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OPPORTUNITIES AND OBSTACLES FOR THE INTRODUCTION OF A FUEL CELL ELECTRIC VEHICLE STRATEGY IN EUROPE AS AN EXTENSION OF THE PRODUCT PORTFOLIO OF EUROPEAN OEMs

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Abstract:
Climate policy goals have now taken on a strongly dominant role in European mobility development. In the current preferred approach, European OEMs are focusing on the BEV strategy, which is considered an established technology. However, the shift towards a purely battery-oriented direction in Europe is advanced, yet there are still long ways to go before speaking of complete market penetration. Meanwhile, Asian, and American providers have embedded themselves in the European market, threatening to snatch significant shares from European OEMs in the overall market. Therefore, a separate approach has emerged to determine possibilities for expanding the product portfolio to FCEVs in Europe, as this market is still in an early stage internationally. An empirical approach was used to identify the factors European OEMs see as implementation or barriers to an FCEV strategy. The results indicate generally that such a strategy extension appears feasible in many factors, yet there are hardly any implementations for real feasibility. Costs and model portfolios are particularly emphasized here. However, there are also cautious attitudes due to a lack of refuelling infrastructure and perceived insufficient demand on the customer side.

Key words: OEM Europe, automotive industry, hydrogen, fuel cell electric vehicles

INTRODUCTION

The European Union has set an ambitious target and wants to become the first climate-neutral continent by 2050. The EU and its member states have committed to this in the European Climate Law as part of the Paris Climate Agreement. The aim is to reduce emissions by 55% by 2030 compared to the 1990 benchmark, and then achieve climate neutrality a further 20 years later [1].
Requirements have been set in various areas to make this achievable. The transport sector occupies an important position here, as 25% of emissions are caused by the existing volume of traffic [2]. In the area of private vehicle use, European OEMs have focussed on the purely electrically powered vehicle using a battery [3, 4]. Other strategies, such as alternative fuels from e.g., biomass or hydrogen cars, play a very subordinate role in planning [4].
However, the plans to date do not appear to be in line with the targets set, as various factors play a role in their realization. The dependencies with regard to the production of batteries for battery electric vehicles (BEV) and the supply of raw materials for manufacturing are considered to be high in view of the dominant Chinese supplier market [5]. In addition, the requirements for OEMs in the area of raw materials for battery production have been politically tightened, with the EU adapting the conditions with the law on supply chain due diligence. OEMs must ensure that the humanitarian conditions for the extraction of raw materials and the requirements for the sustainability of extraction are met [6].
These influences must be considered in addition to emerging risks in the supply chain conditions, as geopolitical factors are increasingly exposing them to the risk of making it more difficult to obtain the necessary components for electric car production [6].
The question arises as to why the OEMs in Europe do not rely on alternative strategies in view of these emerging risk factors and the high political requirements, which on the one hand offer them the prospect of lower dependencies and at the same time fulfill the legal situation. In order to analyze this from the perspective of OEMs in Europe, a survey of the largest OEMs was conducted to determine the factors preventing an expanded strategy. The focus here was placed on fuel cell vehicles, as this is where the greatest potential is seen.
The aim of the research is to analyse how car manufacturers perceive their current structures and implementation as an important part of the environmental issue. The aim

is to identify the parameters that have so far prevented an FCEV strategy from being realised economically and politically from the perspective of OEMs in Europe. From the statements made, it can ultimately be shown which factors need to be improved in order to implement a parallel strategy that helps to address the problem of climate change in the area of private transport more broadly.

Analytical results in this area at research level have not been carried out on the part of European OEMs, so that the chicken-and-egg theorem has prevailed so far, in which there is no clarification in non-strategic problems with several actors as to which services must first exist in order to be able to expect a reaction from other actors [7]. If the OEM's problems are visible, then political goals with corresponding measures on the part of politicians can act as an incentive.

LITERATURE REVIEW

The views of European OEMs with regard to expanding the range to include fuel cell battery vehicles (FCEVs) have not been scrutinized. Research in databases and journal archives as of 2018 did not reveal any results that included a direct survey of OEMs. However, the European OEMs would be an important determining factor as to why FCEV technology is not being implemented in private motor vehicles (cars). By determining parameters that the OEMs themselves consider to be an obstacle, conclusions can be drawn about the existing infrastructure conditions and internal corporate factors that show whether and how an expansion of the range alongside BEVs should be organized and what role policy can play at European and national level.

In the relevant area, the article from 2022 by Samsun et al provided a comprehensive international inventory of the FCEV market, the results of which show the importance of fuel cells and hydrogen in mobility in Asia, the USA and Europe. The statistics show that there is no hydrogen and fuel cell strategy in Europe [4].

Sievers and Grimm published a similar publication in 2022, which shows how research and development in the field of FCEVs with patent figures compares to BEVs and plug-in hybrid electric vehicles (PHEVs). The two authors show that Asian manufacturers from Japan, South Korea and China already have a major lead in the fuel cell sector [3].

Menski et al. have analysed the political and economic strategy in Japan and concluded that with the additional hydrogen strategy, the country will be better able to achieve its climate targets by 2050 than will be the case in Europe [8].

For the rapidly expanding Chinese market in the FCEV sector, Wang [9] has outlined the roadmap for the Chinese government's and national companies' goals for 2021, which aims to ensure the country's climate neutrality in 2060 using hydrogen. It is already apparent that urban centers in particular are preparing for the increasing use of FCEVs and are developing rapidly.

