the variable and fixed costs can be described. The variable costs change with the upscaling and utilisation of the plant, such as the electricity costs to operate the plant, the personnel costs for operation and maintenance, and the costs for consumables. All other costs are fixed costs that remain constant and therefore decrease in percentage in relation to the increase in turnover in the scale-up, thus enabling the effect of an economic upscaling of the result, in parallel with the technical flow. The main part of these costs are the depreciation costs for the plant (see Figure 12).

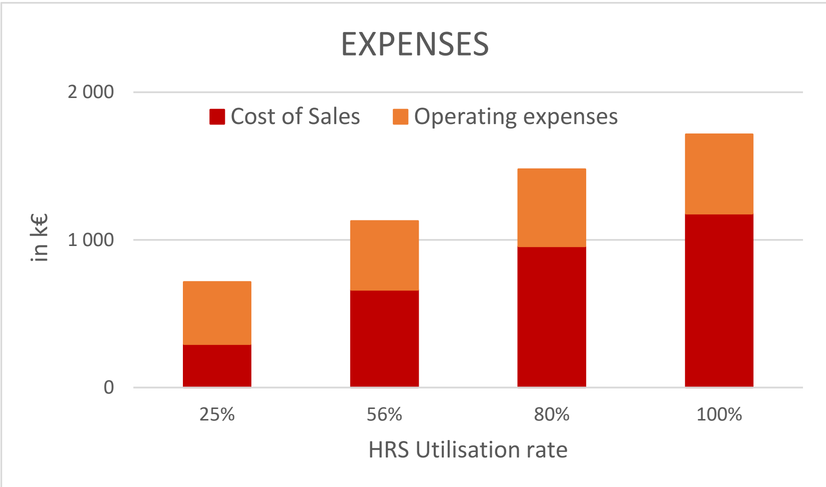


Figure 11: Consideration of the expenses of the "Case 500" with the main categories of costs for the purchase of goods (hydrogen) and operating costs depending on hydrogen sales in parallel with the expansion of the bus fleet.

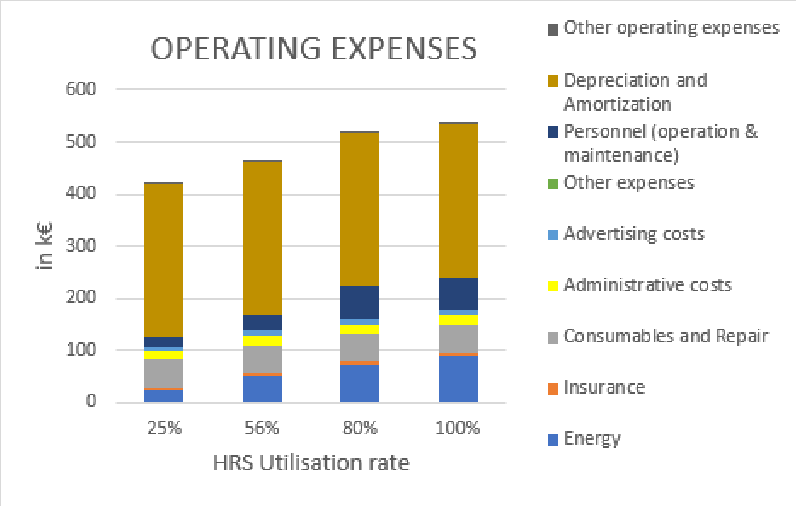


Figure 12: Operational costs of the "Case 500" depending on hydrogen sales and fleet expansion. An increase is only observed in the cost type energy for operation, consumables & repair and personnel costs for operation and maintenance of the plant. All other cost types remain independent of the utilisation of the plant.

4.2.2.2 Result

The result after one year of operation is negative due to the low utilisation of the plant of 25%. For the simulation of the future business years, an annual result is first calculated under the assumption of maximum utilisation of the facility. To reach maximum utilisation, the bus fleet is expanded from 8 buses to 32 buses within the five years. A constant margin of 30% on the purchase price is still included in the hydrogen sales price. With the increase in hydrogen purchase due to the fleet expansion, the turnover increases accordingly. The result of the upscaling is shown in Figure 13: In the fourth year, the plant breaks even.

