VDE Whitepaper



# Whitepaper on the hydrogen economy

VDE FINANCIAL DIALOGUE HYDROGEN 2022

VDE

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Preface
In line with the position of the VDE as a neutral, technical-scientific association, the VDE Whitepaper presents the joint findings of the speakers at the VDE FINANCIAL DIALOGUE HYDROGEN 2022.
The collective results were developed in a constructive dialogue from different perspectives. The contents of this document therefore do not necessarily reflect the opinion of the companies and institutions represented by their employees.

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# Grußwort zum VDE FINANCIAL DIALOGUE WASSERSTOFF 2022

Federal Ministry
for Economic Affairs
and Climate Action


**Dr. Robert Habeck**
Bundesminister für Wirtschaft und Klimaschutz

Ohne grünen Wasserstoff wird Deutschland weder seine Unabhängigkeit von fossilen Energierohstoffen erreichen noch bis 2045 klimaneutral werden. Voraussetzungen für einen schnellen Markthochlauf und die Transformation von Wirtschaft und Gesellschaft sind Transparenz, Akzeptanz und breite Unterstützung. Austausch ist dabei essentiell wichtig; wir müssen alle Interessen mitdenken, das Vertrauen in die Wasserstofftechnologie stärken und ein gemeinsames Verständnis von Qualitätskriterien und Standards schaffen. Nur mit verlässlichen Rahmenbedingungen gewinnen wir Investorinnen und Investoren für eine nachhaltige Wasserstoffwirtschaft in Deutschland und Europa.

Damit das gelingt, brauchen wir die Mit- und Zusammenarbeit aller Stakeholder. Deshalb freut es mich sehr, dass der VDE und seine Partner den Brückenbau zwischen Industrie, Finanz- und Versicherungswirtschaft und der Politik vorantreiben.

Ich wünsche allen Teilnehmenden des VDE FINANCIAL DIALOGUE in Nürnberg interessante Gespräche und neue Erkenntnisse. Damit aus geteiltem Know-How und gegenseitigem Verständnis starke Impulse für den zügigen Aufbau einer nachhaltigen Wasserstoffwirtschaft entstehen.

Ihr

Robert Habeck

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# Executive Summary

Climate change and geopolitical turmoil require a radical transformation of today's fossil fuel-based economy into a renewable energy system. Electricity generation from wind and solar is subject to strong daily and seasonal fluctuations. The potential to produce green electricity also varies greatly geographically. In this context, hydrogen provides an optimal solution for bridging the gap between the volatile generation and the need to supply green energy on-demand across all sectors.

The development of the hydrogen economy has reached a high momentum worldwide. The planned investment of 240 billion US-dollars by 2030 is a strong indicator of this. The emerging market for hydrogen is still characterised by uncertainties about the real-world performance of the products or the expected return on investment. Today's investments are still strongly based on the large, globally established subsidy programs. According to an analysis by *Hydrogen Council in collaboration with McKinsey & Company*, the costs of green hydrogen will quickly fall below the costs of fossil hydrogen as market penetration increases.

The current discussion about efficiency levels is not the decisive criterion here. The decisive factor is the cost, considering all aspects such as the cost of generating electricity, transport to the consumer's location, and storage up to the time of use. The difference in costs between producing hydrogen locally and producing it further afield and transporting it to the consumer should also be compared, including sustainability aspects. The potential for a European regional green electricity production system remains high. A huge availability of electricity from wind power plants with increasing, temporary surpluses that cannot be absorbed by the electricity grid makes hydrogen production in coastal regions attractive. Considerable potential also exists for installing photovoltaic systems on agricultural land currently used for energy crops, on rooftops, parking areas, or along highways. A clever combination of optimised Power Purchase Agreements (PPA) and hydrogen production creates a compelling business model.

Unlike incremental innovations that serve an existing ecosystem, disruptive innovations such as hydrogen technologies require large amount of investment over longer periods of time. Traditional venture capital financing has limited usefulness for this sector, as the level of available venture capital for this sector is low, especially in Europe. New financing models are necessary. It is crucial to adapt the current regulatory framework, which has evolved over a hundred years from the established energy technologies, to the new technologies and products and to reduce the barriers to their market introduction.

The future energy supply will rely heavily on "electrical competences" - from renewable energy generation to electromobility in all its forms. Thus, skilled workers with training in electric and electronic engineering are crucial to the success of the energy transition. At present, there is an acute shortage of skilled workers in Germany and too few students in the MINT[1] fields. This needs to be addressed: young people need to be motivated to work in the fields of renewable energy and storage technologies. This will require a concerted campaign by all stakeholders – training structures, associations/technology organisations and industry.

Key statements and recommendations for action from the hydrogen and finance industries are summarised in this whitepaper based on the results of the VDE FINANCIAL DIALOGUE.

1 Mathematics, Information Technology, Natural Science, and Technology

# 1. Objectives

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This paper aims to bring readers up to date on the latest developments in the hydrogen economy. It discusses lessons learnt from the industry and identifies important technological and policy developments that experts believe will drive progress for this sector.

There is no doubt that hydrogen technologies will be essential in building a sustainable energy supply for the future, as is indicated by the over 680 projects associated with the planned investment of 240 billion US-dollars by 2030. The challenges of climate change, combined with current geopolitical volatility, are forcing us to act even faster. Numerous governments, as well as the European Union have created the framework conditions for technological development and its commercialisation with targeted support programs. At this stage, it is important to develop sustainable and economically successful business models so that public subsidies can be gradually reduced in the foreseeable future.

Despite the aforementioned framework conditions and numerous pioneering projects – both in the stationary and mobile sectors - commercialisation in Germany and Europe is only developing slowly. The VDE FINANCIAL DIALOGUE for the hydrogen economy discussed the current market situation, the state of technological progress and existing challenges and barriers through dialogue with experts in the field to bring clarity to stakeholders and participants. In addition to the hydrogen and automotive industries, selected representatives of the finance and insurance industries were involved to develop a common understanding and market confidence with all stakeholders. This whitepaper summarises the results from the event and aims to provide recommendations to all stakeholders with key messages for a successful development of the hydrogen economy.

# 2. The State of Commercialisation – Technology in Transition

The hydrogen sector is trending upwards, with more than 680 major projects totaling an investment of 240 billion US-dollars by 2030 (see Figure 1). Currently, half of these are still in the planning phase, with only 10% currently being implemented. The latter figure is an important indication of the need for action to get more projects off the ground.

