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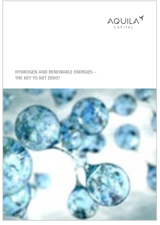
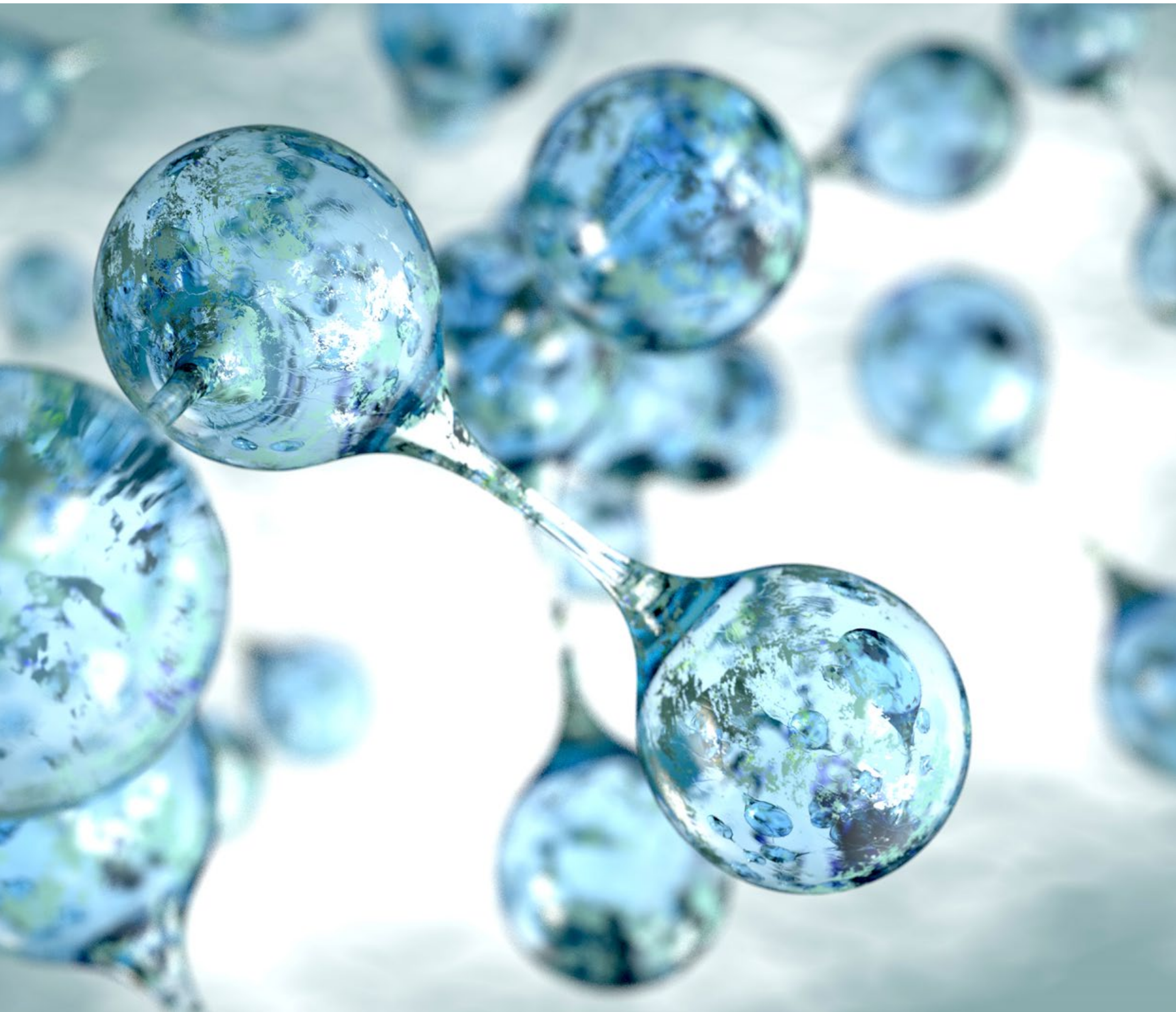


MANAGEMENT SUMMARY

GREEN HYDROGEN – UTOPIA OR THE FUTURE
A SCENARIO ANALYSIS



Abstract

Hydrogen is becoming a beacon of hope for economies striving for emission neutrality in the fight against climate change. Hydrogen offers the technological prerequisites to avoid emissions from sectors that are difficult to electrify and to enable the storage of fluctuating renewable electricity production. However, the economic viability of such applications and the investments required for them are still at the centre of the debate. In order to protect the climate effectively on a global level, it is essential to focus on cost efficiency, as the pursuit of prosperity is dynamically increasing global energy demand.

This paper therefore highlights the synergies and technological advantages of hydrogen. On the other hand, the economic viability of green hydrogen compared to fossil alternatives is examined under real conditions. The aim is to identify the hurdles in the existing environment and to develop specific options for overcoming them.

Analogous to the development in the renewable energy production sector, additional incentives are needed to move from technological maturity to market maturity and competitiveness. Whilst the focus is on the high energy demand for hydrogen production and the associated need to expand renewable energies, there are conflicting goals depending on the price of electricity that are difficult to overcome. High electricity prices create incentives to expand renewable generation capacities, but at the same time limit the economic viability of the production of green hydrogen, which is just as necessary to compensate for fluctuating generation.