With regard to surveys in the field of fuel cell vehicles, surveys were primarily conducted among potential users/customers. These were designed for various countries and investigated possible usage behavior with more detailed information about fuel cell technology [10, 11].

In general, according to the results of Alvarez-Meaza et al. (as of 2020), most publications in the field of FCEVs can be found in the USA and China, followed by Japan and South Korea. Germany is the first European representative to appear in the research publications in fifth place, followed by France and the UK [12].

There is therefore a need to present the OEM's point of view with regard to the potential establishment of an FCEV strategy and the obstacles that exist in this view.

METHODOLOGICAL APPROACH

Preliminary considerations for subject specification

As the survey approach developed was recognized as an initial survey of European OEMs, the basic considerations were incentives for participation and the possibility of a relatively accurate assessment of the views. In order to develop an approach for this, consideration was given in advance to who should answer the questionnaire in sufficient quantity and relevance-related quality to determine the views on an FCEV strategy. This involved an exclusion procedure that did not include senior managers, even though they have extensive knowledge of planning structures and market opportunities. However, it could be assumed that these senior employees invest little time in such surveys or ignore them. A simple, unspecific approach to OEMs was also not possible, as press offices and public relations departments usually deal with such inquiries. It was assumed that the employees would not have comprehensive knowledge of the topic and would produce an unqualified result.

Based on the view of organizations from a social perspective, as represented by companies, as a meso-perspective, the departments provide a micro-perspective which, however, due to the close interlocking of the holistic management view of companies, also have an overall organizational knowledge and cannot be viewed as isolated parts [13].

For this reason, specific departments were selected that have knowledge of the existing market as well as the technical possibilities. The departments addressed therefore consisted of the marketing department, research and development and sales. All three were recognized as having basic knowledge and expertise relating to the FCEV market and at the same time being able to determine factors and parameters that could cause a previous FCEV strategy in the company or in general to fail or not be implemented.

The selection of existing OEMs in the European market was based on two fundamental factors. Firstly, literature-based results were used to determine which manufacturers had already been involved with fuel cell vehicles in the past and had brought prototypes and small series onto the market [14].

As a restriction, it was determined that a survey of board members would be excluded, as the results could be too general, since an overarching opinion is depicted, and the actual implementation is not included. Rather,

department-dependent considerations were considered more meaningful here, even if they do not influence the actual corporate policy of the OEM.

The three cohorts were therefore seen in marketing, research and development and sales, which have an overview of the existing markets and development progress.

In marketing, it can be assumed that existing structures are known and future demand expectations can be determined. R&D provides knowledge of existing and future projects that appear important in connection with an FCEV strategy and have therefore been included in the cohort profile. Sales, in turn, is equipped with data and information on actual demand, which, in collaboration with Marketing, also allows forecasts to be made on future developments. In addition, OEMs were selected that offer a wide range of models and have a large number of model types in their portfolio (small cars to luxury segment). This resulted in the following OEMs for the survey:

- BMW/Mini
- Mercedes/Daimler/Chrysler (German headquarters)
- Fiat
- PSA Peugeot/Citroën/DS
- Renault/Nissan (French headquarters)
- General Motors/Opel (German headquarters)
- VW/Audi/Skoda/Seat

The selected OEMs were contacted and asked to participate. The questionnaire was offered online and provided with a link for participation, so that there was a certain guarantee of addressing participants from the selected test subject groups. The individual test subjects were granted anonymity, which was also expressed in the fact that in this first approach to an OEM survey on the topic, no country-specific differences or economic figures, company names or other information had to be provided.

Questionnaire design and methodological implementation

Due to the geographical distance between the OEMs, an online survey was conducted. The software used for this is Survio®, which was used as licensed software. It enables an appealing and self-explanatory design for the test persons and is easy to use. The participants received a link in an invitation e-mail that led them directly to the survey. The recording of responses is automated and can be accessed both as a design template and in the raw data via Excel. This made it easy to analyze the raw data using the statistical software IPSS from IBM ©. The evaluation data could be generated by IPSS in both a descriptive and inferential statistical analysis of the results.

The questionnaire design of the items was based on the parameters recognized as necessary, which could be seen as a reason for avoiding an FCEV strategy. In order to ask the OEMs about all aspects and parameters considered necessary for a complex topic, these parameters and aspects had to be precisely outlined thematically. The parameters were derived from various study results and research literature derived from customer surveys or general research approaches. Expectations and perspectives from the OEM's point of view had to be determined, as well as the general development trend in the FCEV sector. This should also be done with time limits that can show whether an FCEV strategy could emerge in the near future among European OEMs against the trend.

For the individual parameters that would prevent or enable market entry, the individual factors were each summarised in one question. In this case, the parameters were:

- Finances: Investment capital, restructuring costs, etc.
- Infrastructure conditions: Hydrogen production, import, refuelling infrastructure
- Sustainability aspects: Production and/or import of green hydrogen
- Battery production: existing supplier constellations, dependencies, European production capacities
- Training and knowledge requirements: Shortage of skilled labour and need for new teaching structures

The parameters were derived from various study results and research literature derived from customer surveys or general research approaches.

With regard to demand, a customer survey conducted internationally by Proff et al. 2023 found that the potential demand for drives such as biodiesel or FCEVs is below 10% [15].

Customers are also very reluctant to buy an FCEV due to the costs, which are far higher than the prices charged for BEVs, PHEVs or conventional drives [10, 11].

