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Why the Conversion of Hydrogen H_2 Is Still—or More Than Ever—Delayed

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Numerous decision-makers in politics, science, and business worldwide have acknowledged that hydrogen H_2 will become one of the most important energy sources of the 21st century if the desired energy transition to carbon-free energy sources is to be taken seriously. Nevertheless, this transition in general and the introduction of H_2 in particular is still progressing far too slowly. There are now countless projects worldwide, including several worth billions of US dollars, but we are still waiting for the breakthrough. There seem to be various reasons for this, not just one single or most important one. Purpose: In the overall context of global earth overheating (often downplayed as "climate change"), hydrogen H2 will undoubtedly play a decisive role as of now. The paper aims to identify the key challenges and propose solutions for establishing a sustainable value chain for market penetration of H_2. Design/methodology/approach: This paper aims to shed light on the current situation using freely accessible publications from global management consultancies and the German government, as well as critical reporting. The problem of human behavior is also explained by the Novak Triangle. Findings: Most people have come to understand that anthropogenic global overheating can only be solved by new technologies (which cost money, time, and behavioral change) in production and application. Hydrogen H_2 appears to be an essential part of the desired solution. Nevertheless, there are currently still numerous challenges and also concrete concerns worldwide, which partially cast the implementation in a questionable light. The findings suggest that establishing a demand and supply of H_2 needs a comprehensive infrastructure, circular economy principles, and changes in consumer behavior and policy frameworks. The paper proposes solutions for addressing these challenges. Affected countries: The situation described here relates to Germany and the EU countries, but it is likely to be comparable, or at least similar, for many industrialized countries. The challenges and solutions proposed in this paper are relevant to countries worldwide that are transitioning to sustainable energy and transportation systems. Research/future/practical implications: As of 2024, it must be stated that the implementation of H_2 is still progressing far too slowly, even in the "model country" Germany. There are still problems and stalling in many places. The biggest challenge seems to be the problem: without demand, there is no supply; without supply, there is no demand. This can then best be achieved with simple "out-of-the-box" solutions in mindset (see Novak triangle). The research implications of this paper include the need for further research on the challenges of establishing a sustainable value chain and the effectiveness of the proposed solutions. The future implications of this paper include the importance of establishing a sustainable value chain to mitigate climate change and reduce dependence on fossil fuels. The core point will become the collaboration across the entire value chain to establish a sustainable infrastructure for sustainable energy and transportation systems. Originality/value: Currently, there are virtually no scientific books that would present the overall context of the challenges. Therefore, only current surveys, market volumes, and challenges in environmental and working conditions can be described here. This paper

contributes to the literature by analyzing the challenges of establishing a market model for hydrogen H_2. The paper proposes solutions for addressing these challenges and shows difficulties. It provides valuable insights for policymakers, industry stakeholders, and researchers working towards a sustainable energy future.

Keywords: global earth overheating, hydrogen H_2, Novak Triangle-Motivation/Decision Making for People to Act

Status in Mid-2022

Hydrogen production in Germany has fallen from 2008 (approx. 4.5 million m^3) to approx. 3.8 million m^3 in 2022 (Statista, Bundesamt für Statistik (Germany authority for statistics, Research Department), 2024). This decline can only be explained by assumptions: (1) It is based on increased H_2 imports, for which no figures are available, (2) It is based on the decline in economic production due to the COVID-19 pandemic and/or a relocation of industry abroad, or (3) It is based on changed production processes that require less H_2. It is not only the European Union that has recently tightened its climate targets considerably. More and more countries and companies around the world are also trying to significantly reduce their greenhouse gas emissions. Hydrogen is becoming increasingly important as an energy source for a global energy transition. Demand for it could rise worldwide from the current 76 to up to 600 megatons per year by 2050—provided that suitable infrastructure is created. This is one of the key findings of the report *Hydrogen on the Horizon: Ready, Almost Set, Go?* which the auditing and consulting firm PwC Germany prepared in collaboration with the World Energy Council (WEC) and the Electric Power Research Institute (EPRI). The report examines the market development of hydrogen up to the year 2050. It is based on a review of various energy scenarios, PwC analyses and extensive research by the WEC into national strategy developments. 38 experts from 23 countries were surveyed, accounting for 61 percent of the global total primary energy supply and around 70 percent of global gross domestic product, including the USA, Japan, South Korea, Germany, and France. Overall, forecasts for the share of hydrogen in global final energy consumption by 2050 vary between 6 and 25 percent—depending on the production costs of hydrogen, the required infrastructure, and the level of technological maturity. The development of demand also depends on the temperature target to be achieved in 2050; For example, to ensure that the global temperature only rises by 1.8 degrees Celsius, significantly more green hydrogen is required than if the temperature rises by 2.3 degrees Celsius or more by 2050 (PWC, 2021).