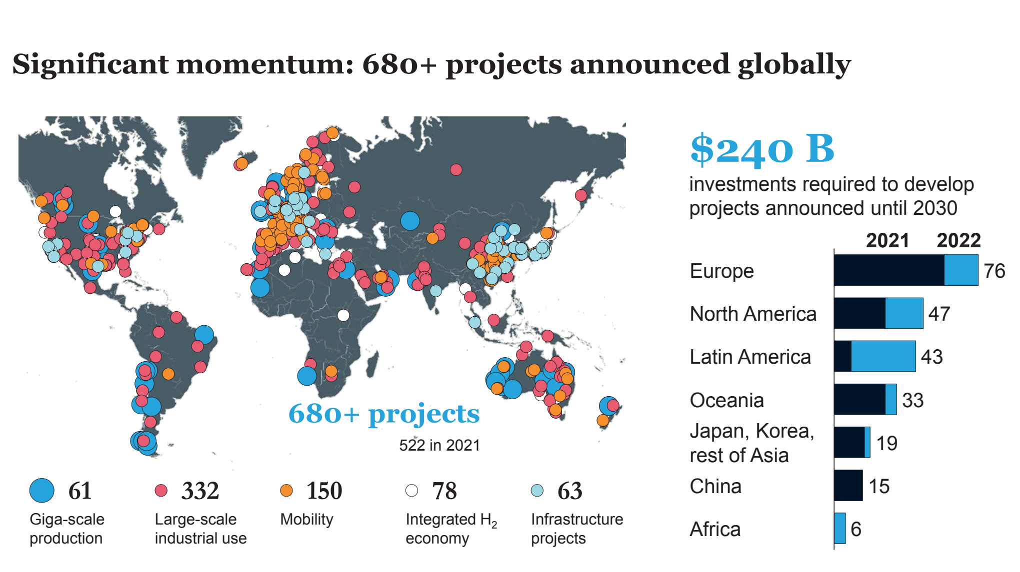


*Figure 1: World map with graphical representation of the 680+ planned projects until 2030 [1] [2]*

*Source: Hydrogen Council, McKinsey*

Today, about 100 million tons of hydrogen (produced almost exclusively from natural gas) are used annually worldwide, mainly in the chemical and petrochemical industries. This "grey hydrogen" is gradually being replaced by green hydrogen sourced from renewable energy. Due to its rapidly increasing use as a secondary energy carrier and fuel, demand is expected to increase by a factor of six by 2050.

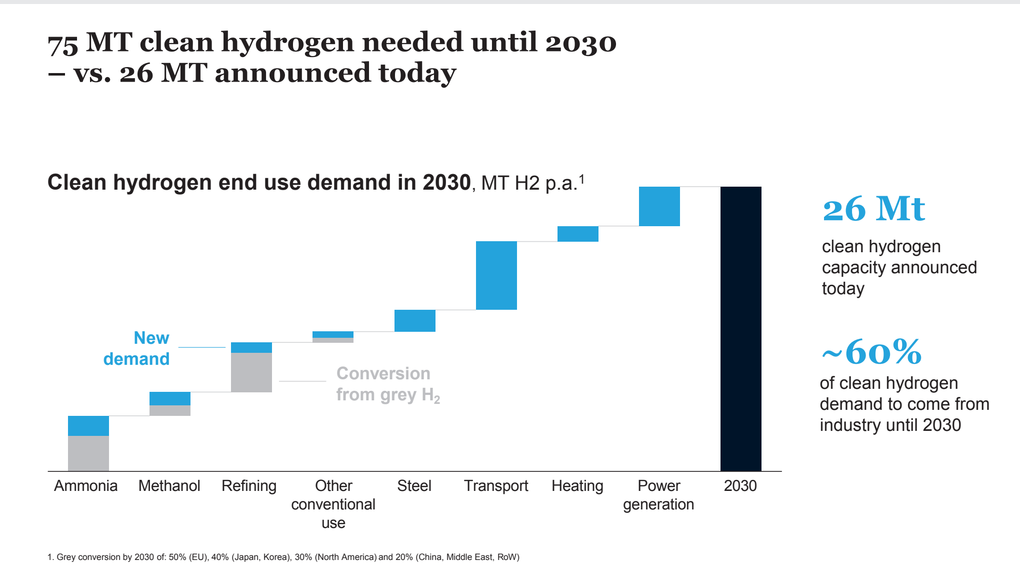


*Figure 2: Global demand for green hydrogen until 2030 [1] [2]*

*Source: Hydrogen Council, McKinsey*

The current target to produce green hydrogen is only at 26 million tons by 2030. However, this demand is expected to reach 75 million tons by 2030 (see Figure 2). Some of this is intended to replace grey (fossil fuel-sourced) hydrogen used in many applications today. The primary usage for green hydrogen is for transportation, followed by electricity generation.

According to an analysis by the Hydrogen Council in collaboration with McKinsey & Company, the costs of green hydrogen will quickly fall below the costs of grey hydrogen as market penetration increases, even if the currently very high prices for natural gas ease (see Figure 3).

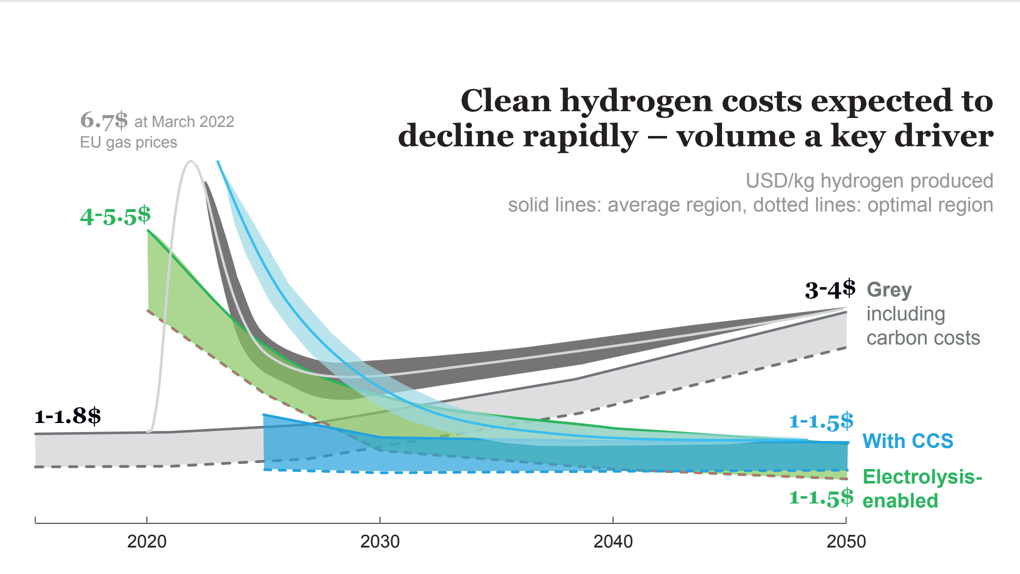


*Figure 3:*
*Cost development*
*for fossil and green hydrogen*
*[1] [2]*

*Source: Hydrogen Council, McKinsey*

# 3. Assessing and Developing the Market

Our current global energy supply (heat, fuels, electricity) is based worldwide, as well as in Germany and Europe, to about 80% on fossil fuels. The consumption of coal, crude oil and natural gas and the resulting emissions of $CO_2$ have been rising continuously for 100 years and are still rising – despite global climate agreements such as those reached in Paris at COP 21 [3]. Climate-related disasters are increasing sharply in frequency and are forcing governments worldwide to adopt mitigation strategies. Regulations to reduce greenhouse gases are becoming increasingly stringent, forcing industry to adapt faster. At the same time, major subsidy programs have been launched worldwide to restructure the energy supply. Examples include the *IPCEI* [2] programs of the European Union for hydrogen or the Inflation Reduction Act of the US government.

The Climate Protection Act adopted by the German government in May 2021 is very ambitious. $CO_2$ emissions are to be nearly halved by 2030 – just 7 years from today (see Figure 4). However, achieving this goal will be very challenging: the reduction in fossil fuel energy to attain the targeted reduction in $CO_2$ emissions corresponds roughly to the amount of fossil fuel energy that Germany imported from Russia in 2021 and currently needs to replace. To achieve the climate targets, this replacement should be based on renewable energies as soon as possible.

In addition to climate protection, the dramatic geopolitical dependencies in the supply of fossil fuels are becoming an increasingly important driver for investments in green technologies.