The question of new training content for the production of FCEVs, which has already been investigated in research during the switch to BEVs [3, 16], is of particular relevance to OEMs.

FCEVs are also still rated as unattractive, as the refuelling infrastructure in Europe is being expanded, but is still far from being widely available [4].

A period of one month was allowed for the survey (September 2023) in order to give respondents sufficient time to react to the survey. The results of the survey, which can be considered complete and analysable, are distributed as follows. From the marketing departments, 31, sales 35 and R&D 27 data sets were included.

The following specially created questionnaire structure (Table 1) resulted from the selected parameters.

Table 1
Questionnaire structure and scale level used

Question no.	Question Text	Scale level
1	FCEV production is not planned in the next 5 to 10 years.	4-step Likert scale from 1 to 4: the higher the number, the higher the level of agreement
2	A FCEV strategy with model developments is currently not possible within the company due to a lack of research and development.	
3	A full FCEV strategy is not financially feasible for our company.	
4	A FCEV strategy nationally and for Europe does not make sense due to lack of refuelling infrastructure.	
5	A FCEV strategy does not make sense due to the lack of national hydrogen production and storage.	
6	An FCEV strategy only makes sense if only environmentally friendly hydrogen is produced in sufficient quantities.	
7	A FCEV strategy is conceivable in five years' time through the expansion of new hydrogen suppliers.	
8	A FCEV strategy makes sense with own battery production at national and European level specifically for FCEVs.	
9	A FCEV strategy needs more political protection against international competition than the existing BEV strategy.	
10	There is too little customer demand for FCEV production today and in five years' time.	
11	FCEV production is only worthwhile if the individual and overall efficiencies are similar to those of BEVs.	
12	An FCEV strategy only makes sense if it would cover all model types.	
13	Establishing an FCEV strategy with own production lines fails due to existing production capacities.	
14	A FCEV strategy needs a new structure and content mediation in educational tasks for professionals and specialists.	
15	An expansion of hydrogen production would pay off more for regenerative alternative fuels that could be used in the automotive industry.	

The perception of certain concepts or behaviours of social groups or organisations is investigated in marketing, customer surveys or company surveys by means of a Likert scale survey [17]. In this case, a limited number of selection parameters are used in constant use. The response options for the individual questions were:

- 1 = does not apply at all,
- 2 = conditionally applicable,
- 3 = applies almost completely,
- 4 = absolutely true
- 5 = available.

As it was expected in advance that the OEMs might consider the topic to be 'sensitive' in a certain way, the structure and content of the statements were formulated in very general terms and were not intended to cause any internal conflicts among the test subjects.

The main objective of the study as an initial survey was to obtain a general assessment from the OEMs as to whether or not certain aspects and prerequisites are necessary in order to be able to implement an FCEV strategy for BEVs and others.

RESULTS

As all the questions in the questionnaire are ordinal, Likert-scaled, and therefore quasi-metric, the hypothesis of the paper can be analyzed for each question/each variable using the one-sample t-test.

The Likert scale runs in constant four levels, so that the value 2.5 represents the constant mean value of the scale. It is therefore statistically tested whether there is a significant deviation from the mean value for each of the 15 questions. The t-test can be applied without checking the prerequisites due to the sample of over 30 ($n > 30$) [18].

The results of the t-test analysis in SPSS can be found in Table 2. The results for the sample as a whole are analyzed here because the three departments are almost homogeneous in their distribution.

Almost all questions are significant. The results can be described as follows:

Question 1: $t(df = 92) = -8.828$; $p = 0.000$ significant. There is a significant rejection of the statement that FCEV production is not planned in the next 5 years. The majority of respondents in all cohorts are of the opinion that this is planned.

Question 2: $t(df = 92) = -11.821$: $p = 0.000$ significant. There is a significant rejection of the statement that R&D prevents the FCEV strategy. It can therefore be concluded that there is sufficient R&D for FCEVs at most OEMs.

Question 3: $t(df = 92) = 0.174$; $p = 0.862$ not significant. No significant statement can be made about finance. This factor is therefore seen as a definite obstacle to the implementation of an FCEV strategy.

Question 4: $t(df = 92) = -4.006$; $p = 0.000$ significant. There is a significant rejection of the statement that the refuelling infrastructure is not sufficient. This infrastructure is therefore seen as sufficient, even if the cohorts can be divided into two groups. Two nations have already completed the expansion at an advanced stage and are

continuing to implement it. All others are not yet in a development phase and are far behind the two nations.