However, there are possibilities to create a basis through technological progress and the use of economies of scale. The scenarios presented in this paper show the current situation and consider possible developments based on changing framework conditions.

Achieving green hydrogen competitiveness can mark a turning point in bringing the energy transition increasingly in line with reality.

Drawing on Aquila Capital's expertise in renewables and the energy markets, we will present a comprehensive and especially reality-based insight and outlook on the development of a European hydrogen economy.

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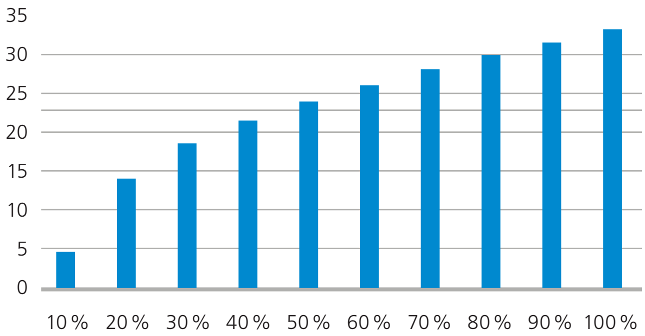
Baseline scenario

Based on the electricity prices on the German market, from which the necessity of storage technologies was already derived in chapter 2, the total costs of hydrogen production are calculated in a baseline scenario. In order to avoid incorrect estimates due to the special effects of the pandemic, we base our calculations on prices from 2019. In addition, the positive effects for the integration of renewable energies are to be examined in particular. For this reason, we subdivide the electricity prices that arose in reality into hours according to the respective price level.

Weighted exchange prices for electricity in Germany sorted by hourly prices in ascending order in EUR/MWh[1]

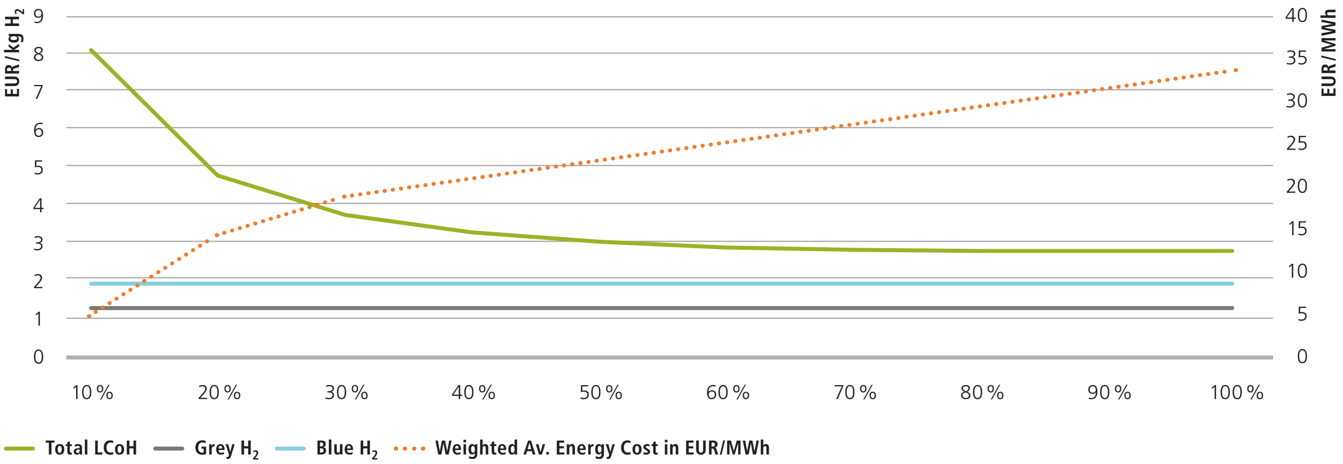


The graphic illustrates the volatility of market prices. Based on the correlations in the electricity market, which consequently reacts to an oversupply with very low, sometimes even negative prices, it will be examined how this oversupply can be channelled into the production of green hydrogen. The weighted average prices of the respective deciles are shown. The respective prices, e.g. bar one 10 % of the cheapest hours, result from the correlation with the supply. Thus, using the cheapest hours for hydrogen production would lead to two positive effects. On the one hand, the oversupply on the electricity market would be reduced and subsequently cause prices to stabilise. Secondly, the high energy demand of electrolysis would benefit from relatively low prices, whilst the sale of the hydrogen produced in this way would lead to further revenues.

Included in the analysis are all costs incurred for the construction and operation of an electrolyser with a capacity of 50 MW under real conditions. In addition, the total price per kg of hydrogen (LCoH – levelised cost of hydrogen) is calculated on the assumption of a 100 % equity-financed plant with a return on equity of 6 % without subsidies. The competitiveness compared to grey and blue hydrogen is examined in each case to enable a comparison without transport and storage costs, which are incurred regardless of the production type.