An energy ecosystem based on renewable energy – primarily wind and solar energy – is quite different from today's system, which primarily relies on fossil fuels. While oil, gas and coal can be easily stored and used as needed, electricity from the sun and wind only partially matches generation with demand. Intermediate storage with batteries or hydrogen requires investment and reduces efficiencies. Both these factors are often forgotten, especially in highly simplified analyses of green power use. For large amounts of energy, the storage then required is only feasible in a meaningful way using hydrogen and its derivatives such as ammonia or methanol (see Figure 5).

In sunny or windy regions, the generation of green electricity is very cost-effective and, in many cases, already cheaper than power generation from fossil fuels. However, transporting

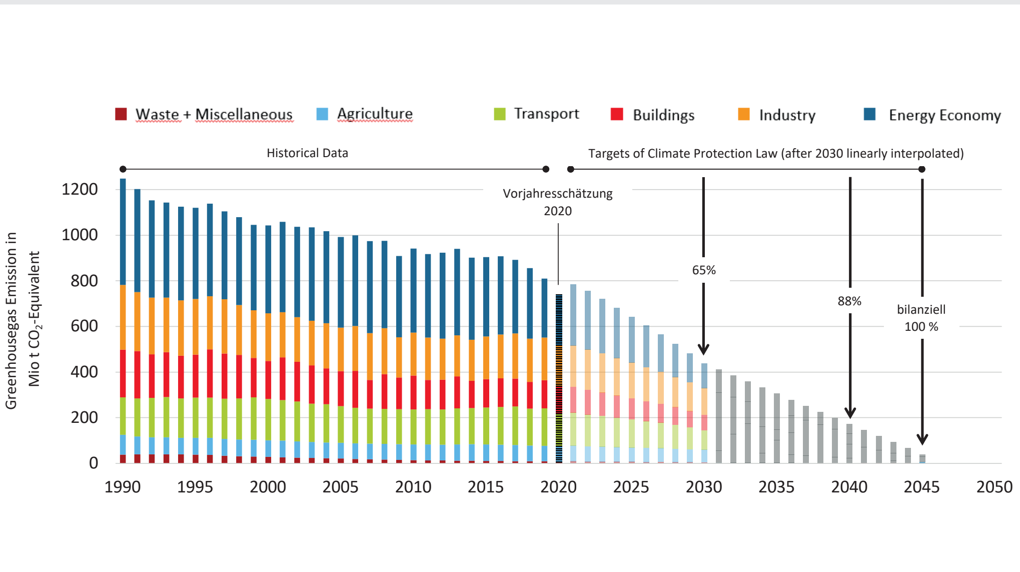


*Figure 4: Historical data and reduction targets for German greenhouse gas emissions [4] [5]*

*Source: Fraunhofer ISE*

2 Important Projects of Common European Interest

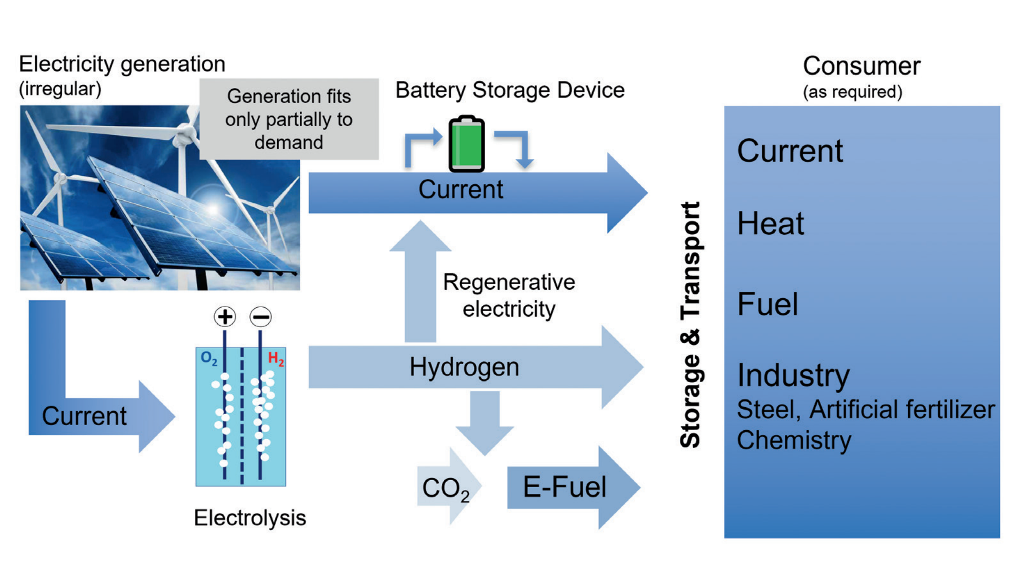


*Figure 5:*
*Energy supply based on electricity from the sun and wind [3]*

*Source:*
*Prof. Werner Tillmetz*

green electricity to consumers remains challenging. The expansion of the (European) electricity grid is not as feasible as assumed in many studies, because it entails high costs and depends on public acceptance. Hydrogen in gaseous form can be transported easily and cheaply over long distances via gas pipelines. For intercontinental transport by sea, only liquid energy carriers are suitable. Liquid hydrogen is the most expensive option. Ammonia or methanol are much cheaper to transport. This is exemplified by a cost comparison for the import of green energy from Namibia between Liquid Hydrogen, Ammonia and Methanol (see Figure 6). This analysis also reinforces the point that highly simplified discussions on efficiencies are not helpful. The true decisive factor is the actual cost, taking into account all aspects such as the electricity generation costs, regionally or in wind- or sun-rich regions, transport to the consumer's location, and storage until the energy is used.

| Component Sizing | $LH_2$ | $NH_3$ | MeOH |
|---|---|---|---|
| Wind (GW) | 1.6 | 0.5 | 0.7 |
| PV (GW) | 1.7 | 1.7 | 2.1 |
| $H_2$ Liquefaction / $NH_3$- / MeOH- Synthesis (tpd) | 410 | 1,236 | 1,086 |
| Battery (MWh) | 61 | 44 | 51 |
| LCoPtX (EUR/MWh) | 167 | 158 | 209 |
| LCoPtX (EUR/ton) | 5,549 | 819 | 1,157 |
| Exported Energy (TWh) | 3.8 | 2.2 | 2.1 |
| Full load hours electrolysis | 6,079 | 4,017 | 4,069 |

All values apply to the optimal cost

C. Hebling et al., The global dimension of hydrogen and its derivates towards climate neutrality, Hydrogen Online Conference 2021

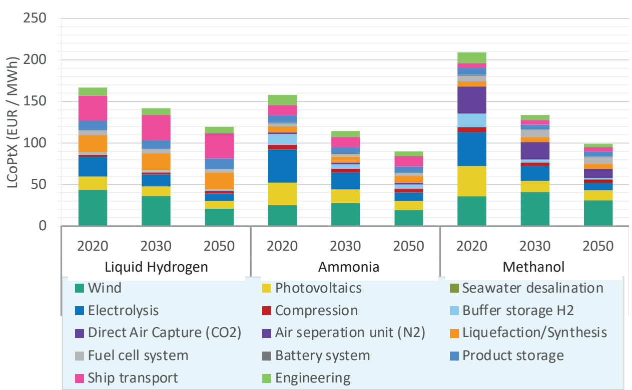


*Figure 6:*
*Comparison of the costs to produce different energy sources in Namibia and their transport to Europe [4] [6]*

*Source:*
*Fraunhofer ISE*

When importing energy from overseas, it should also be increasingly analysed whether it does not make more sense to manufacture energy-intensive products where green energy is available that is much cheaper than in Germany. The goal must be that these products can then be transported more easily and at lower cost than the respective energy source. One example is the production of climate-neutral artificial fertilizers in Norway or Spain.