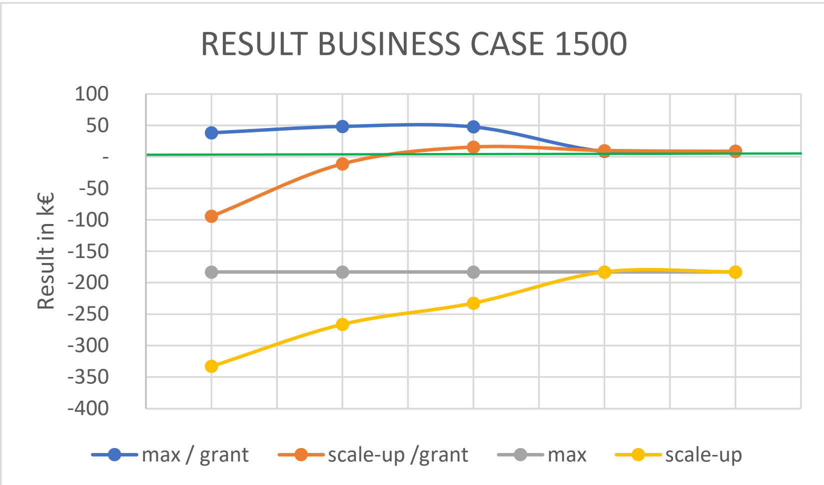
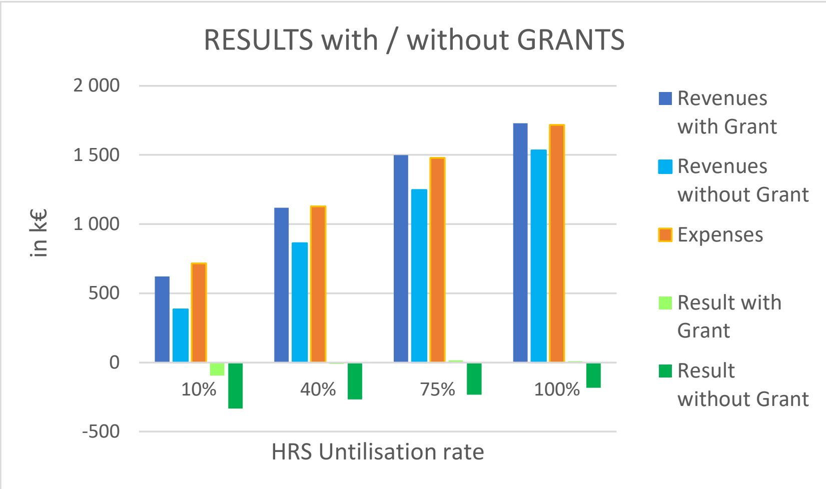


Figure 13: Simulated results of the operation of the hydrogen refuelling system at maximum utilisation and depending on the upscaling of the bus fleet and thus the increase in turnover up to the maximum utilisation of the system. Comparison of the results with and without support from public funding (grant).

4.2.2.3 Comparison with and without funding

The investment of the plant of the "Case 500" business model is largely financed with investment contributions (70%) and the rest with equity capital. The operation is also supported by subsidies in the first years. Due to the public subsidy, there is initially no need for external financing. The MEHRLIN project is intended to serve as a pilot project for the subsequent roll-out of hydrogen refuelling systems. However, this roll-out should be possible without public subsidies, relying instead on traditional financing options such as bank loans. Therefore, the aim of this study is to present the same business case without subsidies and then to examine the bankability. Instead of subsidies, debt financing should be used to finance the investment and scale-up of the plant to profitable operation.