Status in Mid-2024

The TE scenario predicts a global production volume of around 160 million tonnes of green hydrogen by 2050. So far, the expected production capacity according to the reference scenario is expected to be 25 million tonnes worldwide. In the years 2015 to 2018, global production of green hydrogen was around 1.2 million tonnes (Statista, Bundesamt für Statistik (Germany authority for statistics, Research Department), 2024). In addition, there are significant amounts of blue hydrogen (with carbon capture storage CCS), turquoise hydrogen (based on methane pyrolysis with additional extraction of carbon C), and a significant amount of grey hydrogen (currently around 95%, based on the splitting of natural gas/methane CH_4). The production and development of a global hydrogen infrastructure is one thing. On the other hand, the question arises as to whether hydrogen, regardless of how it was produced, is in demand and used. If you look at the subsidies, a clear picture emerges.

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Currently, the supply side in particular benefits greatly from subsidies, while there is hardly any financial support for the demand side. But it would need this to make investments in the conversion from oil and gas-based production to hydrogen. ING economists have calculated that the conversion from gas or oil to green hydrogen alone could increase the costs of plastics production in Europe by up to 50 percent. Steel made from green hydrogen could become twice as expensive as steel made from coal, and in shipping or aviation, clean hydrogen-based fuels could be up to 10 times more expensive than conventional fossil-based fuels. A lack of incentives on the demand side could also become a problem for suppliers as soon as they have problems concluding offtake agreements. This would burden hydrogen production projects with additional risks and ultimately postpone investment decisions. This would slow down the expansion of the hydrogen economy, tighten supply, and keep prices at a high level. However, there are initial efforts to counteract this trend. In the USA, the states of Colorado and Illinois have introduced a subsidy of around one dollar per kilo for users of clean hydrogen, which is aimed in particular at boosting demand for hydrogen in industry.

The European Union is trying to increase demand for clean hydrogen in the coming years with programs such as “Fit for 55” and the EU Emissions Trading System. Users of gray hydrogen will have to replace 42 percent of their hydrogen volume with green hydrogen in the future. The ReFuelEU initiative for aviation requires 1.2 percent of fuels supplied to aircraft at EU airports to be hydrogen-based by 2030. And the FuelEU Maritime initiative requires shipping companies to reduce their emissions by 2 percent by 2025 and pay a carbon price under the EU Emissions Trading System by 2026, which is already increasing demand for hydrogen-based fuels such as ammonia and methanol. Overall, more activity is expected on the hydrogen market in 2024. The exact number of projects or additional capacity is less important. It will be more about laying the foundations for future growth, balancing supply and demand, and realizing initial success stories that will create further confidence in the market. Building a robust hydrogen market is all about balancing supply and demand, but support on the demand side is lacking. Global subsidies available for clean hydrogen are in billion dollars. It is divided into supply: USD 215 trillion, demand: USD 17 trillion, and both: USD 101 trillion (Hieminga & Zhang, 2024).