The costs associated with international transport from production to the point of use (e.g. at a filling station) should also be compared with the costs of a local hydrogen production. The potential for regional generation of green electricity in Germany and Europe is very high. For example, if the 2.3 million hectares of agricultural land currently used for energy crops in Germany were to be converted to photovoltaics, it would be possible to generate twice as much electricity as is needed today [3]. In addition, most roof tops, space on top of parking lots or areas along highways can still have photovoltaic systems installed. Since solar electricity can only be generated when the sun is shining (approx. 1,800 hours per year in Germany), the electricity must be stored for the remaining time (approx. 7,000 hours per year). Considering these quantities, the only feasible storage medium is hydrogen. The reconversion into power and heat can take place in decentralised and highly efficient combined heat and power plants and not only in centralised, large-scale gas turbines, as considered today.

Even today, more than 6 terawatt-hours of surplus wind power is generated in Germany, which cannot be used immediately by the grid and is deactivated [7]. Rather than generating revenue, this incurs annual costs of around 1.4 billion euros. If this unused electricity was converted into hydrogen, it could be used to supply well over 10,000 city buses with green hydrogen, for example.

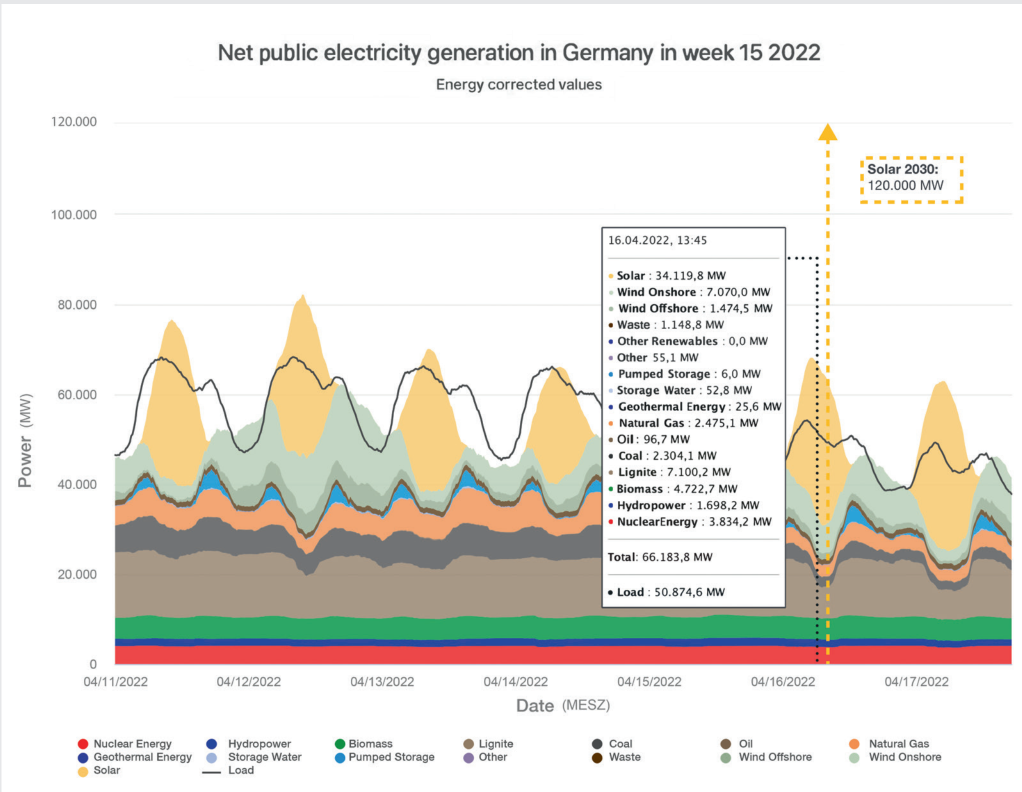


*Figure 7: Electricity consumption and generation on Easter Saturday 2022 and expected solar power generation on a comparable day in year 2030 if the expansion targets are met [3] [8]*

*Source: Fraunhofer ISE and University Ulm*

With the necessary expansion of electricity generation from wind and solar energy (see Figure 7), there will be increasing amounts of surplus electricity that can no longer be fed into the grid at certain times. Storing this energy through hydrogen will also stabilise the grid. The expansion of renewable energy in line with the Climate Protection Act 2021, which was further supported by the German government's Easter package, could lead to a massive overproduction of green electricity. Figure 7 shows that in the Easter week of 2022, a large proportion of the electricity required during the day was already generated from the sun and wind. With the planned expansion of photovoltaics from 63 GW today to more than 200 GW of installed capacity in 2030, many times the required electricity would then be generated on particular days. This creates a high demand for short-term storage (batteries) and long-term storage (hydrogen).

To date, there are only a few studies that have analysed the real-time storage requirements in a grid dominated by renewables over hours, night and day, for the span of a year. According to a data from the *German Institute for Economic Research* (DIW), a 100% renewable energy supply in Germany can be realised with an electrolysis capacity of 70 GW [9]. These results provide an important indication of the storage requirements for an 80% green power supply target, as envisaged in the German government's Easter package for 2030. A green energy system could also greatly reduce the geopolitical dependencies that are so critical today. However, it is crucial that the key technologies for this sector including photovoltaics, electrolysis equipment, and fuel cells are also produced in Germany or Europe. The competences for this are all available today.

Germany has a long tradition in hydrogen technologies. The chemical and petrochemical industries have been familiar with the use of hydrogen for more than 100 years. There are hydrogen pipelines that have been in operation for decades in the Ruhr area (240 km), in the Central German Chemical Triangle (150 km) and in Schleswig-Holstein (30 km) that are symbolic of this. Hydrogen electrolysers have also been a produced in German manufacturing facilities for decades, albeit with historically moderate sales since grey hydrogen from natural gas dominated globally due to its low cost. In the case of fuel cells, the German vehicle industry is well-prepared for adapting the technology and is currently preparing for series production. With about 100 hydrogen filling stations for 700 bar and 60 of them for 350 bar, Germany is also one of the pioneers [10].

# 4. Best Practices and Lessons Learnt from the Industry

A functioning business model is important for launching new products into the market. A relevant example for the purpose of this discussion is the zero-emission logistics in Switzerland. A very high heavy goods vehicle tax on Swiss motorways (multiplied by a factor of 4 compared to Germany) and the exemption granted to zero-emission trucks has enabled the rapid market entry of zero-emission drive systems. A new company has been successfully operating 50 hydrogen/fuel cell trucks daily for more than two years at several logistics companies and together with strategic partners. The fleet will be expanded to 1,500 vehicles by 2025, as will the associated filling station network. Users do not have to worry about maintenance or filling stations – a simple flat rate per kilometer makes adoption of this technology attractive for users. No additional public funding is needed, due to the savings from the heavy goods vehicle tax. In a next step, 250 filling stations will be set up in the D-A-CH region together with international partners. The hydrogen will be produced at a wind farm in Denmark. In cooperation with the operators of the European natural gas network, the hydrogen will be transported to the filling stations.

