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Hydrogen and synthetic fuels
more than theoretical alternatives?

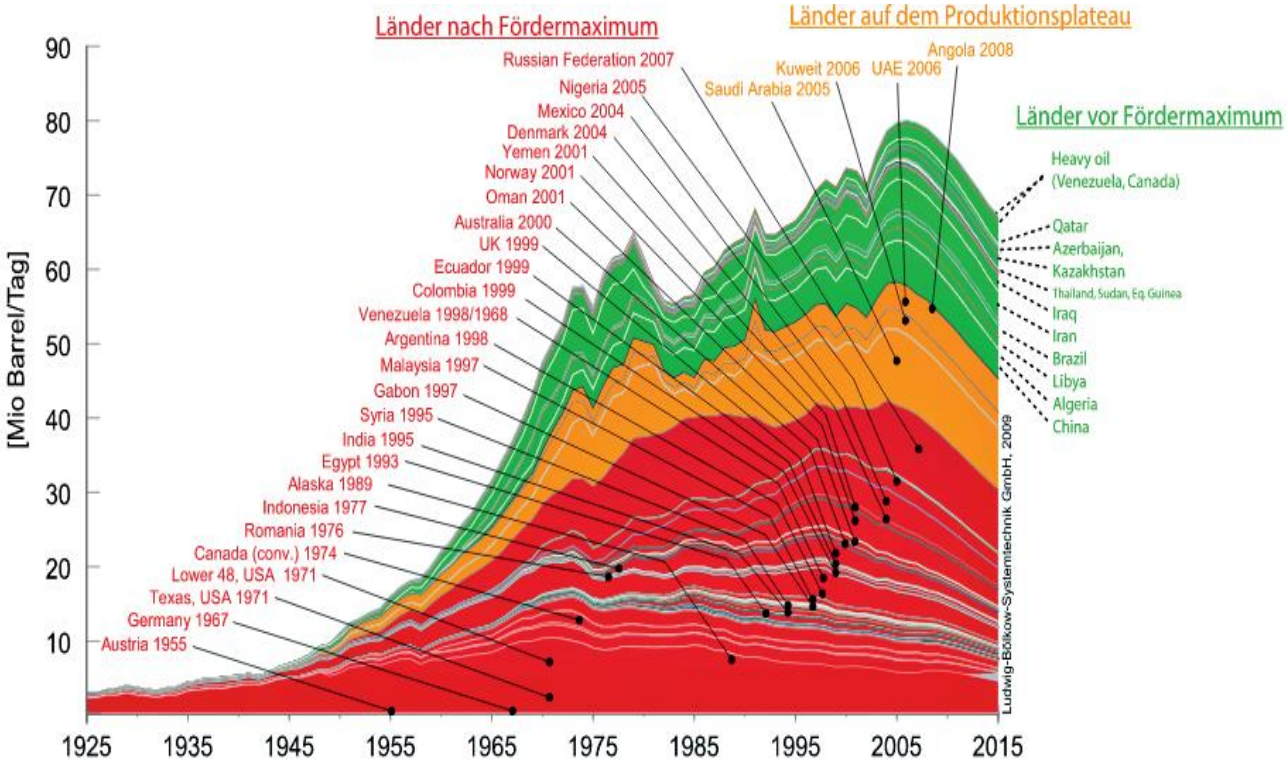
This work is an attempt to summarise the main contents of a large number of sources on this subject. The sources used are referred to in brackets. The sources are listed in the appendix in the order of their use. The Graphs come from German sources and unfortunately could not be translated.

Introduction

Gradually, there is a growing realisation that in the next 20 to 30 years decisive things will have to happen to slow down global warming. It is also becoming clear that if no action is taken during this period, certain tipping points will be exceeded and developments will become irreversible. To put it crudely: if decisive steps to curb global warming do not take place by 2050, things will become uncomfortable on Earth towards the end of this century. More and more people are also becoming aware that this is not a theoretical, distant date, but that the children who are now in kindergarten will still be alive then. (0)

It is undisputed that global warming can only be slowed down if greenhouse gas emissions are massively curbed. This includes, indispensably, phasing out the burning of fossil fuels. This environmental policy approach to phasing out coal, oil and natural gas is also supported by the fact that stocks of these energy sources are dwindling, their extraction becoming more expensive and therefore uneconomic, and one day even more so due to increasing scarcity. This development cannot be prevented even by new discoveries. So there are also economic aspects in favour of developing alternatives.

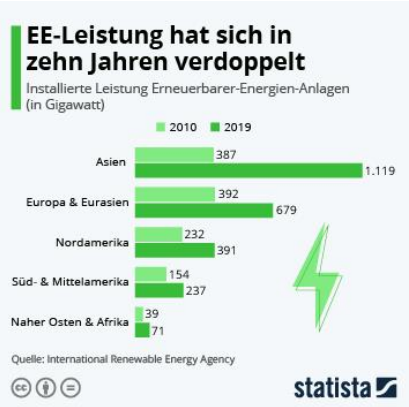
As the following graph shows, the maximum of world production of "cheap" oil was exceeded around 2005.