Table 2

Inferential statistical analysis by one-sample test

One sample test

	Test value = 2.5					
	T	df	Sig. (2-sided)	Medium difference	95% confidence interval	
					lower	upper
FCEV production is not planned in the next 5 to 10 years	-8.828	92	0,000	-0,747	-0,92	-0,58
A FCEV strategy with model developments is currently not possible within the company due to a lack of research and development	-11.821	92	0,000	-0,726	-0,85	-0,60
A full FCEV strategy is not financially feasible for our company	0.174	92	0,862	0,016	-0,17	0,20
A FCEV strategy nationally and for Europe does not make sense due to lack of refuelling infrastructure	-4.006	92	0,000	-0,360	-0,54	-0,18
A FCEV strategy does not make sense due to the lack of national hydrogen production and storage	-7.166	92	0,000	-0,618	-0,79	-0,45
A FCEV strategy makes only sense if only environmentally friendly hydrogen is produced in sufficient quantities	-4.908	92	0,000	-0,446	-0,63	-0,27
A FCEV strategy is conceivable in five years' time through the expansion of new hydrogen suppliers	-6.932	92	0,000	-0,629	-0,81	-0,45
A FCEV strategy makes sense with own battery production at national and European level specifically for FCEVs	-3.116	92	0,002	-0,274	-0,45	-0,10
A FCEV strategy needs more political protection against international competition than the existing BEV strategy	-15.703	92	0,000	-1,059	-1,19	-0,93
There is too low customers demand for FCEV production today and in five years' time	-2.551	92	0,012	-0,231	-0,41	-0,05
FCEV production is only worthwhile if the individual and overall efficiencies are similar to those of BEVs	-5.395	92	0,000	-0,522	-0,71	-0,33
A FCEV strategy only makes sense if it would cover all model types	-0.066	92	0,948	-0,005	-0,17	0,16
Establishing a FCEV strategy with own production lines fails due to existing production capacities	-9.390	92	0,000	-0,812	-0,98	-0,64
A FCEV strategy needs a new structure and content mediation in educational tasks for professionals and specialists	-14.726	92	0,000	-0,941	-1,07	-0,81
An expansion of hydrogen production would pay off more regenerative alternative fuels that could be used in the automotive industry	-12.534	92	0,000	-0,876	-1,02	-0,74

Question 5: t(df = 92) = -7.166; p = 0.000 significant. There is a significant rejection of the statement that the production and storage of hydrogen are not sufficient. These requirements are perceived as sufficient by the majority of the test subjects. With the new LNG terminals and other planned storage options, these storage capacities will increase.

Question 6: t(df = 92) = -4.908; p = 0.000 significant. There is a significant rejection of the statement that the FCEV strategy only makes sense if sufficient environmentally friendly hydrogen is produced. It is therefore not seen as an obstacle, as current production strategies are based on fossil fuels and other processes that still produce high emissions. Further technical possibilities will only arise in the next 10-15 years and will not allow any other options for an FCEV strategy until then.

Question 7: t(df = 92) = -6.932; p = 0.000 significant. There is a significant rejection of the statement that the new hydrogen offerings will enable the FCEV strategy in five years. Based on the previous answers, it can be concluded that this is already considered possible even without the strategy.

Question 8: t(df = 92) = -3.116; p = 0.002 significant. There is a significant rejection of the statement that FCEVs only make sense if the company has its own battery production at national and European level. Based on the earlier responses, it can also be concluded here that this is already considered possible even without a new strategy. As a limiting factor – and this is also taken up in the discussion – current relations with the main exporter China are to be regarded as stable, although the Taiwan issue has not yet been resolved and Chinese intervention does not appear to be ruled out.

Question 9: t(df = 92) = -15.703; p = 0.000 significant. There is a significant rejection of the statement that FCEVs need stronger political protection from international competition than BEVs. It is therefore not clear that such protection should necessarily be provided. Previous major transformations of the economy were also regulated by market forces in earlier years. Exceptions were massive crises (property crisis and banking crisis), but these do not exist in the FCEV strategy question.

Question 10: t(df = 92) = -2.551; p = 0.012 significant. There is a significant rejection of the statement that customer demand for the production of FCEVs is too low today and in five years' time. This demand is seen as potentially not too low. It is particularly important that all three departments, which view the situation from different angles, consider this to be the case in the majority of cases.

Question 11: t(df = 92) = -5.395; p = 0.000 significant. There is a significant rejection of the statement that FCEV production is only worthwhile if the individual and overall efficiency of FCEVs is similar to that of BEVs. The respondents recognize that this is not a requirement for FCEV production to be profitable. There are both advantages and disadvantages.

Question 12: t(df = 92) = -0.066; p = 0.948 not significant. As a statement about the model types, it can be recognised that there is a high degree of ambivalence among the test cohorts. In particular, small, and compact mid-range cars have not been launched as frequently in the last ten years as large mid-range cars, SUVs, family vans and luxury segments.

Question 13: t(df = 92) = -9.390; p = 0.000 significant. There is a significant rejection of the statement that the introduction of FCEVs will fail due to existing production capacities. Production capacities are therefore not seen as a problem, so that theoretically production appears possible at any time according to these statements.

Question 14: t(df = 92) = -14.726; p = 0.000 significant. There is a significant rejection of the statement that the FCEV requires a new structure and content-related mediation in educational tasks for skilled workers and specialists. The majority of the cohorts are of the opinion that the existing structures can be utilized and that a changeover does not need to be demanded from employees.

Question 15: t(df = 92) = -12.534; p = 0.000 significant. There is a significant rejection of the statement: "An expansion of hydrogen production would pay off more for regenerative alternative fuels that could be used in the automotive industry." The statements here are very negative, which may also be related to the exclusion of further transformations in the automotive industry. Previous transformations cannot yet be seen as complete and

require further development steps. Further alternatives beyond an FCEV strategy would exceed capacities.

To summarize, it can be concluded that

- the three departments are relatively homogeneous in terms of content in their assessments, although there are sometimes outliers in the cohorts themselves.
- The responses are more favourable towards the potential FCEV strategy. Few problems and obstacles are seen and the hypothesis of the work can be confirmed in the form that the interest is there, is not completely excluded and only a few parameters represent real barriers to the establishment of the segment.

