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Assessing the future hydrogen demand in the mobility sector for the Ulm region in southern Germany

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Executive Summary

As part of a roadmap for the transition to a hydrogen-based infrastructure, the potential hydrogen demand in the mobility as well as the energy sector for the city of Ulm/Neu-Ulm in southern Germany until 2030 was assessed. Possible consumers were identified and their future consumption was estimated. Results showed that the mobile sector can be the driving force for the introduction of a hydrogen-based economy. A demand of about 200 t per year can be expected from commercial transport applications, which will grow to about 1226 t per year in 2028. The sector with the second largest potential is public transportation where a demand of 289 t per year can be expected until 2028, which will grow to a demand of up to 400 t per year until 2030. The demand for trains and garbage trucks were found to remain negligible in comparison until at least 2027.

Keywords: hydrogen, infrastructure, demand, market development, fuel cell vehicle

1 Introduction

The use of green hydrogen produced from renewable sources for storing large amounts of energy is seen as a key component for the transition to a sustainable energy supply [1]. The potential for the production of green hydrogen varies greatly depending on the availability of large amounts of surplus electricity from renewables [2]. Nevertheless, in order to avoid the transport of hydrogen over large distances, locally produced hydrogen should be consumed locally as far as possible [3]. For building the required infrastructure for the successful implementation of hydrogen as energy carrier, potential producers as well as consumers have to work together with local governments.

Ulm is a city in the south of Germany with a population of about 120.000 inhabitants. It is part of the region Donau-Iller which has a total population of approx. 1.000.000 inhabitants and is particularly suitable for establishing an H2 infrastructure since the topic of H2 is not completely new in the area and some initial prerequisites are already in place. Being home to Ulm University and the Ulm University of Applied Sciences, the city of Ulm has a strong focus on research and teaching. The Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) is a research institution located in Ulm that focuses on fuel

cell systems and related topics. There is already a hydrogen fueling station operating on the premises of the ZSW, which is the starting point for a hydrogen infrastructure in Ulm [4].

Ulm is surrounded by various industrial sites and several companies located in the are already active in hydrogen technologies. IVECO for example will manufacture trucks based on hydrogen technology in cooperation with NIKOLA in the coming years at their site in Ulm [5]. Another example is the company WEH GmbH Gas Technology, which among other things produces hydrogen refueling components [6].

Ulm is also connected to strategically important traffic routes. Being situated between the two larger cities Munich and Stuttgart it is located directly at the freeway E52 (A8) connecting the two. The freeway E43 (A7) running from north to south is also passing through Ulm. The intersection of both freeways makes it a strategically good point for supplying hydrogen for long distance traffic.

2 Identification of possible consumers and hydrogen consumption

As the first step towards a roadmap for transitioning towards a hydrogen-based infrastructure the potential demand in the area around the city of Ulm in south Germany was estimated by identifying possible consumers within 100 km of Ulm. The sectors of public transport (busses and trains), commercial transport and transport companies as well as applications like garbage disposal trucks were considered as they regularly drive considerable distances. The possibility to introduce hydrogen driven busses and local trains was explored in telephone calls with representatives of the respective organizations. In order to assess the potential for the use of hydrogen for commercial transport more than 50 companies were contacted and questioned as to their plans with respect to a future use of hydrogen in the transportation sector. Companies were chosen within a radius of 100 km from the city center of Ulm and Neu-Ulm. Medium sized as well as some large companies were contacted that own a fleet of vehicles, which could potentially be replaced by hydrogen driven versions. The companies were asked to answer questions or fill in a questionnaire. Information on the type of the company, the number and types of vehicles, as well as the application and average distance travelled per year was collected. 34 % of the vehicles are used for urban transport, 30 % for regional transport, 16 % for long-distance transport and 20 % were classified as other applications like for example tractors and forklifts. In order to assess the necessary time for a transition to hydrogen the average number of years a vehicle would remain operational was determined. Information on possible scenarios and timeframes under which the companies would be willing to start a trial phase for hydrogen vehicles was gathered. Other questions regarded the necessary infrastructure in the form of number and location of fueling stations as well as the preference for company owned versus external workshops for the maintenance of the fleet. The last questions regarded the companies' preference for different business models (leasing, complete ownership, pay per km) for the operation of hydrogen driven vehicles and the expectations regarding the source of the hydrogen (locally produced, green hydrogen versus imported hydrogen as well as the willingness to use grey hydrogen with CO2 compensation for the transition period). Out of 50 companies that were contacted, 28 participated in the survey, which gives an indication as what to expect in the next decade. The sector of private cars was considered to remain small in the next 10 years in comparison, as battery powered cars will remain the cheaper alternative for short distances for some time to come [7].