This last point already refers to another business model that is developing in the North Sea littoral states. With the increasing availability of electricity from wind turbines, temporary surpluses that cannot be absorbed by the power grid makes coastal hydrogen generation attractive. A clever combination of Power Purchase Agreements (PPAs) and hydrogen production can already generate good returns. Hydrogen is ideally used locally or distributed to further distances by pipeline. For the latter, long investment horizons of 10 years and more are necessary. The often lengthy and regionally-variable approval process makes life difficult for pioneers and delays the all-important and fast market launch.

Worldwide M&A (Mergers & Acquisition) activities in the advanced hydrogen technology sector, particularly for elektrolysers and fuel cell companies, have rapidly increased in recent years. For example, many corporations from traditional internal combustion engine manufacturing or vehicle manufacturers are acquiring new technology companies. It is also striking that there are many strategic partnerships that are emerging across the entire value chain: from hydrogen production to refueling infrastructure and vehicles, including new operator models. This strategic cooperation is also a core element of many funding programs. Figure 8 very clearly shows the scope of the value chain of a hydrogen economy.

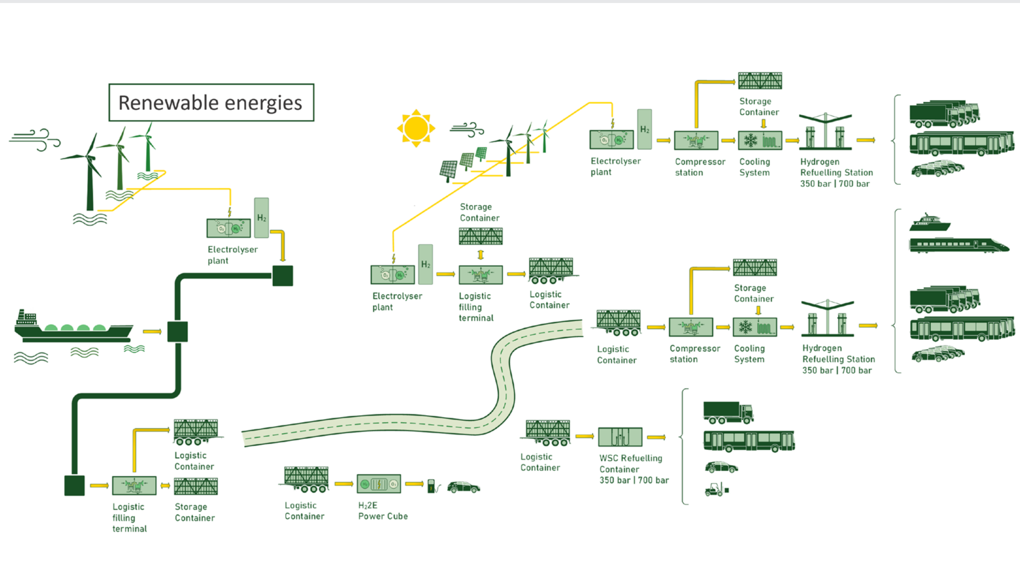


*Figure 8: The value chain for hydrogen in the transport sector [11]*

*Source: Wolftank Group*

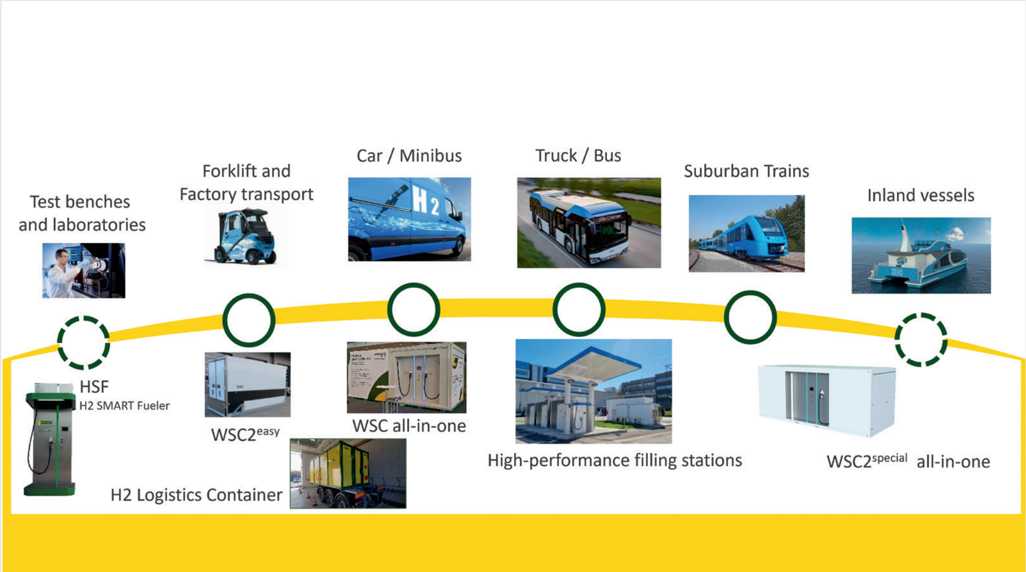


*Figure 9: The diversity of hydrogen refueling infrastructure [11]*

*Source: Wolftank Group*

A California-based company has demonstrated the importance of an end-to-end value chain for battery-electric vehicles. In contrast to the established practice in the vehicle industry, it has built up the essential charging infrastructure itself and did so without subsidies or lengthy international standardisation processes. Internet-based services, such as the digital coupling of the vehicle with the charging infrastructure, were also decisive in the high level of acceptance of the new product.

In Germany, very agile small and medium-sized enterprises have played a key role in innovations up to now. For the fundamental, international upheavals, as is also the case with the hydrogen economy, small and medium-sized enterprises lack the financial strength required in the long term. In many cases, typical small and medium-sized enterprise (SME) lack direct access to international markets, too. This is where strategic cooperation within the German economy and new financing models have even greater significance. The multitude of applications and the associated complex challenges for a supplier of hydrogen refueling systems is vividly conveyed in Figure 9. Each application has its own requirements and regulations for supplying users with hydrogen.

The main driver for sustainability in the energy economy is the increasingly restrictive global legislation aimed at reducing greenhouse gases. The introduction of $CO_2$ emission standards for passenger cars and the *Clean Vehicle Directive* are striking examples from the transport sector. Here, the focus is on vehicle emissions. The *Alternative Fuels Infrastructure Regulation* (AFIR) will set new standards to regulate the necessary infrastructure for “green fuels” (electricity, hydrogen, e-fuel), which could also pose regulatory and technical challenges for new market entrants. In addition, very complex life cycle assessments will become increasingly important in the determination of product strategy for many manufacturers [12].