[1] *Aquila Capital Research based on data from ENTSO-E (2021)*

Total costs of hydrogen production as a function of electricity price.[2]



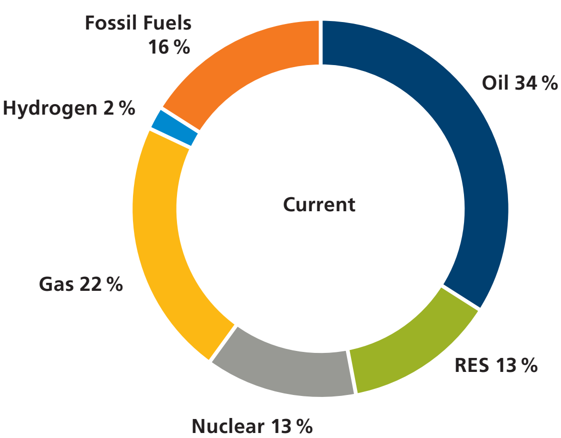
The graph shows that the production costs for green hydrogen decrease with increasing utilisation of the plant. Despite the electricity costs, which increase with higher utilisation of the plant due to sorting, this effect dominates. The distribution of the currently included CAPEX over increasing utilisation leads to the dominance of the fixed cost degression over the electricity price effects. As a result, the most favourable price to be achieved for green hydrogen under current conditions is 2.74 EUR/kg at 100 % utilisation of the electrolyser. This makes green hydrogen about 50 % more expensive than the alternative of blue hydrogen, whilst the price compared to grey hydrogen is more than double. Moreover, no positive effect on the fluctuations in the electricity market can be expected if the plant is running at 100 % capacity.

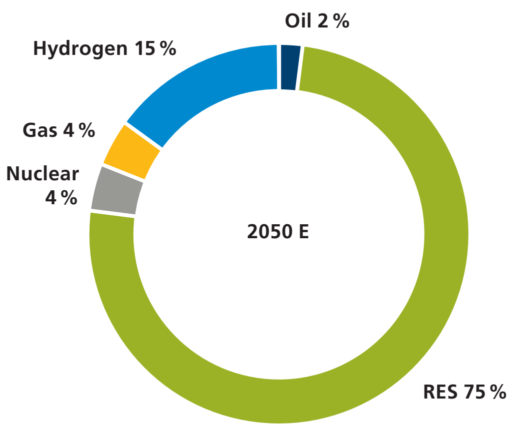
So are the ambitions of the EU and other member states to establish a hydrogen economy just wishful thinking or will appropriate measures change the conditions?

Changing framework conditions

Currently, hydrogen accounts for less than 2 % of primary energy consumption. By 2050, however, the share should be up to 15 % on the way to net zero.

EU hydrogen ambitions[3]



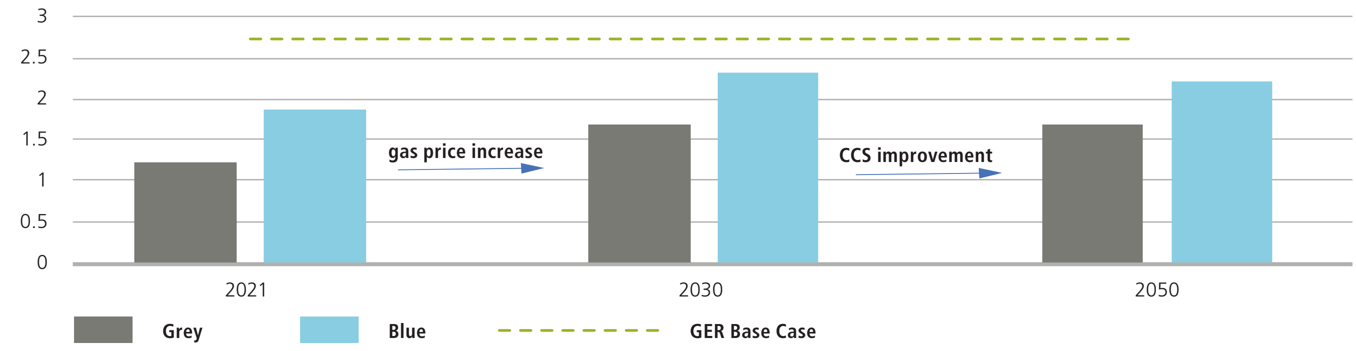


[2] *Aquila Capital Research (2021)*
[3] *Goldman Sachs (2021)*

To achieve this goal, massive investments will have to be made, which only the private sector can provide. But in this context, the competitiveness of green hydrogen must improve significantly. Several effects will significantly determine future development.

Effect 1: Fossil alternatives become more expensive

Development of costs for grey and blue hydrogen (based on gas)[4]