Stationary applications within the energy sector like the use of hydrogen for auxiliary or decentralized power supply where also considered. Hydrogen could for example be used for powering the already existing fuel cell systems in the area of Ulm and Neu-Ulm that in total amount to an electrical power of 68 kW [8]. The storage and distribution of hydrogen via the natural gas grid was also considered. The possible demand was estimated from the amount of natural gas consumed in 2021 and the percentage allowed due to legal restrictions.

3 The mobile sector

Hydrogen-based vehicles are already available on the market and can be used in different sectors like commercial and public transport. The potential for the region of Ulm was examined with the help of a survey and personal interviews.

3.1 Commercial transport

Hydrogen driven trucks and vans are already on the market and more are currently being developed. Some examples can be seen in Table 1 and Table 2.

Since hydrogen consumption could not be found for all vehicles, approximate consumption was calculated from maximum range and tank size for all vehicles (Table 1, Table 2, Table 3, Table 4). It should be noted that additional ranges with energy from the battery were neglected in this calculation.

Table 1: Available hydrogen-based trucks

Supplier	Name	Range in km	Tank size in kg	Estimated hydrogen consumption in kg/km
Faun	Bluepower [9]	250	16.1	0.064
Hyundai	Xcient Fuel Cell [10]	400	31.08	0.078
Faun	Citypower [11]	500	32	0.064

Table 2: Available hydrogen-based vans

Supplier	Name	Range in km	Tank size in kg	Estimated hydrogen consumption in kg/km
Opel	E-Vivaro Hydrogen [12]	400	4.4	0.011
Peugeot	E-Expert Hydrogen [13]	400	4.4	0.011
Citröen	ë-Jumpy Hydrogen [14]	400	4.4	0.011

The survey amongst companies described above was used in order to assess the potential hydrogen demand for transportation and logistics companies in the area. The interest the companies showed in hydrogen technologies is high. 65 % of the companies said they were planning to incorporate hydrogen driven vehicles into their fleet in the next decade, while 71 % in total said they were open to considering it. In the survey, 17 companies provided detailed information on the number and timescale of the possible acquisition of hydrogen vehicles. Of these, 14 companies indicated a possible entry date until 2028. The resulting development of the number of hydrogen vehicles in the area can be seen in Figure 1. Based on the survey a number of 48-54 hydrogen vehicles can be expected until 2028.

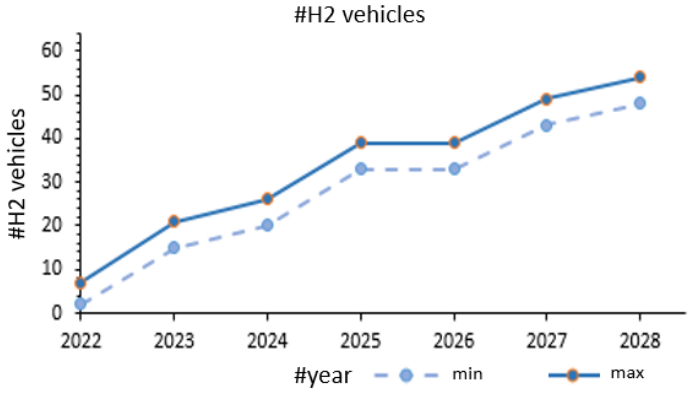

Figure 1: Expected number of hydrogen vehicles

The resulting total consumption of hydrogen per year was obtained by the multiplication of the average consumption of hydrogen per kilometre for the different vehicle types and the average mileage per year as given by the companies. The average consumption of hydrogen per kilometre is derived from an average value of the estimated average consumptions calculated from tank size and range as given in Table 1. The result is shown in Figure 2 and can be understood as the expected development of the hydrogen demand. Assuming the companies' plans are realised and considering the average distance the companies vehicles travel per year, a hydrogen demand of about 200 t per year can be expected until 2024 as shown in Figure 2. Two companies even voiced plans to transition their entire fleet until 2030, starting in 2024. This would lead to a hydrogen demand of at least 1750 t per year in 2030.