By deducting the periodically allocated subsidies, the income is reduced while the cost structure remains the same. As shown in Figure 14, the result and the return on sales are reduced. The return on sales at full load is <1% and remains negative without subsidies. It can be concluded from this that with this economic performance the "Case 500" cannot achieve a return without subsidies, which is why bankability cannot be given.



Return on Sales (ROS)				
HRS Utilisation rate	10%	40%	75%	100%
ROS with Grant	-15,2%	-1,0%	1,0%	0,6%
ROS without Grant	-86,9%	-30,9%	-18,7%	-11,9%

Figure 14: Comparison of the business case with and without subsidies: Expenses remain the same, while revenues, results and return on sales (ROS) are reduced without subsidies.

4.2.3 Customer Perspective

4.2.3.1 Comparison with diesel operation

The bus operator purchases the hydrogen at the pump in the given case (delivery of hydrogen as a by-product from the chlor-alkali industry) for 8.53 €/kg. On average, the FC buses consume 8.5 kg of hydrogen per 100 km of travel. This results in fuel costs of 72 €/100 km. As a comparison, diesel buses cost 54 €/100 km to operate, assuming that a diesel bus fills up with 45 l/100 km of diesel at a price of 1.2 €/l at the pump. The fuel costs for FC buses in this case are therefore still much higher than for diesel buses. Without subsidies, the difference is even greater. The prerequisite for achieving this simulated business case with the associated sales price is, in addition to the price level indicated, the operation of the hydrogen refuelling system at full load.

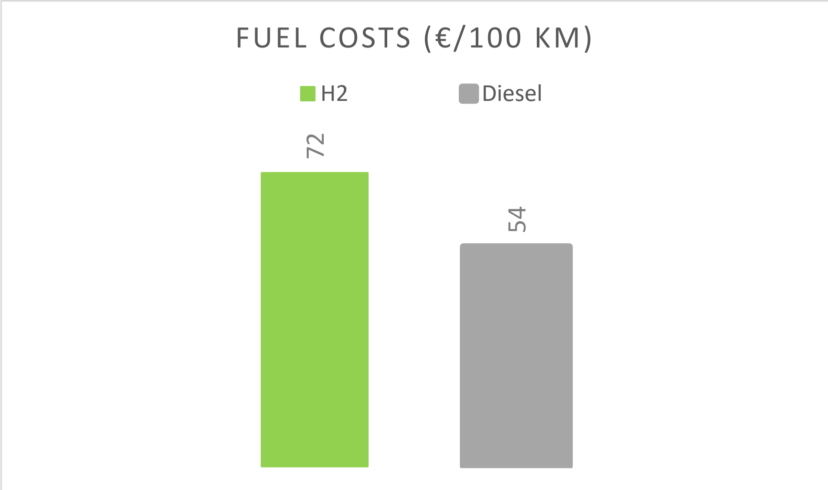


Figure 15: Business model "Case 500" and derived fuel costs for FC buses in comparison with the operation of diesel buses, with purchase of the hydrogen as a by-product of the chlor-alkali industry.

4.2.3.2 Simulating different price levels

The assumed business case is based on the supply of hydrogen as a by-product from industry. As this hydrogen can be purchased cheaply, the price level is very low compared to hydrogen produced via electrolysis from renewable energy sources. In the pre-crisis period, hydrogen could be produced on-site at similar costs and was comparable in price level. The energy crisis, on the other hand, has greatly increased this price level due to the link to the electricity market. Consequently, results from simulations with different price levels are presented to illustrate the effects of price increases and different price levels.

The simulations are carried out with the same business model and structure. Only the purchase price of hydrogen was changed. The sales price results from the purchase price with a certain margin: This margin is chosen such that the return on sales remains positive and presents the best possible sales price. The reference is the purchase of hydrogen from the chlor-alkali industry at 6.56 €/kg and 30% margin.

Table 4: Simulations with the business model "Case 500": effect of purchase price and sales price on fuel costs.