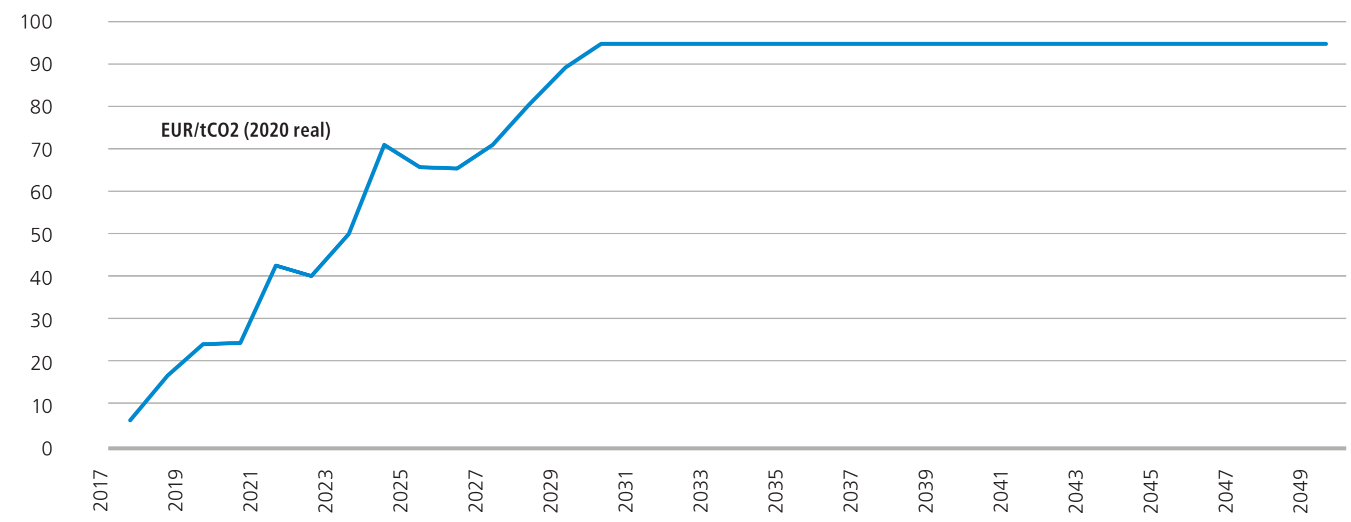


With an expected increase in gas prices, hydrogen production based on steam reforming is expected to become more expensive in the next decade. By 2050, on the other hand, it is expected that the production of blue hydrogen will fall again somewhat due to efficiency gains in CCS processes (CCS – carbon capture and storage), but will remain above the current level.

Effect 2: EU emissions trading

In the course of the EU's Green Deal, climate targets were significantly increased. To achieve these goals, the „Fit for 55" package was presented, which includes a comprehensive reform of emissions trading. Among other things, the supply of certificates is to be reduced linearly to the emissions target (– 55 %) by 2030. This will have a significant impact on prices.

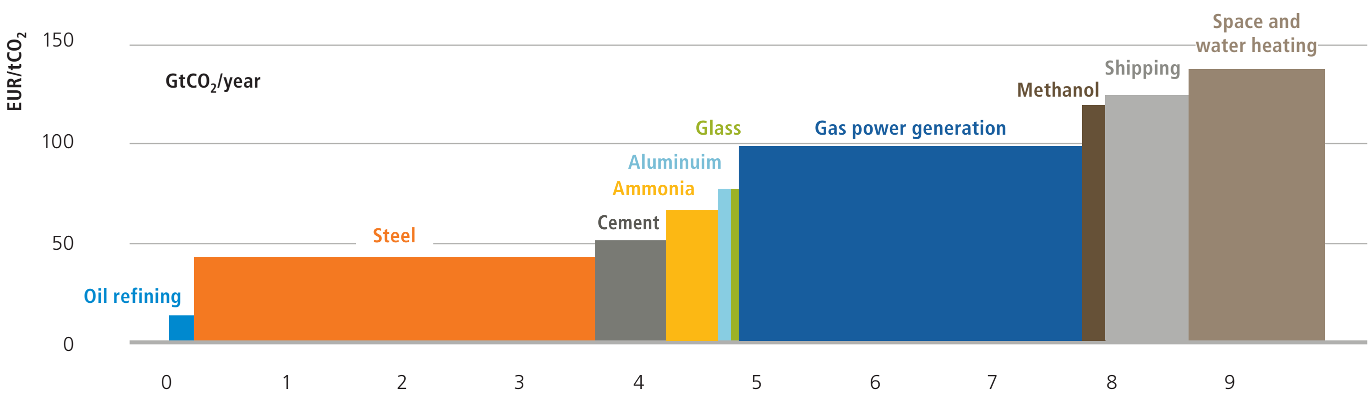
Forecast of the price development of EU emission allowances[5]



[4] *BNEF (2021)*
[5] *BNEF (2021)*

The already proven functionality of this instrument, which paved the way for renewable energies in the energy sector, will be extended to other sectors under the new regulations. In the course of this, competitive changes can be expected in the respective dependence of the price development.