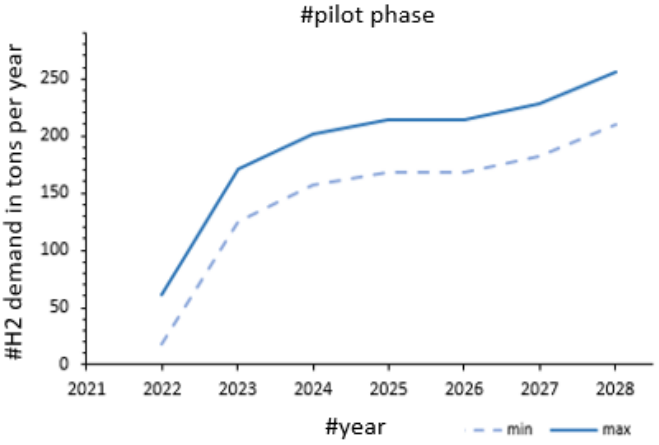

Figure 2: Development of potential hydrogen demand arising from pilot phases with hydrogen vehicles the in commercial transport sector based on the answers from 10 companies

3.2 Communal vehicles for special applications

Communal vehicles for rubbish collection could in the future also run on hydrogen since they travel large distances every day and have a high-power demand. Several trucks are already available or being tested like the Bluepower by Faun or the garbage disposal trucks from E-Trucks as shown in Table 3. The Faun Blue Power has already been in test operation since 2019.

Table 3: Available hydrogen-based waste disposal trucks

Supplier	Name	Range in km	Tank size in kg	Estimated hydrogen consumption in kg/km
Faun	Bluepower [15]	300	16.1	0.054
Geesinknorba	GPM IV Split [16]	250	15	0.060
E-Trucks	[17]	400	30	0.075
E-Trucks	[17]	400	20	0.05

For other applications like street cleaners or snow removers hardly any producers could be found with the exception of Green Machines [18] offering a street cleaner that was demonstrated in 2021. Due to the scarcity of vehicles, this sector was not considered in the present study.

The city of Ulm currently operates rubbish trucks, eleven run on Diesel and one on natural gas, each of them travelling between 160 and 200 km a day. If the entire fleet was replaced by hydrogen trucks and assuming a hydrogen consumption of 0.06 kg/km, the annual consumption of hydrogen would be about 43 t per year. However, the usual time a garbage disposal truck is operated is around 8 years meaning that a complete replacement by hydrogen vehicles would take at least 8 years. Since the procuring process for garbage disposal trucks is slow, the earliest a hydrogen-based vehicle could be used is in 2023. Vehicles for a pilot phase were considered in the estimation for Figure 2.

3.3 Public transport

Public transport is very suited for introducing a new technology, since a whole fleet of vehicles is operated and municipal operators have to meet goals as to the sustainability of their fleet. Hydrogen is interesting as the fuel for busses that drive large distances. For shorter distances battery driven busses can be a more economical alternative [7]. Several busses for passenger transport based on fuel cells are already on the market and others are being developed. There are more than 20 companies worldwide that manufacture fuel cell busses or plan to launch them on the market in the near future. Some examples and their approximate hydrogen consumption can be seen in Table 4. Their hydrogen consumption is estimated from the tank size and the range of the vehicle. Most available hydrogen busses have a length of 12 m, however larger busses with a length of 18 m are also available as can be seen in Table 4.