Purchse price	***Sales margin***	***ROS***	***Fuel costs***
€/kg	% Aufschlag	%	€/100 km
5,0	30	1	59
6,56	30	0,6	72
11,0	20	1,6	112
17,0	12	0,5	161

The results show a high price sensitivity, which has a strong impact on the fuel costs per 100 km (additional costs compared to diesel operation).

5 Bankability

5.1 Business Model „Case 1500"

5.1.1 Bankability Assessment

The objective of this assessment is to determine whether the business case of a hydrogen filling station is mature enough to be economically viable even without public support and whether it can be financed through traditional bank loans. The assessment focuses on the dynamics of the economic model with attention to financial structure, repayment capacity, and applicable financial market conditions.

The business case foresees public contributions of € 1.864 million with investment costs of € 4.557 million, which corresponds to a subsidy intensity of 40.9%. The public subsidies on CAPEX are 100% replaced by corresponding bank financing for the same amount. The amount of equity to be contributed thus remains unchanged.

The following assumptions were made:

- Financing: € 1,864,218.00 (40.9%)
- Interest rate: fixed 6% p.a. (IRS 10 years = 3.00%. As of 28.04.2023)
- Term: 10 years - thereof 1.5 years pre-amortisation (from commissioning) plus construction phase
- Further assumptions according to the business model, in particular a margin of 30% on the raw material price.

Under the above assumptions, the repayment ability is given, even in scenarios with reduced margins (> 22%). The sensitivity analysis confirms the financability with a shortened term (>5.5 years). Experience shows that the bank considers an equity share of around 60% to be unusual, which is why a simulation of the financing structure was carried out. This shows that financing is still possible up to a debt share of 65%. However, as the financing amount increases, so does the necessary financing term. A term of less than 10 years then no longer seems possible. In addition, the margin tolerance is reduced and a surcharge of at least 30% on the raw material price is necessary.

It should be noted that the scale-up phase is characterized by weak, and in some cases insufficient, cash flows. Without subsidies, the plant can just cover its costs in the first operation year (10%), but there is no additional cash flow to cover the financial burden. A grace period during the start-up phase is therefore imperative. The accruing interest debt requires additional liquidity subsidies from other business areas or the shareholders (or cross-financing within a group of companies, if applicable). Only when the station is fully operational will it be sufficiently profitable to be able to meet its payment obligations independently.

5.1.2 Guarantee

Apart from the necessary dynamics of the business model, this constellation requires guarantees so that the bank is willing to grant debt financing. The support of a solid shareholder (or parent company) is crucial, especially in the start-up phase. The bank therefore sees a corresponding corporate guarantee from the shareholders (or a qualified company) as indispensable. This is on the one hand to guarantee the necessary liquidity subsidies, and on the other hand an additional security to the project. Banks actually finance consolidated transactions on the basis of broad experience in order to be able to make a well-founded assessment of the default risk. The case of hydrogen filling stations is a very innovative topic in which experience values and market events are still lacking. Therefore, other financing instruments would be more suitable than bank loans.

Smaller banks tend not to take the risk of such financing, medium-sized banks would have the transaction additionally secured with a corporate guarantee or a state guarantee. The mortgage on the project property together with the privilege on plant and machinery as pure project security is not considered sufficient by the bank. The definition of an all-risk insurance policy covering all relevant risks is a prerequisite. Under certain circumstances, a key account manager insurance policy may also be required.

5.1.3 Soft facts und Risk factors

The expansion of the bus fleet and thus the purchasing volume and turnover of the service station represents one of the greatest risks in the business model. The decision to purchase fuel cell buses is usually made by the public sector or driven by subsidy programmes. Since this is usually a lengthy process, there is a risk of a delayed scale-up. The respective framework conditions (political agenda, funding programmes) must be taken into account when evaluating the individual projects and thus have an influence on their financial viability. Even though the refuelling station itself may have sufficient economic viability, it still appears necessary to ensure the purchase of hydrogen vehicles for potential customers so that the required full utilisation can be achieved and guaranteed on a permanent basis. The conclusion of long-term purchase contracts and increased customer loyalty to secure hydrogen purchase by the bus companies is also considered necessary.