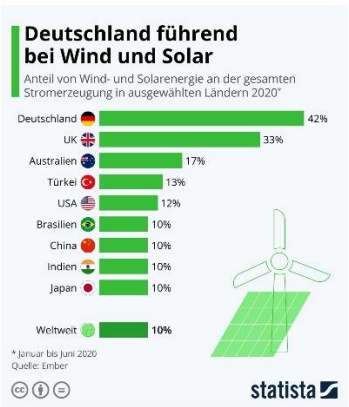


It is therefore essential to develop and make use of alternative forms of energy. This applies in particular to solar energy. With the exception of tidal energy and geothermal energy, renewable energy sources are more or less direct effects or consequences of solar energy. The solar energy radiating onto the earth is 15,000 times the current energy consumption. It is therefore a question of developing techniques to compensate for the disadvantages of solar renewable forms of energy. Namely that they are discontinuous and have a lower efficiency than the chemical energy conversion of fossil fuels.

In this case of renewable forms of energy, the focus is on hydropower, wind energy and direct solar energy. All this energy sources are used to generate electricity. With the exception of hydroelectric power, however, these forms of energy are not available on a continous basis, which means that electricity generation can only be adapted to electricity demand to a very limited extent. This raises the problem of power storage. Electricity can be stored directly in batteries, accumulators and capacitors. The storage quantities are relatively limited. Indirectly electricity can also be stored in pumped storage power plants or in various pressure chamber systems. Although larger quantities are possible here, these are technically complex, capital-intensive and sometimes very space-intensive processes. (1)

It is unmistakable that the development in the energy sector is moving towards more alternative energies, even if there is justified criticism that this development should be faster. The following graphs are show this. They also show that this development is a global one, albeit with different speeds across the continents and regions. (2)





With this development towards significantly more electricity from wind and solar energy, hydrogen is becoming increasingly important as an energy storage and energy carrier.

Hydrogen

Hydrogen has the advantages that it is available on earth in almost unlimited quantities, that it is very light and has a very high energy density. However, it has the disadvantage that it is only available in bound form, i.e. it has to be released from this bond in order to be used. It cannot be exreacted, but must be produced. (3) This naturally entails costs and puts hydrogen in a competitive situation with other energy sources.

The first question to be adressed is therefore what emphasis should be placed on the development of hydrogen as the energy carrier of the future..

The current Austrian Federal Government has set out in its programme, the goal of making Austria the world's No. 1 hydrogen nation. This may be an exaggeration by the government of a small state, but it does show that the Austrian government wants to push ahead with research and development of the hydrogen economy. The Federal Republic of Germany recently presented its national hydrogen strategy. In stategy assigns, hydrogen a central role in the further development and completion of the energy system transformation. (4) Recent news indicate that the Netherlands intends to make a major start in the devevopment of offshore wind farms and the production of green hydrogen. (5) Japan was the first industrialised country in the world to present a national hydrogen strategy several years ago. At the Olympic Games it is to be demonstrated how far this has alredy gotten. (6) The same applies to the entire Asian region as for Japan. In Australia, too, a massive shift towards alternative electricity and green hydrogen is underway. Although not by the government, which is currently still holding on to coal, but driven by entrepreneurs. (7) There is also news from China and Arab countries that they want to turn increasingly to hydrogen. Associations of states and companies with the aim of advancing the hydrogen economy, such as the Hydrogen Council, should also not be underestimated either. (8)

The development of the hydrogen economy is clearly and undeniably gaining in intensity. This is to be welcomed because it has the potential to reduce the use of fossil fuels and thus to cut CO_2 emissions. But hydrogen is already being used to a certain extent.

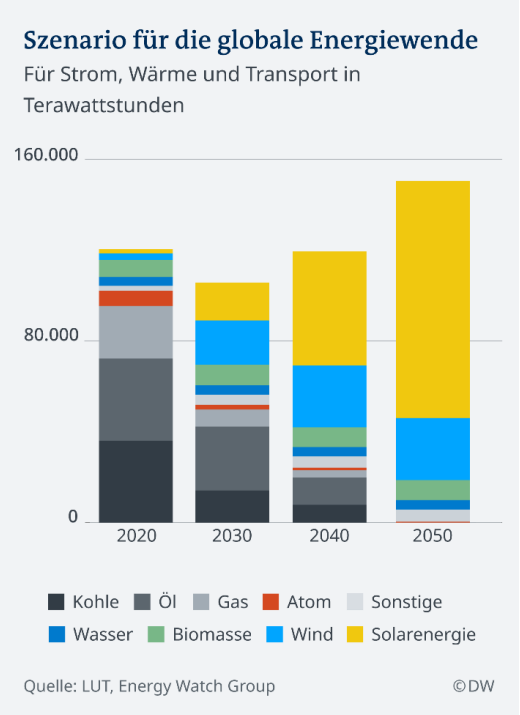
Hydrogen is an important basic material for the synthesis of chemical compounds and for Reduction reactions in metallurgy. From the point of view of the energy industry, hydrogen is a secondary energy source which today is produced almost exclusively from fossil raw materials. Worldwide, the current annual consumption of hydrogen is estimated at 500 billion Nm^3/a, which at 5,400 PJ/a is a negligible contribution from an energetic point of view. Almost half of these are in turn used directly for energy generation, mostly in contaminated form as a waste product of chemical processes. About half of the hydrogen produced in Germany (approx. 19 billion Nm^3 a) is produced from natural gas and naphtha. The other half is a by-product in refineries, where it is largely used for hydrogenation. A small proportion (approx. 2%) is a by-product of chlor-alkali electrolysis. (9)