The own results obtained are assigned to the questions in a continuous manner and connected with other results of research.

Many of the respondents from all three departments at the OEMs were in favour of introducing an FCEV strategy and production in the next 10 years or less. 51.4% of the sales departments, 48.2% of the R&D departments and 35.5% of the marketing departments are of the opinion that there will be an expansion to an FCEV strategy.

When assessing a gap in research and development at their own company, it was found that although development is underway, the statement was confirmed to some extent. 48.1% of respondents from the R&D departments, which are particularly relevant here, stated that research and development is ongoing. However, the same number stated that this was partly true. From this it can be deduced that about half of the OEMs are definitely researching and developing in the field of FCEVs, but there is no standardised orientation for establishing a strategy in Europe.

When it comes to the perception of the financial possibilities of establishing an additional FCEV strategy, the respondents' assessment is that they consider the financial scope to be limited, although not impossible. 65.2% of respondents from the sales departments, 48.4% from marketing and 29.6% from R&D departments are positioned here. 33.3% of the R&D departments are sceptical about the assessment of the financial possibilities, which allows a conclusion to be drawn about the investments in the FCEV area at one third of the OEMs.

The connection between the refuelling infrastructure and an FCEV strategy at OEMs in Europe is seen by the majority of respondents as crucial. 41.9% of the marketing respondents, 51.4% of the sales department respondents and 29.6% of the R&D departments agreed with the statement. What is striking is the high level of rejection of the statement among the R&D respondents, with 48.2%, almost half of them agreeing. Looking at the proportion of German participants, it can be assumed that they perceive a relatively well-developed national infrastructure, which may explain this result. As of the end of 2022, Germany has 105 hydrogen refuelling stations in operation, followed by France with 44 and the UK and Switzerland with 17 refuelling stations each [19].

When it comes to the statement that an FCEV strategy makes no sense because there is not enough hydrogen production and storage facilities, 22.6% of marketing respondents, 54.3% of sales respondents and 40.7% of R&D departments disagree. The majority of marketing respondents largely disagree, with 45.2% as a proportion. The results reflect the efforts in Europe to make hydrogen more widely usable as an energy carrier, which have been in an expansion phase since 2022. The construction of LNG terminals and extended agreements with producer countries from the Arabian Peninsula regions show that expansion steps are being taken to make hydrogen usable for industry and energy supply [20]. In addition, the potential for utilising electricity generation from sustainable sources for the electrolysis of hydrogen is considered high. Wind and solar energy are the two focussed energy sources here. Coastal regions (North Sea and Atlantic coast) are ideal for further wind turbine installations, while in southern Europe Spain, Portugal and Italy offer numerous areas for solar energy. Existing production potential is currently still covered by grey and blue hydrogen [21].

The perception of the OEM departments regarding the introduction of an FCEV strategy only under the condition of environmentally friendly hydrogen production was determined in direct relation to this. The interviewees only recognised this connection to a limited extent. Around 48% of R&D departments did not recognise this as an obstacle, as did around 26% of sales and around 29% of marketing. 18.5% of R&D, 31.4% of Sales and 38.7% of Marketing recognised this as a lesser reason. Thus, it can be stated with a clear majority that the introduction of an FCEV strategy is not solely dependent on the production of green, ecologically clean hydrogen.

The International Hydrogen Compass published by the Society for Chemical Engineering and Biotechnology and the German Academy of Science and Engineering for 2022 states that leading industrialised nations worldwide want to use and plan to expand a hydrogen strategy for various areas of energy supply. The core of this strategy has so far been grey hydrogen from fossil raw materials, but there are plans to expand production in the area of blue and green hydrogen. This would reduce both the environmental impact of production and the costs of ramp-up phases in production [22].

As large-scale hydrogen production to date has been concentrated in non-European countries, it will only be possible to realise an FCEV strategy in five years' time through closer international cooperation with hydrogen exporters. Here too, the opinions of those surveyed tend to indicate that this is not the case. 57% of sales, 35.5% of marketing and 37% of R&D are of the opinion that this is not the case at all. A further large proportion deny this to some extent. This shows that the current economic relationships and interdependencies would be sufficient to make an FCEV strategy feasible. Current collaborations with countries on the Arabian Peninsula and the development of LNG terminals in coastal cities with distribution networks make it clear that hydrogen is becoming increasingly important as an alternative energy source. The EU is also planning to expand its own hydrogen production to 10 million tonnes by 2030 [21].

The view of OEMs is somewhat different when it comes to producing their own batteries in Europe. 45.2% of marketing, 45.7% of sales and 37% of R&D see this as a barrier to implementing an FCEV strategy. 13% of marketing, 20% of sales and 40.7% of R&D do not see this as an obstacle to designing such a strategy. The proportion of R&D is probably due to the fact that research into new battery generations is taking place at a high level in Europe, but this also needs to be integrated into European production. However, the realisation is still too slow, but would protect Europe from raw material shortages or difficult supply conditions with further development of the batteries [23].

The statement that an FCEV strategy requires greater political protection and support than the existing BEV strategy did not receive any significant approval. Only 13% of marketing, 8% of sales and around 4% of R&D see a need for more political protectionism and support to make an FCEV strategy feasible.

However, the statement that there are currently too few customers for such a strategy to trigger efficient production received higher approval ratings. 54.3% of sales, 54.9% of marketing and 30% of R&D are of the opinion that potential and actual demand is too low. Sales and marketing are considered to have a greater knowledge of the demand markets, so that the low position of R&D is understandable.