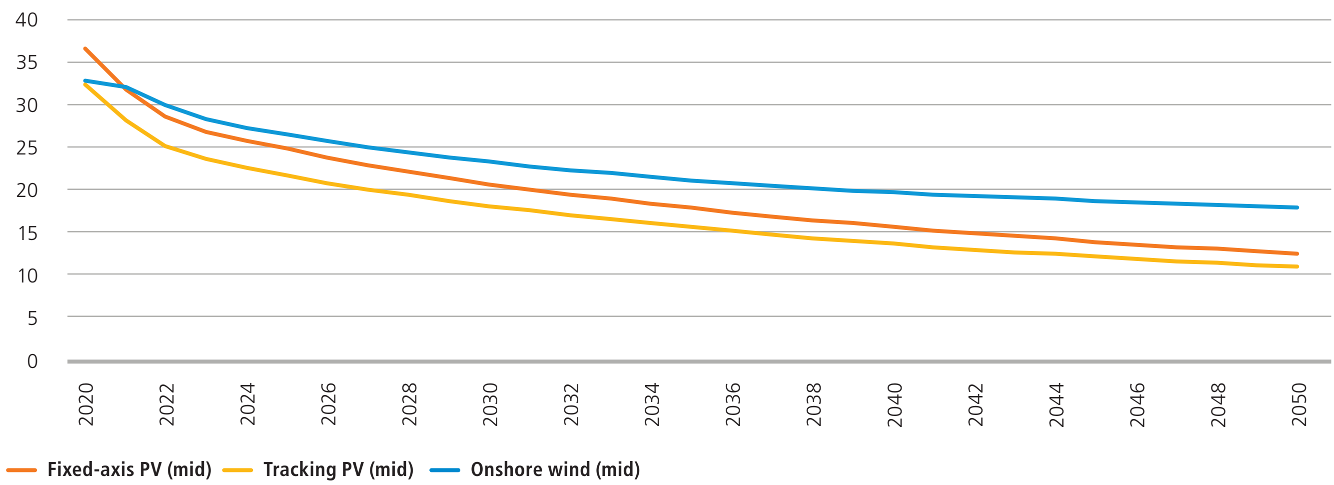
Economic viability of green hydrogen compared to conventional methods and associated fuels as a function of the carbon price[6]



In particular, oil refineries that use hydrogen to desulphurise fuels, but also the replacement of coal in steel production will be among the first applications in which the use of green hydrogen is economical, depending on the emission price.

Effect 3: Production costs of renewable energies continue to fall
After considerable price reductions in recent years, the increase in efficiency in the renewable energy sector continues.

Total costs (LCoEs) of renewable energies Spain[7]



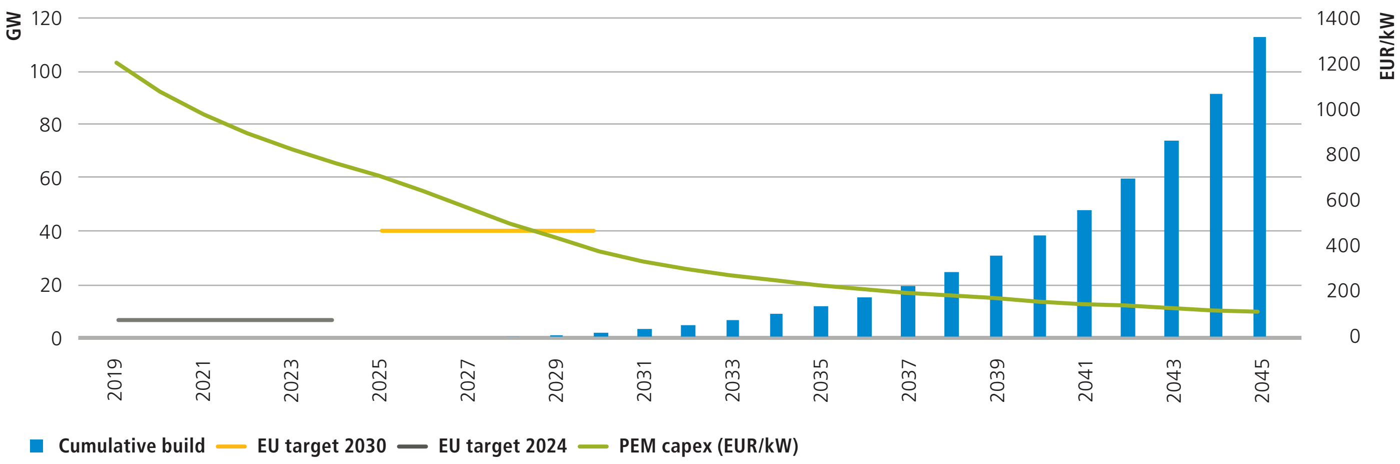
[6] *BNEF (2021)*
[7] *BNEF (2021)*

In Spain, which has the lowest LCoEs in a European comparison due to extremely positive climatic conditions, prices are expected to fall by 66 % in the solar sector and 45 % in the wind sector by 2050. This development is particularly due to efficiency improvements, as the underlying return on equity for solar PV in Spain only marginally decreases.[8] In this context, however, it must be added that electricity prices do not necessarily follow the electricity production costs of solar. In Southern Europe in particular, electricity prices, as well as the average prices of long-term purchase contracts, are higher than today's LCOE because fossil-fuel power plants are the price-setters in the market.

Effect 4: Learning curve and economies of scale for electrolysers[9]
Effect 4 is – also with reference to the baseline scenario, which was dominated by the high CAPEX costs – the decisive one. Although the EU is currently the global leader in terms of electrolysis capacities, these are still at a very low level.

However, with the increase in global ambitions, the expansion will accelerate significantly. In this context, learning effects and economies of scale will have a massive impact and drastically change the initial situation.