From the procurement of raw materials to product manufacturing, to their use and recycling; the entire supply chain is increasing in importance for customers and legislators. At the same time customers will be sensitive to any inconveniences or disruptions in the use of the products. Hydrogen technologies are well-suited to addressing this concern because they promise lower costs due to high relative energy density as well as offering convenience in the form of short refueling times and flexibility in application. Green hydrogen can be refueled at any time of the day or year. For green power, this is not as simple as is often assumed due to fluctuating generation. Worldwide, more and more manufacturers of private

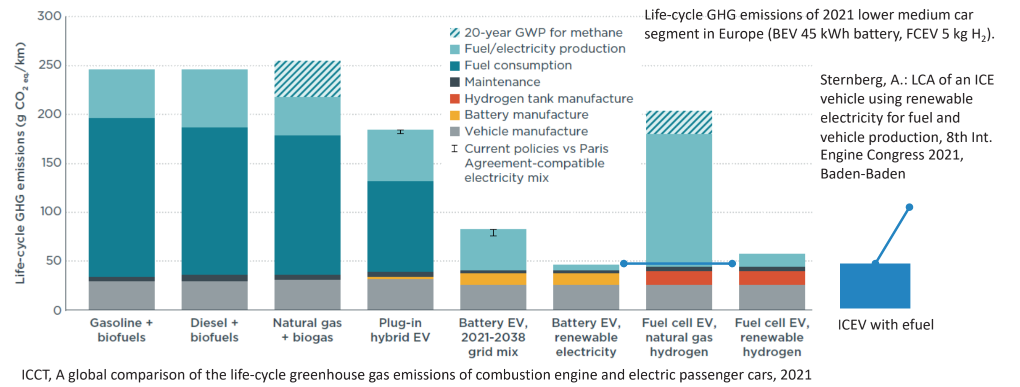


*Figure 10: Comparison of greenhouse gas emissions of different drive concepts and fuels over the entire life cycle [4] [13]*

*Source: Fraunhofer ISE*

cars as well as light and heavy commercial vehicles are turning to electric drives with fuel cells and hydrogen as fuel.

An example of a holistic analysis of greenhouse gas emissions over an entire product life cycle is shown in Figure 10. In the example, a medium-sized passenger car clearly shows that electric drives, whether with battery and green electricity, or with fuel cell and green hydrogen, or with electricity generator and e-fuel, are all about equally good and significantly better in terms of Greenhouse Gas (GHG) than fossil fuel-based drives or engines.

# 5. Providing investment funds and loans for start-ups and established companies

The rapid transformation of the global economy, which is reliant for 80% of its energy on fossil fuels, to one dominated by renewables is a gigantic challenge for all the players involved. The upcoming change is comparable to that, that happend more than one hundred years ago, when Rockefeller and Ford brought oil and the automobile into the market, replacing horse-drawn carriages. This should shape the world for the next hundred years – and its global growth and prosperity. It also had consequences for geopolitics and climate change.

The restructuring of the established energy system requires enormous investment. At the same time, the developing market based on renewable energies and hydrogen is difficult to describe today and must deal with the typical risks of a new industry. Today's standard financial evaluation tools are often not applicable and the actual return on investment can only be assessed in the long term.

Can a shift to green power still succeed? For this to happen, it is crucial to adapt the current regulatory framework, which has evolved over a hundred years with established energy technologies, to the new technologies and products. Above all, it must remove hurdles to bring innovations to market. In Chapter 8, this topic will be discussed in greater detail.

Another essential element is the governmental support for the critical market introduction phase for this new technology. There are two crucial issues here: First, building up economies of scale for production in order for costs to reach competitive levels. Second, ensuring the quality of these new products are qualified in the "real world", which can be incredibly complex. The following statement illustrates the inherent challenge in achieving this: "Low numbers in production lead to high costs per unit; only with the low costs resulting from higher numbers in production can you become competitive". Effectively, this describes the key challenge facing new market entrants, a problem known as the "chicken and egg" dilemma. At the same time, the costs of building higher production quantities are enormously high. Entering mass production is connected to many challenges associated with this stage of industrialization, including the development of new supplier industries. The newly created IPCEI instrument of the European Union helps to overcome these challenges. However, this funding instrument is not very accessible to SMEs.

The second topic is the qualification of the new products. It is only when they are tested in real-world operation that the many problems become apparent, which then must be remedied through an improvement of production processes. A good example of this was the case of the first hydrogen filling stations, which experienced service interruptions and poor reliability. In the meantime, many of the "teething troubles" have been solved and the convenience and quality of the refueling process have improved significantly. However, the long-term process optimisation required for this is very expensive. Funding programs coordinated by the National Organisation Hydrogen and Fuel Cell Technology (NOW) can provide support here.

No product can be developed based on funding instruments alone. Equity capital is also needed to jump-start a business. Especially start-ups and medium-sized companies are not able to finance this from their running business. The insurance industry can offer support for financing of new products and business models in new markets by cushioning the technical and business risks associated with new products (such as safety, durability, reliability, efficiency). The prerequisites for this, however, are technical criteria catalogues, standards and partnership-based collaboration so that the products become "bankable" [8].

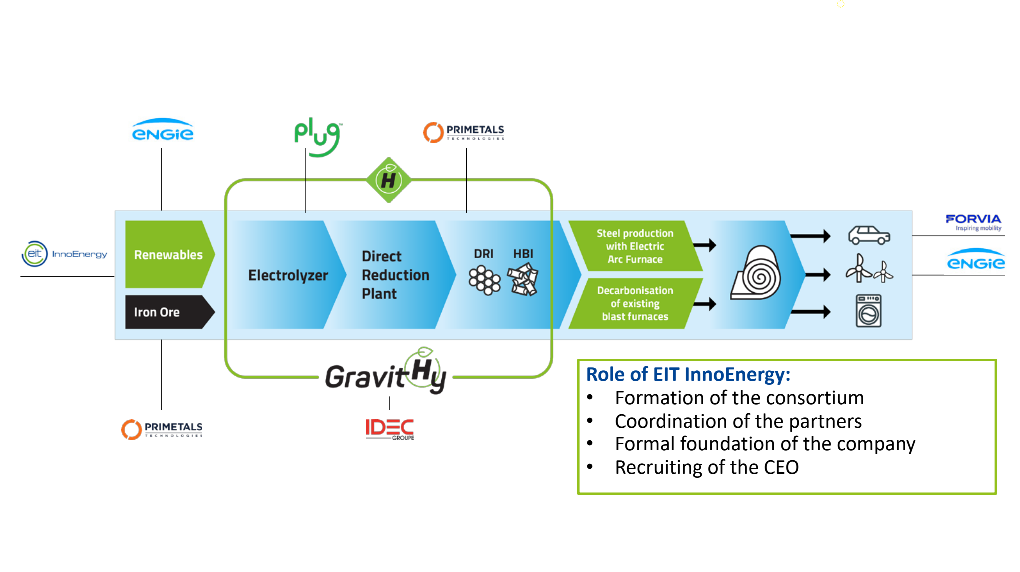


*Figure 11: Role of EIT InnoEnergy - GravitHy: Strategic partners establish a joint venture aimed at industrializing the production of green steel [14]*

*Source: EIT InnoEnergy*

The financing of new companies (start-ups) is a key area for the transformation of the energy system. Unlike incremental innovations that serve an existing ecosystem, disruptive innovations, such as the hydrogen economy, require large investments over long periods of time. Traditional venture capital financing has limited effect for this sector – furthermore, the available venture capital, especially in Europe, is low.

New financing models possess significant advantages. For example, the companies that play a key role in the successful commercialisation of new fields of technology could jointly invest in companies that then drive the implementation of the technology into a product. To ensure the financing of the business models, the financial/investment sector must actively invest in supporting them. This has proven successful in the case of renewable energy sector and can also be implemented in the hydrogen economy. Figure 11 shows an example from the "green steel" sector. Through strategic partnerships, the often complex interfaces (mechanical, electrical, data transfer) between the subsystems can be clarified and implemented quicker than via the very lengthy international standardisation committees.

Another new business model is to involve strong institutional investors to participate in the development of the hydrogen economy. These investors would then demand fund management that is both technologically competent and also able to guarantee trust and reliability for the technology. Qualified assessments by an impartial third party, one that is also familiar with the latest technological developments, is crucial to achieving this [15].