Table 4: Available hydrogen-based busses

Supplier	Name	length in m	Range in km	Tank size in kg	Estimated hydrogen consumption in kg/km
Van Hool	Exqui.City 18 Fuel Cell [19]	18	240	38.7	0.16
Van Hool	A330 Fuel Cell [20]	12	350	38.5	0.11
Solaris	Urbino 12 hydrogen [21]	12	350	37.5	0.11
CaetanoBus	H2.City Gold [22]	11	400	37.5	0.09
Safra	HYCITY [23]	12	350	35	0.1

Busses in Ulm are operated either by the municipality or by contracted private companies. If it is assumed that the city will operate about 50 hydrogen busses in the future, each of them traveling an average of 450 km per day a hydrogen demand of 903 t per year can be calculated. For calculating the consumption, an average value of 0.11 kg/km was taken based on data available of the hydrogen busses in Table 4. The transition to hydrogen busses would not happen at once. In the normal course of event about 4 to 5 busses are replaced each year. If it is assumed that from 2024 the new replacements would be hydrogen busses, the demand for hydrogen in this application could grow as shown in Table 5 reaching approx. 433 t per year in 2030.

Table 5: Assumed development of hydrogen demand in the public transport sector

	2024	2025	2026	2027	2028	2029	2030	2031	2032
Assumed number of H2 Busses	0	4	8	12	16	20	24	28	32
Resulting H2 demand (t/year)	0	72.27	144.54	216.81	289.08	361.35	433.62	505.89	578.16

Apart from the municipality several private companies also provide busses for public transport in the area of Ulm and Neu-Ulm. One of them took part in the survey described above and said they were planning to operate around five hydrogen busses until 2028. Their busses drive an average of 50 000 km per year resulting in an additional hydrogen demand of 27.7 t per year.

3.3.1 Trains

There have already been trials of hydrogen driven trains in Germany [24], [25] and more are planned [26]. Several parts of the rail network around Ulm are not electrified and could potentially be serviced by hydrogen trains. Ulm will also have a maintenance workshop for hydrogen trains [27], which is being prepared to service the Siemens Mireo in the year 2024. However, the refueling of the train will be done in Tübingen, about 70 km from Ulm, so that this will not create any significant demand for hydrogen in Ulm. The rail network which is the most suited (Netz 5 Donau Ostalb [28]) for hydrogen because it is largely un-electrified, will be re-contracted in 2027 [29]. The tender process will start in 2024, than the decision for the type of trains will be taken. Therefore, it is not be expected that any significant hydrogen demand will arise for trains until at least 2027. Should hydrogen be chosen a demand of up to 985 t per year can be expected from 2027

onwards if an average consumption of 26 kg of hydrogen per 100 km [30] and max. 15 trains is assumed. Since electrification of several yet un-electrified tracks is planned, the demand might well be lower.

3.4 Required infrastructure developments

For the use of hydrogen driven vehicles sufficient refueling stations are needed. Ulm currently has one 700 bar hydrogen refuelling station which is located at the research institute ZSW. The filling station is designed for cars and the access for trucks is limited.

It is marked in red in Figure 3. Furthermore, two stations are currently being planned; one in the north and one in the industrial site in the south. The location of them can also be seen in Figure 3 as well as the locations of some of the companies that showed an interest in using hydrogen driven vehicles in the next couple of years. Several companies located at a greater distance from the city center are not shown.

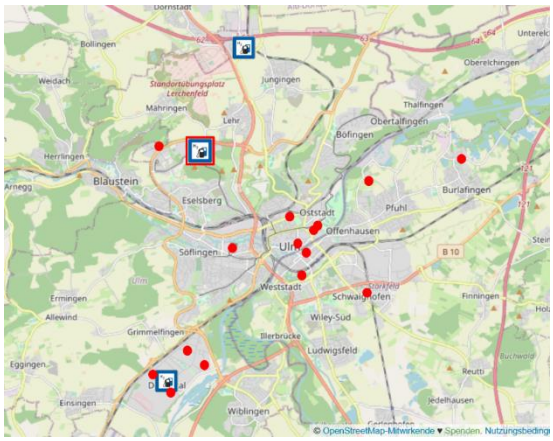

Figure 3: Existing (red frame) and projected hydrogen refueling stations in Ulm as well as the location of possible consumers (red dots)

It can easily be seen that several interested companies are located in the eastern part of the cities, where there are currently no plans for additional refueling stations. More than half of the companies responded that two refuelling stations are enough for them to start a first trial of the technology.

About 46 % of the companies said they were considering to operate their own refilling stations. This shows that the initiative of the companies can be reckoned with to improve the existing infrastructure, once a basic infrastructure is available.