Another risk is the purchase price or the production costs (electricity price) for hydrogen. The achievable purchase price of hydrogen is a central factor for the economic viability of a filling station. Due to the currently prevailing conditions on the electricity market, local production by means of an electrolysis process proves to be economically disadvantageous, as the purchase of hydrogen as a by-product of the chlor-alkali industry currently proves to be more cost-effective. However, this scenario may change again, and onsite production may become more attractive again in the medium term. In any case, the conclusion of long-term (and alternative in the sense of diversification) supply contracts for hydrogen (or for electricity for electrolysis) is advisable to enable more efficient pricing.

In order to achieve the simulated economic efficiency, the technical functionality of the system is also crucial. For this purpose, a dedicated maintenance and team is to ensure the smooth functioning of the system and its continuous availability. The conclusion of corresponding operations and maintenance (O&M) contracts is therefore a prerequisite.

5.1.4 Conclusion

The bankability of the "Business Case 1500" proves to be given under the prevailing premises, whereby the following conditions must be met:

- The corporate guarantee of a solid company or a state guarantee as an additional guarantee and to secure necessary liquidity subsidies (especially in the start-up phase) is indispensable.
- The hydrogen can still be acquired at a reasonable price.
- The margin of +30% on the raw material price is achieved.
- The economic viability is only achieved at full capacity.
- The expansion of the bus fleet is implemented as planned and must continue to be promoted if necessary.

- The conclusion of longer-term supply and purchase agreements should ensure improved customer loyalty and more efficient pricing.
- The technical maturity of the equipment is reliably increased and proper maintenance of the equipment is ensured.

5.2 Business Model „Case 500“

The bankability of the "Case 500" is not given under the conditions presented (such as a 30% margin) and the deducted result. The cash flow is too low to be able to service the debt burden.

Plants that just break even at full load are not a possible subject for loan financing. Nevertheless, this case is mentioned and described here because public transport companies often choose this scale for their entry into hydrogen technology. However, since these cases are mostly publicly supported or in-house operations, the investments are covered by public subsidies.

In many cases, the ownership model of "In-House Service" is found in the public sector, where the HRS is installed as a company fuelling station to refuel the own bus fleet. Consequently, no hydrogen is sold, and the purchase risk is eliminated, as the bus fleet is purchased by the company itself and only the operation of the buses is outsourced. The problem in this segment shifts to the purchase of fc-buses, which are currently much more expensive to invest in. Consequently, a bus operator has significantly higher financing requirements for the purchase of buses. Here, the usual lending criteria apply (among existing balance sheet data), from which the creditworthiness can be derived. If it is an in-house company, the creditworthiness is supported by the public sector.

6 Use of innovative approaches

In the MEHRLIN project, various innovative approaches were tested that can lead to a reduction in costs, especially for the onsite production of hydrogen.

- <u>Reduced electricity expenses</u>

For the local production of hydrogen from renewable energy sources, an attempt was made to reduce the electricity costs, which have an impact on the production costs of 70-80%. This can be achieved where the H2 production plant (electrolysis) is installed close to an electricity production facility and supplied via a direct private line. In addition, the legislator must provide for a regulatory constellation that allows the electricity used for electrolysis to be self-consumed for electricity generation. By avoiding the use of the public electricity grid, grid charges such as line fees and system costs can be avoided. In this way, only the direct energy costs of the supplied electricity and some taxes must be included in the cost price of the hydrogen. In this constellation, the total energy costs for the production of hydrogen can be reduced by up to 50% compared to the purchase of electricity from the public grid.

The energy crisis then wiped out this advantage in 2022, but this was not foreseeable. A levelling out of electricity prices can be assumed for the years 2024 and following, which is why this constellation can deliver positive results in the future.