Foundations that focus on initiatives and business models for renewable energies and storage technologies could also support the transformation of the energy system with their commitment.

The "traditional" energy industry has invested billions of dollars in infrastructure and oil and gas production. Upcoming projects in the hydrogen sector also require large investments, as the 61 major projects in Figure 1 show. A sustainable financing model that can also anticipate and mitigate unplanned changes and delays in the course of business is quite crucial for strengthening and expanding the hydrogen sector. The financial community is using tools established in other industrial sectors to evaluate hydrogen economy business plans. Adapted simulation models can be used to comprehensively analyse and optimise the overall project [16]. To this end, individually adapted criteria catalogues and the development of pre-standards with quality seals are important prerequisites for making products bankable and insurable. This has already been a key success factor for photovoltaic and battery projects in the past. The discussions of experts at the VDE FINANCIAL DIALOGUE specified that the criteria for bankability should also include a neutrally confirmed service life and risk analysis, as well as assessing the availability of important supplier components. The resulting model calculations for different scenarios are essential decision criteria for investors and insurance companies.

# 6. Capacity Development – It's all about People

In the last century, coal miners were extremely vital in guaranteeing the energy supply and the prosperity that developed from it. The future energy supply will rely heavily on "electronic and electrical skills" - from renewable energy generation to electromobility in all its forms. Thus, skilled workers with training in electric and electronic engineering are crucial to the success of the energy transition. This includes people in the skilled trades (solar technicians, electricians and electronics technicians) and would continue with electrical engineers and computer scientists, all the way to the creation of a strong academic environment in key technological sectors. The fact that 4.3 million people are currently working in the global photovoltaics industry provides an interesting indication as well as an impetus for reflection. Of these, only 50,000 are employed in Germany, significantly fewer than 15 years ago [17].

Today, there is a massive shortage of skilled workers in Germany and far too few students in the MINT[3] subjects. This makes the primary challenge and its solution clear: young people should be motivated to work in renewable energies and storage technologies.

For the emerging hydrogen economy, however, there are also many areas of expertise in today's economy that are crucial to its development. One of these is chemical process engineering, which is now established in the chemical and mineral oil industries and will play an important role in many areas of the hydrogen economy in the future. The traditionally strong German mechanical engineering sector can contribute significantly by creating efficient hydrogen compressors, electrolysers or fuel cells, for example. For the upscaling and the eventual mass production of the products, which will start in a few more years, existing German advantages in automation technology and the high professional competence of employees are a great advantage.

These examples show that there are numerous synergies with established German industry. Compared to their Asian competitors, German automotive companies have so far been hesitant to make the shift towards hydrogen-based powertrains. In contrast, some internationally active supplier companies have already positioned themselves well by adopting new hydrogen technologies. For German medium-sized companies, which have traditionally been innovative, how they position themselves will also play a decisive role in the development of the hydrogen value chain. However, it is still difficult for them to gain a foothold in the turbulent global market with their existing resources.

In a disruptive environment, the managers of companies that have so far been able to rely on established technologies, processes and networks are facing completely new challenges. This requires a risk-taking corporate culture that values creativity, as well as long-term oriented and entrepreneurial thinking – as well a lot of courage. These characteristics are still present in many family-owned and start-up companies. Listed companies are usually committed to the very short-term and high return expectations of their shareholders – one of the biggest hurdles for the upcoming change and upheaval in the energy sector.

In terms of the economy and corporate policy, it is not about growth and optimisation, but about a radical change in our energy system and thus in the entire economy. This is illustrated by two examples that we are all familiar with: The light bulb was not created by optimizing the candle, and the LED was not created by optimizing the light bulb.

3 Mathematics, Information Technology, Natural Science, and Technology

# 7. Lessons Learnt from the Solar Industry – Maintaining hydrogen technology leadership and strengthening the production location

Over the past decades, Germany has achieved a leading position worldwide in so-called incremental innovations. “German Engineering” has a strong brand of its own. A well-known example of this is the drive towards perfecting engine technology and excellent driving dynamics, qualities attributed to German manufacturers in the automotive industry. Long-term optimisation over decades, a highly specialised supplier industry and a high level of value creation in Germany characterise the resulting successful economic ecosystem.

When it comes to disruptive innovations, such as internet technologies, modern communication products or new, internet-based business models, both Germany and Europe have been at a disadvantage compared to American and Asian companies.

The development of the photovoltaic industry over the last two decades is a good lesson in this respect. A strong technological base with application-oriented research excellence in combination with a very attractive market introduction instrument (Renewable Energy Act, EEG) and agile, medium-sized companies had made Germany the world’s leading location for photovoltaics in the 2000s. When the success became visible, two very decisive things happened: China recognised the potential and invested in the mass production of photovoltaic modules, supported by German engineering companies for whom this was a very attractive business. This made modules from China unrivalled in price compared to other competitors and step by step they took over the German and then the international market, which today has reached a turnover of well over 100 billion dollars.

Meanwhile, among German energy suppliers and power plant operators, photovoltaics were facing increasing competition, even as they were increasingly displacing the very profitable peak load power plants. Thanks to targeted lobbying by other sectors, the German solar industry did not receive the necessary political support and many the companies slipped into insolvency or were bought up by foreign concerns. Germany relied on cheap natural gas from Russia which entailed high political risk – with today’s result.

Germany also achieved a very good technological position in modern hydrogen technologies 20 years ago. Promising passenger car models and about 40 city buses were successful in everyday use for years in a still manageable pilot market. The trigger for the very intensive activities worldwide at that time was California’s “Zero Emission Legislation”. After this was severely watered down in 2003, and no further legislation existed that would have motivated the established vehicle and mineral oil industries to change their products, many activities were relegated to the back burner. In the meantime, legislation relating to climate protection is becoming increasingly restrictive, forcing the industry to radically change its products and overall system solutions. International competition is becoming increasingly fierce – Asian companies are adapting and advancing at high speed.

The transformation of our energy system requires a comprehensive and technology-neutral strategy that considers all aspects from raw materials to regulatory frameworks. A wide range of analysis has been published on this subject in the form of strategy papers. These are usually not very concrete in their formulations and objectives – they are often a political statement of intent and the basis for funding programs. Concrete milestones and defined success criteria are usually absent.

The very clear implications of the Climate Protection Act passed in May 2021, which picked up the agreements of the Paris climate protection agreement (COP 21), are largely not taken into account in the strategies. In addition, the current geopolitical crisis is exerting enormous pressure on all actors to act. This is a completely different situation compared to the development of photovoltaics 20 years ago.

Under these new conditions for the energy industry as a whole, all stakeholders must revise their analyses and the roadmaps they have applied up to now. This includes topics such as refined, real-time models for the highly fluctuating solar and wind power generation and how energy storage with hydrogen can complement this variable supply. Examining the best means to transport hydrogen and its derivatives should be substantiated and refined and continuously updated with innovations.

The most urgent priority for policymakers should be to adapt regulatory frameworks to the new situation (see chapter 8).

For companies in all the relevant sectors, it is crucial to develop long-term strategy for the energy transition and the hydrogen economy, considering the new framework conditions. This should include a resilient procurement strategy for critical raw materials, such as iridium for PEM electrolysis or copper for the electrification of the transport sector and the expansion of the electricity grid.