Planned Status 2030 Resp. 2032 (Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Science), 2023)

Only with hydrogen can large parts of industry and transport be made climate-friendly. However, climate-friendly hydrogen is still on the rise—out of the laboratory and into practice: a completely new market is emerging. Germany wants to be there from the start and secure a pioneering position in international competition—and use hydrogen itself to achieve our climate goals. The federal government has laid the foundations for this with the National Hydrogen Strategy 2020. The update of the hydrogen strategy from July 2023 once again increases the level of ambition for entering the hydrogen economy and specifies its implementation. The update names four fields of action. Sufficient availability of hydrogen: The federal government wants to build 10 gigawatts of electrolysis capacity by 2030. This is expected to be enough to cover 30 to 50 percent of Germany’s hydrogen demand. To make this possible at all, the Federal Ministry of Research is funding the hydrogen flagship projects: H2Giga and H2Mare. H2Giga is bringing the production of electrolyzers for the hydrogen strategy into series production, H2Mare is developing technologies for the production of hydrogen and hydrogen derivatives on the high seas. In addition to domestic transport, Germany will have to import hydrogen in large quantities. Details of this will be clarified as part of an import strategy that is to be published in 2023. The Federal Ministry of Research is already building up comprehensive hydrogen partnerships, setting the course for our energy supply

of tomorrow. With Australia, for example, Germany is currently testing HyGATE information on hydrogen cooperation between Germany and Australia and is examining the import of hydrogen via the port of Rotterdam. A potential atlas has also analyzed over 30 African countries to determine where in Africa the production of hydrogen is cheap and sensible under which conditions. Six projects are already underway here that are preparing a German-African hydrogen partnership. Further hydrogen partnerships have been initiated with Canada, the USA and New Zealand, among others (Maizière, 2023).

H_2 Infrastructure

The basic prerequisite for the ramp-up of the hydrogen economy is that hydrogen is available in sufficient quantities. And that is where it is needed. A hydrogen core network over 11,000 kilometers long is therefore to connect all major hydrogen feeders with all major consumers by 2032. In addition, the hydrogen filling station network is to be extensively expanded. At the same time, the hydrogen lead project TransHyde is already working on further developing all market-relevant hydrogen transport technologies, testing them, and analyzing when, where, and under what conditions which transport method is best.

Establishment of H_2 Applications

Climate-friendly hydrogen can significantly improve the carbon footprint of industry and transport. For this to work, however, entire industries must be fundamentally restructured. This applies in particular to the steel and chemical industries—but also to the entire transport sector. The EU and the federal government are supporting this transformation comprehensively. In the steel sector, the Federal Ministry of Research is funding the Carbon2Chem project, which uses hydrogen to extract chemicals from exhaust gases, and the BeWiSe project, which is investigating how a steelwork can be converted to hydrogen during ongoing operations. In the field of chemistry, the Federal Ministry of Research is supporting, among other things, the Copernicus P2X project, which produces specialty chemicals and plastics from electricity and CO_2, and CatLab, which develops particularly important catalysts for the chemical industry. In the field of transport, the Federal Ministry of Research is supporting the production of eFuels from air and electricity as part of the hydrogen flagship project H2Mare and the Copernicus P2X project. The ministry is supporting fuel cells as part of basic hydrogen research and in international research collaborations, for example with Canada (Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Science), 2023). As of 2024, it is not even possible to make a serious estimate of how large the hydrogen demand will be in Germany alone. According to Statista, forecasts are between 220 and 450 TWh/a for 2050 (Imolauer & Ueltzen, 2022). However, these may be significantly higher. In any case, the majority will have to be imported. The reasons for this are both the much lower full costs in certain countries and simply the lack of excess green energy in Germany.