4 Energy sector

Stationary applications within the energy sector like the use of hydrogen for auxiliary or decentralised power supply where also considered but the demand within the next decade was concluded to be negligible. Hydrogen could be used for powering the already existing fuel cell systems in the area of Ulm and Neu-Ulm that in total amount to an electrical power of 68 kW [8] . If it is assumed that these systems are operated for 360 days per year with an average electrical efficiency of 34%, a hydrogen potential of 52 t per year can be deduced. Since the systems are distributed over a large area the transport and local H2 storage required in order to operate them with hydrogen instead of the readily available natural gas, is considered to be high and only viable if a hydrogen supply or source is close by. It is not to be expected that hydrogen for supplying electricity and heat to private consumers will be economically comparable to other technologies before 2030 [7]. It was therefore assumed that the demand from these applications will remain negligible over the next decade.

The storage and distribution via the natural gas grid is also considered to remain small in the next years. Assuming a future allowed hydrogen content of 2 % in the natural gas grid up to 225 t per year of hydrogen

could be stored considering the amount of 1.412 GWh natural gas consumed in 2021 [31]. The value of 2 % results from the fact that various terminals and natural gas filling stations cannot currently process higher hydrogen concentrations [32]. At a hydrogen content of 5 %, the value would increase to 563 t per year. This is the legal limit for hydrogen content as defined by the Scientific Services of the German Bundestag [33] . Since green hydrogen is currently a very expensive and rare energy carrier, feeding it into natural gas grid and thereby diluting it is not the preferred use.

5 Conclusions

In order to assess the hydrogen demand in the next decade in the area of Ulm/Neu-Ulm in Germany, potential hydrogen users within 100 km of Ulm were identified and the expected hydrogen consumption was obtained by means of a questionnaire and personal talks. The resulting hydrogen demands until 2028 from different applications are summed up in Table 6.

The results show that the mobile sector is going to be the driving force in the transition to a hydrogen-based economy. Especially in the sectors of commercial transport and public transport considerable quantities can be expected in the coming years. Several companies showed interest in starting pilot phases with hydrogen-based vehicles. Based on their plans a hydrogen demand of about 200 t can be expected already in the year 2024. Until 2028 this demand can grow to 1226 t per year.

Public transport also offers a high potential; however, it depends on political decisions. Should the municipal utilities decide to start using hydrogen-based busses a demand of 289 t/year can be expected until 2028 which will grow to a demand of up to 400 t per year until 2030. The demand from hydrogen driven trains will remain negligible until at least 2027. The demand from hydrogen driven garbage disposal trucks will also remain small.

Stationary applications in the energy sector and adding green hydrogen into the existing natural gas grid are expected to remain negligible in the coming years, although the natural gas grid offers a sink for any surplus hydrogen production, in case this were to grow faster than the demand.

Since the mobility sector was identified as having the greatest potential in the near future, activities supporting the growth of hydrogen-based mobility should be encouraged. The results of the project showed that at least two refuelling stations are needed for redundancy. The results also showed that information on available technologies have to be made available to potential users.

Table 6: Hydrogen demand in 2028 in for different applications in the mobile sector

Sector	H_2-demand in 2028	Comment
Commercial Transport	254,8 t/a (maximum of the pilot phase) 1226,4 t/a (incl. conversion of two fleets to hydrogen)	Demand based on the results of the questionnaire
Public Transport with buses	289,08 t/a	Theoretical demand if all new purchases from 2025 are H2 vehicles
Public transport with trains	-	No demand expected until at least 2027
Waste disposal	43 t/a	based on the theoretical conversion of the entire fleet of the municipal waste disposal trucks

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Presenter Biography

Prof. Dr. Michael Schlick is the director of the Institute for Applied Research at the Technische Hochschule Ulm. After studying electrical engineering at the University of Karlsruhe (now KIT), he obtained his doctorate from the Université de Haute-Alsace, Mulhouse (France). In 1999, Michael Schlick joined Robert Bosch GmbH. Since 2015, Michael Schlick is Professor of Vehicle Electronics. His main fields of research are electro mobility and connected mobility services, he is involved in various research projects. Prof. Schlick is a member of the innovation committee of the city of Ulm and advises the city on mobility issues.