- <u>Use of flexibility on the spot market</u>

On the spot market, electricity quantities are procured for the current demand, usually for the following day. Accordingly, supply and demand can be matched in real time. This means that hydrogen can be produced flexibly and in line with demand, and the electricity can be purchased in favourable market phases while avoiding the peak price. At the same time, the varying hydrogen production and thus availability also requires flexibility in the use of the buses. This is achieved, among other things, through adapted vehicle scheduling and dispatching. The hydrogen production plant must be designed accordingly: PEM electrolysis for fast reaction times, a back-up system for hydrogen in the event of a shortage, increased storage capacity for the storage of hydrogen under favourable production conditions.

- Delivery of hydrogen from large scale production sites – e.g. windfarms

The large-scale production of hydrogen exploits economies of scale and opens the possibility of using cheap surplus electricity from temporary excess capacities etc. Surplus capacities that are not used or surplus electricity that would otherwise be lost are to be used to produce hydrogen cheaply.

Due to an unpredictable increase of energy cost during the energy crisis due to geopolitical reasons, the costs for hydrogen from renewable energy was unfortunately not decreased but increased, and the desired effect could not be shown. It is expected however, that the energy market will normalize in the future making hydrogen from renewables a cost-effective option.

- Diversification of customers

To improve the utilization of the HRS, the hydrogen should be sold to other applications besides buses, such as municipal vehicles (refuse collection, road services) and heavy vehicles for regional logistics. The development of the market for such vehicles is still in an embryonic phase. However, the refuelling system and the sites are equipped for this possibility.

- Grid balancing function and highly responsive PEM electrolyser

The use of balancing revenues available in national markets can reduce the effective cost of hydrogen from green electricity. In practice, offering these services requires electrolysers to be operating constantly which is the opposite of the current regime where demand is relatively low and consequently electrolysers are run overnight sporadically taking advantage of cheap electricity. The grid balancing effect can only be realized if there is a corresponding demand (size of the bus fleet) and therefore a high utilization of the plant. Another prerequisite is an appropriately dimensioned storage capacity of hydrogen on site.

7 At a glance

The hydrogen refuelling stations installed with the support of funding projects such as MEHRLIN, CHIC, JIVE and others were realized by pioneers in the sector and politically supported initiatives with their equity supported by funding contributions. The aim of MEHRLIN is to evaluate the financial viability of traditional financing instruments, such as bank loans, for a future roll-out of HRS by various economic actors.

The most important findings from MEHRLIN are listed below, which must be fulfilled as conditions for an HRS to become bankable:

a. Matching the capacity of the HRS and the bus fleet to achieve maximum utilization of the HRS; the business case can only be positive with maximum utilization rate
b. Installation of an HRS with a refuelling capacity > 1500 kg/day.
c. Technical maturity of the HRS: >99% availability; >99% reliability
d. Efficient operation & maintenance contracts (e.g. through securing via penalties)
e. Maintaining plant utilization at a high level (utilization close to 100%)
f. Securing the demand through long-term offtake contracts with strong customer loyalty
g. Diversification of the customer base (besides buses also municipal vehicles, logistics vehicles etc.)
h. Securing the supply through long-term supply contracts (for hydrogen or electricity in the case of onsite production).
i. At present, a positive business case can only be achieved with the supply of hydrogen from the chlor-alkali industry as a by-product.
j. A positive business case for onsite production of hydrogen via long-term electricity supply contracts (PPA) or via the constellation of self-consumption of electricity for H2 production at energy production sites (avoidance of the public electricity grid and thus of grid fees and system costs) and the use of remunerable smart-grid functions of electrolysis can be realized in the future.
k. Safeguarding via several alternative suppliers of hydrogen
l. In the case of a scale-up of the bus fleet, full expansion can be achieved within 2-3 years.
m. A scale-up requires liquidity subsidies in the first years due to realized shortfalls
n. Promotion of the purchase of vehicles for a guaranteed purchase of hydrogen
o. Margins of +30% on the purchase price
p. Clearly positive business case with cash flow covering (equity and debt) capital costs
q. Corporate guarantees or government guarantees as collateral for the bank loan