Technical Challenges

This requires less technical innovation than the implementation of known necessities. In countries with a “normal” climate, such as in temperate latitudes, there are tasks such as building terminals for ships so that in the future all the tankers loaded with H_2 or NH_3 can dock and transfer their goods into the appropriate tanks. In addition, there is the conversion of existing gas networks, where the seals and valves have to be replaced, as H_2 is a very volatile gas. The expansion of existing filling stations is then only a very limited technical problem. In any case, however, a new industry will (have to) develop around H_2 so that all relevant future customers have to be supplied with the appropriate equipment and accessories. This includes the areas of gas pipes with distribution

stations, the area of electrolyzers for production, the associated power electronics, the fuel cells, and much more. In arid areas of the world, seawater desalination plants are still being used. In the best case, these can be supplied by green energy from wind and/or solar energy. And the construction of ports or piers will also have to be added, because H_2 or NH_3 still have to be loaded for export. But none of this is "rocket technology", it is all possible if you just want it and do it. As of 2024, there are absolutely no insurmountable obstacles to production and transport. In the area of applications, things look different. Numerous car manufacturers, mainly in the EU, are persistently refusing to rely on H_2. Volkswagen (Watson, 2021) and the Mercedes-Benz Group (ADAC, 2021) in particular are making an inglorious name for themselves here, trying to keep quiet about everything except conventional combustion engines and pure electric cars (BEV), which are rejected by the majority of customers, to talk them down or simply refuse to produce them. The influence of politics (behind closed doors) here can only be guessed at, but not definitively proven. In any case, and this fact is obvious, it is not due to a lack of technical knowledge or skills. Note: The statements against H_2 all come from 2021. For whatever reason, there are no more recent ones.

The situation is different in the steel industry, where billions of state subsidies are being used to completely change production processes, which the steel companies themselves cannot manage. There are also other industries such as the chemical, fertilizer, and cement industries, where new/modified production processes are still being tested and have not yet been finalized. But here too, nothing is known about insurmountable obstacles.

Market-Based Challenges

Nevertheless, hydrogen is still progressing too slowly in Germany. That is why the federal government has created a Hydrogen Acceleration Law. This law creates the legal framework for the rapid development and expansion of production and supply capacities. The aim is to significantly accelerate the market ramp-up of hydrogen by 2030. This is because hydrogen will play an important role in the near future in the transformation of industry, in air, shipping, and heavy goods transport and in the restructuring of the energy system. An efficient hydrogen infrastructure is crucial for the decarbonization of industry, the hydrogen pipelines will be the lifeblood of industrial centers. The law removes obstacles to the approval of infrastructure projects that produce, store, or import hydrogen. It is another milestone on the way to the hydrogen economy.

The Hydrogen Acceleration Act simplifies further planning, approval, and award procedures for the production, storage, and import of hydrogen. For example, maximum deadlines are set for water law approvals, the early start of measures is made easier, the process of appeal is shortened, expedited procedures are accelerated and testing procedures for electrolyzers are simplified. In addition, the hydrogen infrastructure projects should be in the overriding public interest. This gives them particular importance in the balancing decisions of the approval authorities. Acceleration measures are used: digital processes, maximum limits for applications, early start of measures, simple and more general application. The federal government has already accelerated the expansion of renewable energies, electricity grids and the construction of LNG ships.

Political/Social Challenges

When it comes to inducing changes in the behavior of their own citizens, countries usually face considerable challenges. This (the so-called energy transition towards the use of green/renewable energies) is one of them. The Novak triangle below shows what possible solutions could look like.