The low demand is reflected in the low numbers of FCEVs on the road. For 2021, Samsun et al. state that of the 51,437 vehicles registered worldwide, only Germany has a number of over 1,000 vehicles (1,542 in absolute terms) in all classes (cars, lorries, and buses). In the other European countries, the figures are far below 1,000 [4].

With regard to the necessary efficiency of FCEVs compared to BEVs for the introduction of an FCEV strategy, the majority of OEM departments are of the opinion that this would not be a reason to prevent it. 80% of sales, 61.3% of marketing and 55.6% of R&D see a high potential for FCEVs. This also corresponds to research on the range and ease of use of FCEVs. It can be assumed that refuelling times will be the same as for petrol or diesel vehicles and that ranges will be greater. Only the utilisation efficiency of the primary energy is slightly lower than that of BEVs [24].

The respondents were ambivalent about the usefulness of introducing an FCEV strategy by covering all model types. Some agree to a certain extent, while a roughly equal proportion disagree. At 48.6%, the sales department is of the opinion that a broad range of models would have to be offered in order to make a strategy appear sensible. The other two departments are almost equally divided between those who tend to agree and those who tend to disagree.

Current developments in the manufacture of vehicles are moving strongly in the direction of sport utility vehicles (SUVs), which appear to be increasingly favoured by all suppliers in Europe [25, 26].

Perceptions of a lack of existing OEM production capacity are not seen by the vast majority as a barrier to adoption for an FCEV strategy. 85.7% of sales, 71% of marketing and 77.8% R&D see sufficient production capacity at OEMs to establish FCEV production. In relation to the previous results, expanded battery production in Europe would be necessary for increased resilience and simpler supply chains.

The OEM departments argue similarly with regard to the training situation in relation to an FCEV strategy. Here too, more than ¾ of respondents believe that the existing employee training programmes are sufficient to manage FCEV production without any problems. This would eliminate the need to reorganise curricula and training content as well as the need for extensive and costly further training.

The last point addressed the use of hydrogen for the production of alternative fuels (e.g., biodiesel, biofuels, methanol, and ethanol), which could possibly be of more interest to the passenger car market. The majority were not in favour of this. 94% of sales, 80.6% of marketing and 92.6% of R&D were negative. The respondents also see the potential of hydrogen production in efficient utilisation for FCEV production.

This is also in line with the barriers to the production of biofuels. Too much land is required for cultivation, which would be lost to the rest of the agricultural industry. In terms of biodiversity, large monocultures also run counter to the requirements of species conservation [27, 28].

DISCUSSION

The results of the survey of European OEMs reveal the following factors that are considered to be obstacles to an FCEV strategy.

- The refuelling infrastructure must be expanded (German OEMs are more likely than other EU countries to see the national infrastructure as a good basis).
- The battery production required in Europe must be expanded, as it is necessary for both FCEVs and BEVs.
- Customer demand is too low and will remain so in the foreseeable future.
- Several model types for the FCEV strategy (small car, mid-range, SUV, and luxury segment).

Therefore, the factors of hydrogen production and import are not factors where the majority of the three departments do not see a problem. Similarly, production capacities, employee training and finances are not an obstacle to a premature exit strategy for FCEVs.

In 2020, Deloitte conducted an international survey of 35,000 consumers in 20 countries and the results (Figure 1) still show that the trend in the major economies is still in favour of conventional fossil fuels or hybrid technology. With regard to the topic at hand, it should be noted that the 'Others' category also includes FCEVs. "Japan has two market-leading providers with Honda and Toyota. In South Korea, Hyundai has turned to FCEVs in the passenger car segment. Additionally, previously unknown Chinese providers will enter the market with the help of government subsidies" [29].

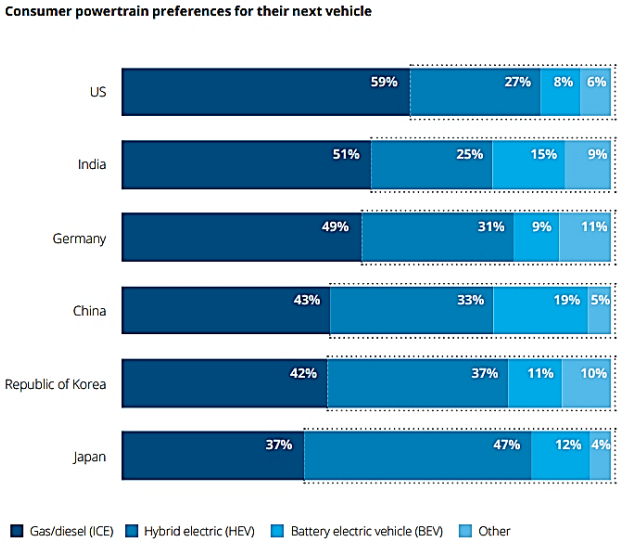

Fig. 1 Survey on future preference for the next car by drive system 2020

It is recognizable that BEV preferences are higher in the Asian regions than in Europe or the USA. However, the highest preference shares of 19% in China lags far behind ICEs and HEVs. This has changed since then, particularly in China, where a new economic stimulus programme and domestic purchase incentives have greatly increased demand. As a result, China has become the world's largest supplier of electric vehicles [30]. And Europe? Norway was the only country with exceptionally high demand for BEVs (Figure 2).