Learning curve as a function of the predicted expansion[10]



The figure above illustrates the potential of an increasing expansion of electrolysis capacities. Contrary to the forecast of Bloomberg New Energy Finance regarding the expansion, the announced ambitions of the EU are significantly higher. Should production capacities be expanded to this extent, even a faster cost degression can be expected. In addition to learning curves and expected economies of scale, technological innovations continue to offer high potential to increase efficiency and consequently reduce costs. One example of this development potential is this year's research achievement in the field of water electrolysis, which was awarded by Aquila Capital and an independent panel of experts.

[8] BNEF (2021)
[9] BNEF (2021)
[10] BNEF (2021); EU Commission (2021)

Aquila Capital Transformation Award 2021

The second Aquila Capital Transformation Award in 2021 went to Dr Ning Yan, Assistant Professor at the Van't Hoff Institute for Molecular Sciences at the University of Amsterdam. A distinguished jury awarded the lead author for the research paper "A membrane-free flow electrolyser operating at high current density using earth abundant catalysts for water splitting". The annual prize supports research initiatives to mitigate climate change and is endowed with 20,000 euros.

The jury found that Ning Yan and his team demonstrate a promising and innovative way to produce green hydrogen, which will play an important role in our future energy system, more cost-efficiently and on an industrial scale. Central to the new innovative and energy-saving process of water electrolysis for the production of pure hydrogen is the combination of the advantages of different electrolyser concepts. In particular, the use of a membrane-free solution in a novel cyclic process offers potential to significantly improve economic efficiency.

Effect 5: The fluctuating production of renewable energies will lead to more grid-related curtailments in the course of the expansion

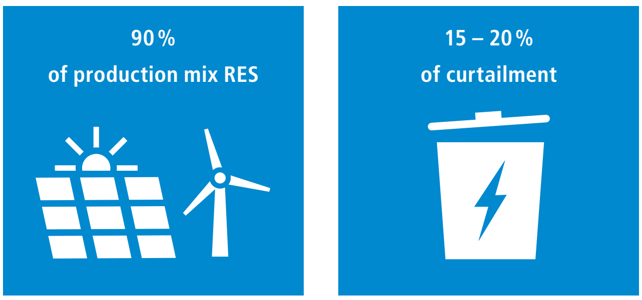
In order to keep the electricity grids stable, a balance between production and consumption is necessary. However, since renewable energies have a low scalability depending on the weather, they must be shut down, i. e. taken off the grid, in hours when high production does not match consumption to stabilise the grids. In Germany, a total of more than 6,400 GWh was shut down in 2019. This corresponds to a share of 2.8 % of all renewable electricity this year. Around EUR 710 million was paid to operators as compensation for electricity that was never produced. With an increase in the share of renewable energies, these curtailments will increase as expected.

Outlook

a) Baseline scenario Germany 2030

Based on the baseline scenario for Germany, the effects described, i.e. reduced CAPEX (–69 %), emission prices (+0.95 EUR/kg for grey hydrogen) and the increase in the price of hydrogen alternatives are included in the calculation. All other parameters, i. e. electricity prices in 2019, 100 % equity and return on equity of 6 % – remain unchanged.

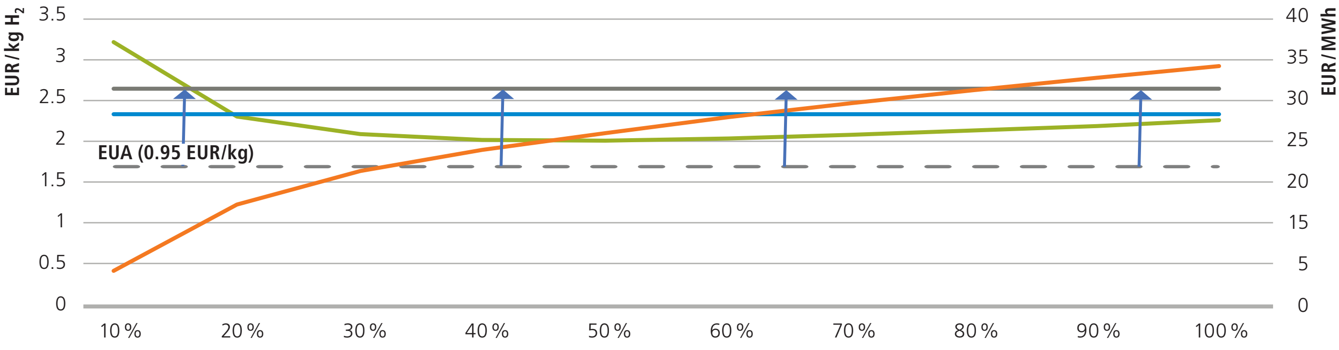
Forecast of the amount of regulated electricity with a 90 % share of renewable energies in the electricity mix[11]



Only storage solutions and sector coupling can dampen these effects. If this electricity were to be used at „zero cost" for the production of green hydrogen, on the one hand an emission-neutral alternative would be created for other sectors and, on top of that, the proceeds would directly reduce the compensation payments. From this dependency, government support for hydrogen production would represent an investment that shows a path to emissions neutrality whilst reducing the need for subsidies elsewhere. This case could mark a starting point from which a parallel expansion of renewable energies and the hydrogen economy can be designed in an economically sensible and climate-politically valuable way.