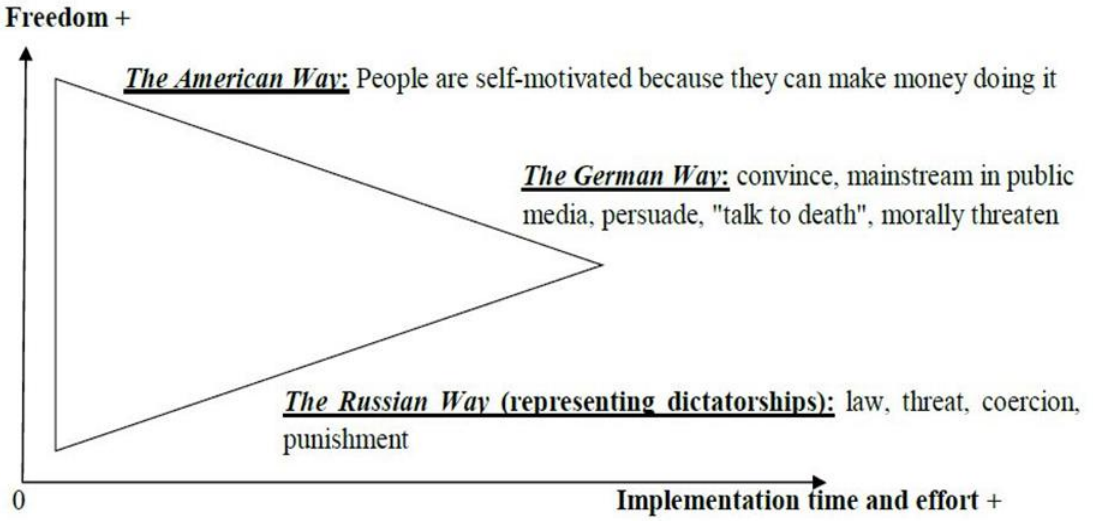

Figure 1. Novak triangle (Novak, 2022).

Personal opinion or worldview as a belief is part of the way people think. Predetermined attitudes are the benchmark for desired behavior not only in politics, but also in unions, clubs, and ultimately of course in religions. This mentality desired in public can be achieved through various measures, including all kinds of opinion-forming through communication, argumentation, persuasion ,and ultimately a kind of "talking someone to death" (talking someone down until they are forced to give up for the sake of peace and/or agree with the predetermined opinion). This approach is referred to here as "The German Way" because it seems to be typical of Germany. Freedom is sometimes much less here than in the USA and lasts much longer because there are numerous political steps and laws and convincing the population through the media can take years/decades. At the same time, a process of awareness must also take place among people.

The goal is something that is aimed for in the short, medium, and long term. Since, according to Freedom House, around 28% of all countries worldwide are pure dictatorships and another 32% are only partially free, lack of freedom can be described as a core feature in these countries. In these around 60% of all states, the goal of the people should be to at least not suffer any disadvantages through coercion, persecution, and punishment. The people there will therefore be motivated by themselves to do what the state wants, without having to be convinced of it, as in the German way, and without being able to earn money from it, as in the American way. The risk of punishment can also be seen as so great that the implementation time and effort for introducing these innovations is very low. At the same time, however, freedom also tends towards zero. It is therefore called "The Russian Way" here. It can be summarized: The ways in which a state can get its people to do something can be summarized as follows: money/costs, or opinion/conviction, or coercion/punishment. When producing or implementing climate protection solutions such as H_2, pure electric cars (BEV), and hydrogen cars (FCEV), especially as global temperatures are rising ever faster (exponential increase), the time factor is obviously crucial. From the author's point of view, only simple "out-of-the-box" solutions make sense that are: (1) easy to understand, (2) technically easy to implement and therefore, (3) reasonably cost-effective. So: the provider can explain it to the potential customer in a simple way, who then understands it immediately; the provider can simply install and activate the solution at the customer's site; the customer can afford it because it is cost-effective and, ideally (American way), even make money with it. These "out-of-the-box" solutions must be standardized and

certified in advance and then only require standardized acceptance by official inspection bodies according to Novak and Doost Mohammadian (2023).

Conclusion and Outlook

Hydrogen is still progressing too slowly, especially in Germany. The pressure to achieve climate policy goals is great, but there are still numerous hurdles, brakes, and obstructions that want to call everything into question. The question of whether we are on the right track with H_2 can only be answered with "yes". The goals and paths are clear, but many things are happening more slowly than desired and needed. Delays, as bitter as they are, are a necessary evil in a free society and economy. Will H_2 play a much larger role by 2030 than it does now? Undoubtedly, at least if no attempt is made to slow it down with legal maneuvers and years of litigation, the future will require billions of tons of green H_2, even if there are still numerous stumbling blocks to overcome as of 2024.

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