The Netherlands is highlighted with two high peaks in January 2021 and December 2022. All other European nations listed show a similar peak at the end of 2021, followed by a massive decline in demand in some cases. It is a persistence at a low level [31].

It must therefore be questioned why – despite many positive perceptions of the possibilities – a comprehensive expansion strategy using FCEVs has not yet materialised. This would also be necessary in relation to lorries, buses, and other means of transport, as prototypes and small series to date would enable meaningful use. However, especially in the passenger car sector, European OEMs are still reluctant to mass-produce hydrogen drives. Instead, they are sticking to small series and prototypes (BMW and Mercedes). "However, European OEMs have not entered the passenger car market to establish serious competition against a developing Asian market" [21]. This also goes against the opinion of consumers, according to a survey conducted by Civey on behalf of Der Spiegel. This shows that the majority of citizens would prefer a fuel cell car to a purely battery-powered vehicle [32]. However, a hydrogen car requires the decisive factors to make it profitable for customers. The purchase costs for this vehicle class are still too high for it to be profitable as a mass product [16]. This was and still is partly a reason for the still very low penetration of all-electric vehicles in the transport sector [26] and also applies to FCEVs.

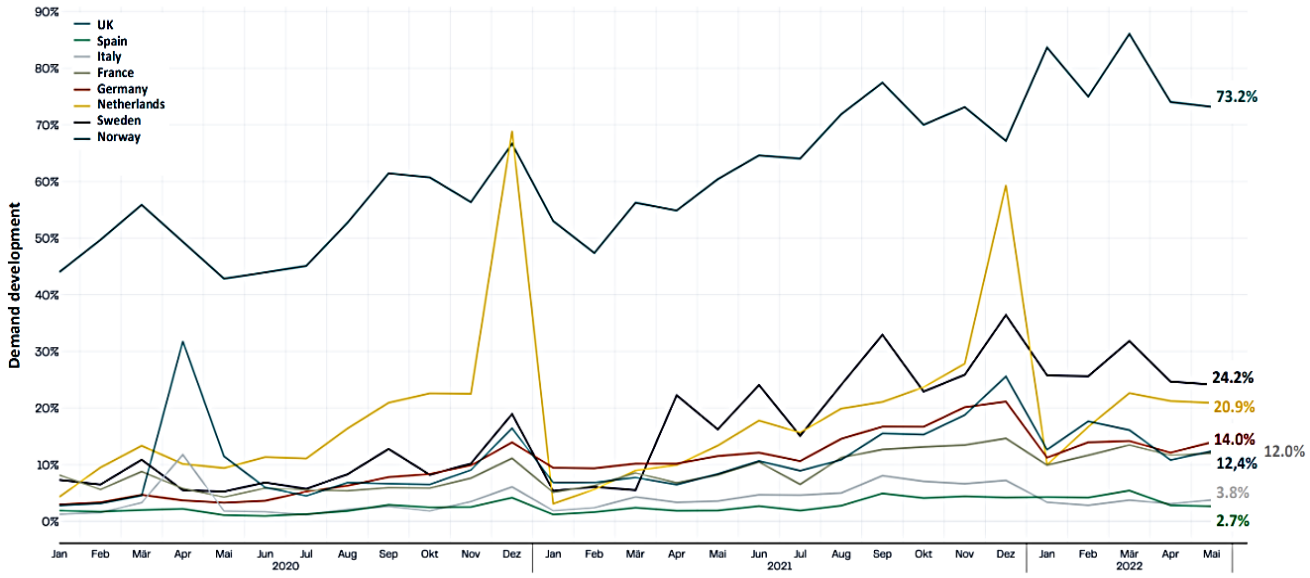

Fig. 2 Development of demand for BEVs in selected European nations 2020 to 2022

One factor that is repeatedly included in the discussions is the cost of producing hydrogen. However, a distinction must be made between grey or brown hydrogen and the absolutely sustainable production of green hydrogen. This would require an expansion of the wind and solar energy infrastructure.

In the current constellation of a high import quota of hydrogen, costs arise above all in the production and liquefaction in the country that exports, as well as the transport with corresponding special ships. If Europe were to optimally utilise the possibilities for producing electricity using wind and solar energy, it could supply itself with a high proportion of its own energy. It would also be possible to enter into cooperation with surrounding countries that could also provide high capacities using solar and wind energy. These would be North African countries with short supply distances [33].

Furthermore, until the 2000s, hydrogen was never a prioritised energy source for a comprehensive distribution infrastructure, so existing networks are used as an argument as

to why a large-scale vehicle industry is not being built. An infrastructure covering the whole of Europe with distribution networks via pipeline would still have to be expanded. A pipeline network of this size would cost energy suppliers between 80 and 143 billion euros and would be ready for use in 2040. This network would then cover all areas of application for hydrogen [20]. This would require large-scale state funding, which would then make hydrogen a viable alternative.

A new factor for the industry has been added to the discussion about supply chain sustainability, which raises the question of compliance. Existing supply chains for the production of electric vehicles need to be reviewed and reorganised if there are risk-based factors that threaten compliance. The raw materials for battery production in particular are increasingly coming under scrutiny here, as they are mined and processed in countries where supply chain compliance needs to be urgently examined.

Based on this, an in-house hydrogen supply and utilisation in the transport sector would simplify supply chains and compliance requirements for OEMs. The battery would still be a problem area until sufficient in-house production is established but would increasingly recede into the background as the strategy expands.