[11] *Goldman Sachs (2021)*

Baseline scenario in 2030 [12]

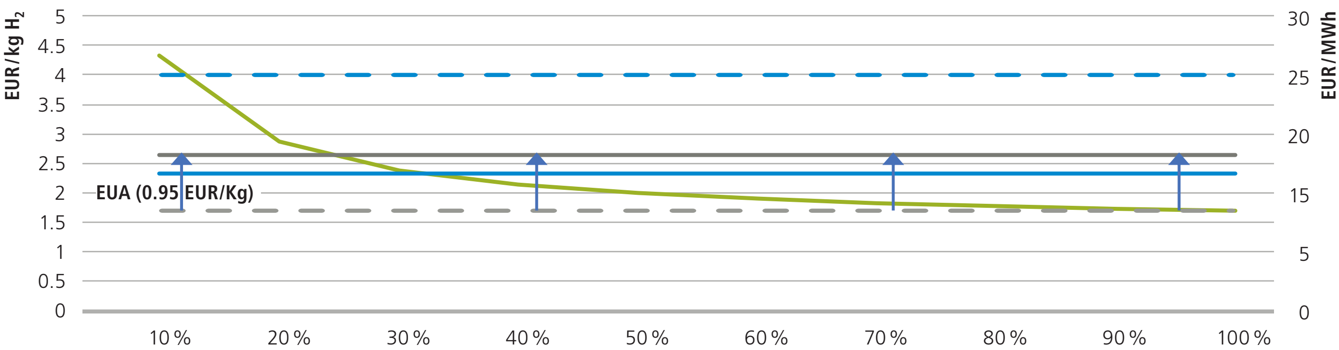


The figure illustrates how the effects work. Due to the reduced CAPEX, the prices for energy become much more important. The desired flexibilisation of the supply of renewable energy can thus be managed cost-efficiently even with lower utilisation of the electrolyser. Even at a capacity utilisation of 20 % – which can be roughly achieved with renewable energies – the comparative mark of blue hydrogen is undercut. Taking emissions trading into account, this also applies in competition with grey hydrogen. At a minimum cost utilisation of 50 %, the LCoHs correspond to almost 2 EUR/kg and are thus significantly below the alternative of grey hydrogen.

b) Hydrogen production Spain 2030

In this case – compared to scenario a (baseline scenario Germany 2030) – the electricity costs from 2019 are replaced by the projected LCoEs for solar PV plants in Spain. All other parameters remain at the same level as in scenario a) for Germany 2030.

Scenario Spain 2030 [13]



In contrast to scenario a), it becomes clear that competitiveness is only achieved from a utilisation rate of around 30 %. This follows from the fact that electricity costs are considered constant and the utilisation of favourable hours, as in the case of Germany, is not given. The favourable production costs in Spain, even if only theoretical, nevertheless give an indication of the potential in southern Europe. Here, too, the volatility of electricity prices will stand out in the future and significantly improve competitiveness.

Taking into account the effects described above and based on the forecasts of Bloomberg New Energy Finance, the competitiveness of green hydrogen compared to grey hydrogen will be achieved in Spain – under constant electricity prices – as early as 2026. It should be noted, however, that such an ideal-typical development from a hydrogen perspective does not correspond to reality. On the one hand, the actual electricity costs, especially in Spain, are already significantly higher than the electricity production costs for wind and

[12] Aquila Capital Research (2021)
[13] Aquila Capital Research (2021); LCoE based on BNEF (2021)

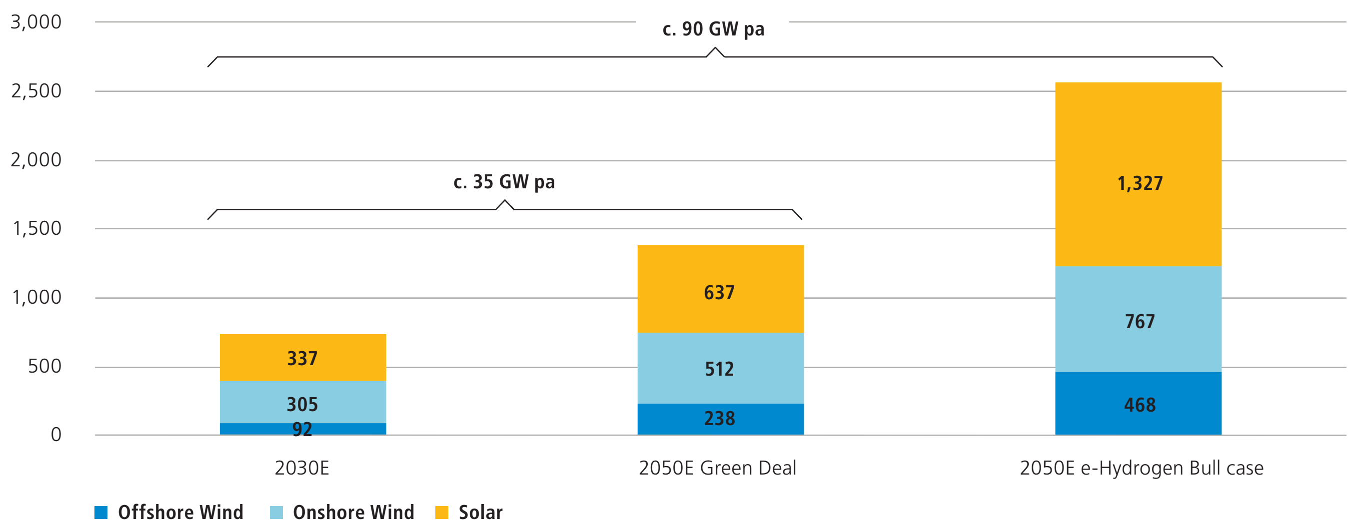
solar PV. On the other hand, in addition to other effects, the dynamically growing demand for electricity and the securing of the base load by gas-fired power plants will give electricity prices a further boost.