Rebuilding the European photovoltaic industry will be one of the strategic tasks of industry, investors and political figures. Rapid development of international standards is also urgently needed. The newly created RCS platform[4] from NOW hydrogen is enormously helpful in this respect. Strategic cooperation between all stakeholders is crucial for long-term success. This creates a functional and resilient value chain for the hydrogen economy, which will gradually reduce dependency on Asian suppliers.

4 Regulations, Codes and Standards for the Hydrogen and Fuel Cell Technology Sector; https://rcs.now-gmbh.de/

# 8. Reduction of bureaucracy and overcoming regulatory barriers

Headlines are full of reports about lengthy approval processes for wind turbines or the grid connection of solar power plants. The approval of hydrogen filling stations also currently requires a lot of negotiation, although NOW has published a helpful guide for this. In addition, there are increasing numbers of successful implementation in Germany. At the European level, as of yet there are no uniform approval processes for hydrogen technologies – a major hurdle for the European internal market that should not be underestimated.

The discrepancy between legislation to achieve climate protection targets and the continuing existence of regulatory hurdles is a considerable and potentially disruptive challenge. The existing regulatory framework is the greatest obstacle to the rapid implementation of the energy transition and correspondingly the development of a hydrogen ecosystem. Rapid improvement to address this unsatisfactory situation is enormously important for project developers and operators of plants and investors. Figure 12 shows these interrelationships and dependencies using the example of a typical large-scale project.

The upcoming development of new regulatory frameworks in the near future is crucial for the achievement of climate and industrial policy goals in the hydrogen economy. The regulatory frameworks include the *Renewable Energy Directive II (RED II), RED III,* the *Alternative Fuel Directive (AFIR)* and the *greenhouse gas reduction quotas* in the transport sector (Federal Emission Control Act) [18].

The multitude of obstacles was already pointed out in detail by industry representatives to politicians and responsible authorities in the past. The relevant ministries have been working at full speed on the necessary adjustments and changes. Unfortunately, the legally prescribed coordination with the European Union always requires a great deal of time due to lengthy coordination processes.

Another major hurdle is the lack of political will. A large number of strongly diverging interests from society and business at the state, federal and European level is the biggest stumbling block to rapid implementation. Addressing this will require the streamlining of unnecessary bureaucratic processes as well as the acceleration of approval procedures. A quote from the presentation by Rudolf Hilti, one of the speakers at the VDE FINANCIAL DIALOGUE, sums up the fundamental dilemma:
*"The vast majority of our citizens are afraid of change. With that, politicians are also very reluctant to change and promote the preservation of what exists – but what we need are radical changes!"*

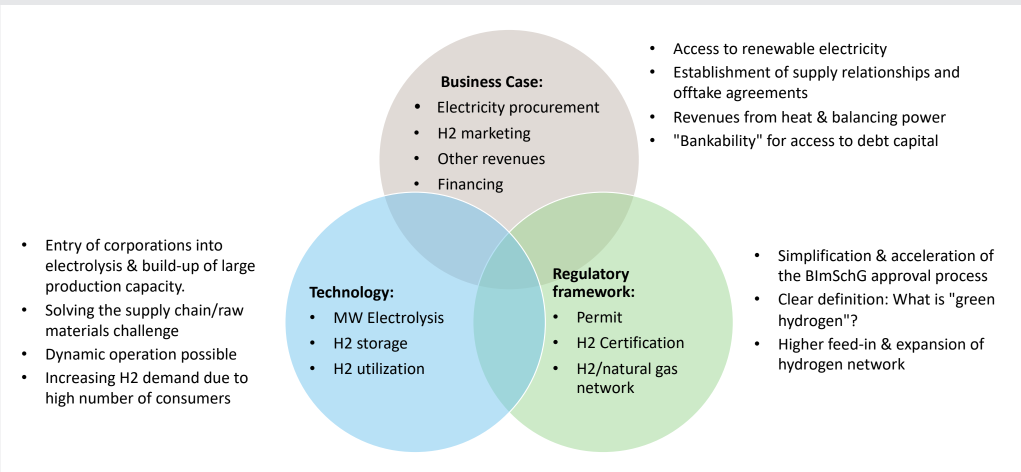


*Figure 12: Prerequisites for the implementation of major projects [14]*

*Source: EIT InnoEnergy*

# 9. Quo Vadis – Key messages and recommendations for action

Within the framework of the VDE FINANCIAL DIALOGUE for the hydrogen economy, the experts jointly developed the following key statements to enable a successful hydrogen economy:

I. Climate change and geopolitical upheavals are forcing a faster expansion of renewable energy. Wind and solar power can generate many times more energy than is needed today. This also applies to Germany and particularly to Europe.

II. In view of the still increasing consumption of fossil fuels worldwide and their share of around 80 percent of the total energy supply, the energy transition presents us with immense challenges. The new energy world is not based on optimising today's energy supply, but on radically changing it.

III. The magnitude of the challenge is illustrated by the example of the halving of $CO_2$ emissions over the next seven years, a key part of the German Climate Protection Act.

IV. Hydrogen and its derivatives as secondary storage mediums form the ideal complement for the high daily, seasonal, and geographical variability in the generation of green electricity and demand-oriented supply of energy in all sectors. The corresponding real-time renewable energy generation model calculations, considering current political goals, are important decision-making tools for all players.

V. Both hydrogen and e-fuels from sun- and wind-rich regions are attractive energy storage mediums, bearing in mind all costs: from generation to storage and transport. The relocation of production for energy-intensive and easily transportable products to regions with very low-cost energy from the sun and wind should not be ruled out either.

VI. The development of a hydrogen economy has gained enormous momentum worldwide and is seen as an eventuality by all sectors. The planned investment of 240 billion US-dollars by 2030 is a strong indicator of this. At the same time, the acquisition of technology companies and strategic partnerships along the value chains have also rapidly increased. It is important to craft and maintain a technology-neutral industrial policy that supports rather than prevents emerging developments, particularly those with promising potential for commercialisation.

VII. Hydrogen, as a new and emerging industry, is still characterised by uncertainties about such topics as product reliability or return on investment – through these are typical features of disruptive innovations.

VIII. Extensive support programs are playing an important role in market ramp-up and the start-up phase, with a race between regional economies for technological leadership becoming increasingly apparent.

IX. The existing regulatory framework, especially in highly regulated energy markets, is the biggest hurdle to a rapid market introduction of new technologies. Combined with the limited ability to accurately estimate future returns on profitability for experimental technologies, these factors contribute to major uncertainties that affect important investment decisions for the sector by financial institutions.

X. Mobilizing private capital – especially for innovative small and medium-sized enterprises – is critical to success. Strategic partnerships of sector-focused investment companies, industrial companies and established funding providers should create efficient platforms for this.

XI. The rapid introduction of the necessary regulatory frameworks for the new technologies represent an important prerequisite for the bankability and insurability of the new products and business models. Uniform approval processes throughout Europe are another prerequisite for exploiting the potential and opportunities of a European single market.

XII. Courageous and visionary managers, as well as strategic cooperations along the value chain, are decisive for rapid economic success. Strategic risks such as raw material or supply dependencies must also be addressed and reduced.

XIII. For Germany to remain a technology leader in the hydrogen economy and to succeed in commercialisation with the establishment of its own production and service areas, the hydrogen economy urgently needs concerted initiatives to educate skilled workers. There is an urgent need for action both in vocational training in companies and at universities in order to provide the market with sufficient junior staff.

This basic recommendation for action can be derived from these key statements:

A broad consensus in society that is open to technology is necessary for the rapid removal of existing hurdles and the rapid implementation of new technologies in the markets.

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