International market volumes to date are at a comparatively low level if you take the BEV infrastructure as a counterpart. However, the course has been set in Asian countries with their own large OEM infrastructure to switch to an FCEV strategy in the ramp-up phase and thus take a leading market position. If Europe delays its entry, it will once again be in an inferior position, as can already be seen in the BEV sector.

The analysis of the OEM results shows that an additional strategy with FCEVs does not fail in many factors due to the OEM's basic requirements. Even the fear that customers will not generate demand cannot serve as a reason for rejection, as many citizens would be prepared to purchase an FCEV. However, the basic conditions still have to be increasingly created, which is mainly due to government agencies as triggers. Once the hydrogen infrastructure has been developed and is available nationwide, all subsequent infrastructure requirements would be integrated into the market. This would also eliminate the chicken-and-egg theorem, in which a relevant strategic partner – in this case the state – would take the first step.

No matter how the decisions turn out, both solutions (BEV and FCEV) will entail immense costs in the European infrastructure and production landscape [34]. However, it makes sense to spread the costs across a wide range of industries and their shareholders, as the cost distribution is broader and both technology paths can still be followed. The first small-scale realizations in the FCEV sector have taken place in commercial vehicles and buses. The potential is particularly high here, as other sizes and load capacities can be utilized that make hydrogen profitable. But here too, an infrastructure needs to be established.

"More than USD 450 bn investments will be required to develop new recharging and refueling infrastructures alone. These investments need to be made before zero-emission trucks can be deployed at scale, but they will only pay off once fleet sizes are large. In addition, a dozen giga-factories worth of battery supply will need to be developed, and renewable power generation expanded to support the decarbonization needs of not only transport, but wider society. Any additional acceleration in uptake of zero-emission trucks means a further scale-up across the whole value chain" [34].

Looking at China as a benchmark for establishing an FCEV strategy shows that targets can also be achieved in Europe with appropriate investment. The Chinese roadmap for this is shown in the following Figure 3 [35].

		2020	2025	2030-2035
Target		FCV: 10k Refueling stations: >100 System production: >1000/sector	FCV: 50k-100k Refueling stations: >1000 System production: >10k/sector	FCV: 1 million Refueling stations: >5000 System production: >100k/sector
Passenger vehicle	Cool start temperature (℃)	-30	-30	-40
	Fuel economy (kg/100km)	1.2	1	0.8
	cost (yuan)	800,000	300,000	200,000
	stack/system power density (W/L)	500/3000	600/4000	800/6000
	Stack/system cost (yuan/kW)	3500/7000	1800/3500	500/1000
Commercial vehicle	Cold start temperature (℃)	-30	-30	-40
	Fuel economy (kg/100km)	6	5.5	10
	Cost (yuan)	1.5million	1million	500,000
	Stack power density to volume(W/L)	2	2.5	3
	Stack power density to weight (W/kg)	250	350	450
	Stack/system cost (yuan/kW)	2500/5000	1200/2000	400/600
Hydrogen infrastructure	Hydrogen production	Encouraging hydrogen production from industry by-products and renewable energy. Require for 10k-30k t/yr	Encouraging hydrogen production from renewable energy. Require for 200k-400k t/yr	Hydrogen production is mainly from renewable energy. Require for 200k-400k t/yr
	Hydrogen fuel cost (yuan/kg)	40	40	25

Fig. 3 China's roadmap for an FCEV strategy in the country

Whether the goals are absolutely realizable for China in this form can only be surmised today. But the clear structure of a master plan is definitely a good approach that can help China in this endeavor. The EU lacks such a plan and the individual nations are also unable to provide one in this form. It is therefore important and useful to look at China – also with regard to the competition – in order to be able to develop our own counterstrategies for the future.

CONCLUSION

The question of the opportunities and risks of an FCEV strategy was investigated in a survey of European OEMs in the form of a departmental survey. This showed that the risks identified for OEMs from their own perspective

are not as prevale6nt as initially assumed. Neither finances, production capacities nor labour and training conditions stand in the way. The promotion, supply through imports and in-house production of hydrogen are also not seen as a market barrier.

Rather, external risk-based factors are put forward that prevent an FCEV strategy. According to the OEMs, these include the refuelling infrastructure, the supposed lack of demand, the internationally dominant battery production and a requirement for model depth and breadth.

All of the factors mentioned could be largely resolved within the next 10 years, so it would be reasonable to assume that an FCEV strategy could be developed within this time frame. If European OEMs miss this timetable, they run the risk of losing touch with FCEV technology, as has already happened to some extent with BEV technology.

Hydrogen must either be imported in sufficient quantities. This is then again subject to certain dependencies on producing and processing nations. Alternatively, the EU can step up its own production on the basis of its own energy production, which requires both fossil and sustainable sources, and free itself from the necessity of an increasing import quota.

Infrastructures must be in place for an FCEV supply so that production is worthwhile and sales prospects can be created. This requires that the oil companies, which also own extensive petrol station networks, are integrated into the strategy, and are offered an incentive to support the hydrogen strategy. If this is tackled now, the companies will have alternatives when fossil fuel technologies disappear from their portfolios. The companies have capital, networks, infrastructure, and logistical capacities that can support a hydrogen strategy in the same way as was previously the case with petrol and diesel.

In order not to consider the battery, which is used in FCEVs with fuel cells, exclusively, the direct use of hydrogen can be used to reduce dependencies or to autonomize in-house production.

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