It remains to be said that the competitive production of green hydrogen is limited in the medium term by the high energy demand and the resulting costs. Political decision-makers are thus caught between the conflicting demands of supporting the development of electrolysers in order to benefit from economies of scale and limiting the burden of energy prices. Conflicts of interest arise from high electricity prices, which offer incentives to accelerate the expansion of renewable capacities, and the development of a hydrogen economy. Solutions can be found through subsidies in the hydrogen sector, which reduce demand elsewhere and provide stable framework conditions for producers of renewable electricity. Only the parallel development can make the efficiency and functionality of the energy supply systems a sustainable success.

Conclusion

From 2030 onwards, green hydrogen is expected to become competitive with the green and blue hydrogen alternatives based on fossil fuels. On the road to net zero, hydrogen can be the missing green molecule that enables the decarbonisation of non-electrifiable sectors and at the same time increases the integration of renewable energies and significantly improves the efficiency of the electricity market. But the energy demand requires a huge acceleration of renewable energy development, with the price of electricity becoming the key determinant on both sides.

Energy demand [14]

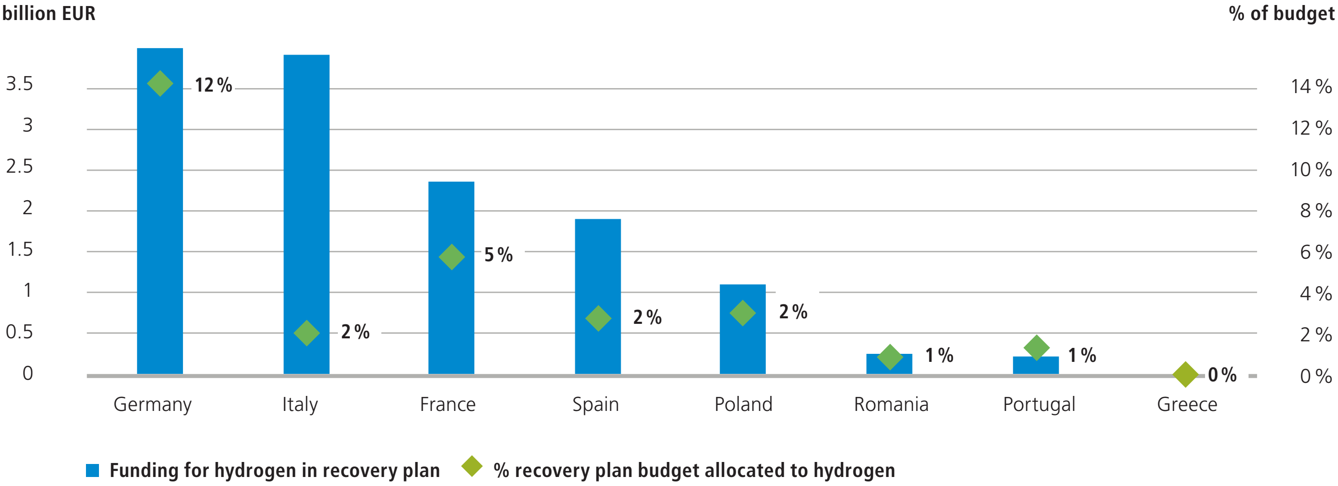


The figure above illustrates the enormous demand for generation capacity, which is largely shaped by the hydrogen demand of industry, for which hydrogen offers technological alternatives. For example, the German chemical industry estimates that an emissions-neutral reorganisation of the sector would require additional generation capacity to that currently available in Germany. The IEA further estimates that converting the Swedish steel sector to hydrogen would amount to about 45 % of current electricity consumption.

Analogous to renewable technologies, whose competitiveness was also based on initial elementary subsidies, there are opportunities to set appropriate incentives, which in turn result in synergies with the restructuring of energy systems.

[14] *Goldman Sachs (2021)*

Shares of the EU economic stimulus package directed at the hydrogen sector [15]



Within the EU, opportunities have been strengthened. Through the stimulus package and set „green quotas" for its use, there is financial scope in an increasing number of member states to support the development of a hydrogen economy.

In this context, competitive hydrogen could represent a tipping point in the energy transition. By reducing CAPEX through government subsidies but also through access to cheap debt capital, the required capacity utilisation can be reduced, as shown in the scenarios. As a result, a flexible reaction to existing supply prices would be possible. In this way, excess supply could be used economically and in this way stabilise the balance of the energy systems.

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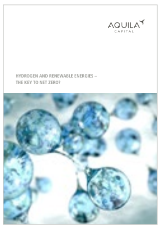

[15] *BNEF (2021)*

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