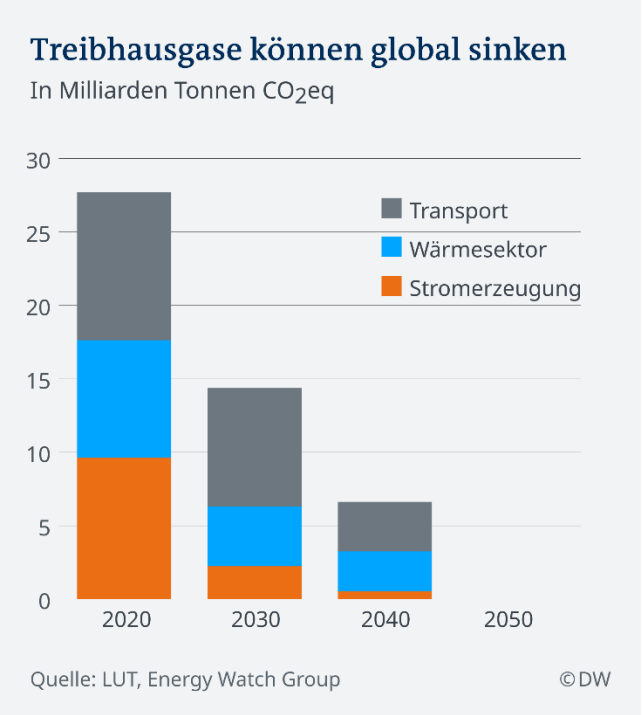
As indicated above, hydrogen can be generated in different ways. Here we distinguish between grey, blue and green hydrogen. Grey hydrogen is produced from fossil fuels, mainly natural gas. Blue hydrogen is also obtained from fossil fuels or biogas. The difference to grey hydrogen is that in the case of blue hydrogen, the CO2 produced during steam reforming is not released into the atmosphere, but is separated and stored permanently or used industrially. Green hydrogen is produced by electrolysis. This separation of water into its components hydrogen and oxygen means that only electricity from renewable energy sources can be used. (10)

Green hydrogen

It is clear that a sustainable hydrogen economy can be based exclusively on green hydrogen. The commitment of an increasing number of governments, including the EU bodies (11), to implementing the Paris Climate Convention and the implementation of CO_2 pricing schemes are making alternative energies more competitive and giving them a boost. This means that more and more companies see a new, profitable business area emerging here and driving development forward, such as the German energy group RWE (12), among others. The result is a self-accelerating process of research and development which not only improves existing products and methods, but also produces new, even more effective ones. In the long term this will also optimise the costs of alternative forms of energy.

The following graph also shows a forecast of the development of the distribution of energy sources in the coming decades. This could also lead to a corresponding reduction in CO_2 emissions. (13)





Engines powered by liquid fuels will in future face competition from hybrid or purely electric drives that draw electricity from renewable sources. The fluctuating renewable energy can be stored in batteries or as electrolytically produced hydrogen. The hydrogen produced in this way can be used directly in hydrogen vehicles or coupled into the production of liquid fuels, for example to hydrogenate petroleum components in the refinery. Hydrogen can also be combined with carbon monoxide or carbon dioxide produce synthetic hydrocarbons, methane or other energy sources. (14) Hydrogen is a key technology of the energy transition and opens up export potential, especially for Germany. With costs continuing to fall due to economies of scale, hydrogen technology will make a significant contribution to economic performance. All in all, it is optimistic that funding programs are being set up worldwide and that, within the framework of climate protection, work is being done to develop the economic use of hydrogen technology. It is also optimistic that important parts of this value chain will gradually be transferred from the laboratory to industrial production. (15)

Due to the steadily increasing production of electricity from the discontinuous forms of energy wind and sun, long-term storage of electricity using hydrogen and methane is becoming increasingly important. Therefore an enormous development is underway in this field. Hydrogen and methane are highly regarded as energy stores for electrical energy. In principle, these gases can be easily extracted from water using electrical energy. With the extraction, electrical energy is transformed into chemical energy. As hydrogen or in the form or methane, energy can also be stored in the long term. Storage options are of decisive relevance for energy transformation, because solar, wind, wave or tidal energy are so-called supply-dependent forms of energy. (16)

Intensive research is being carried out in the field of hydrogen production, but also on how to increase the efficiency of photovoltaics by increasing the efficiency of photovoltaic cells. Numerous projects are under way and are producing promising interim results.

The Leibniz Institute for Plasma Research and Technology (INP) in Greifswald is working together with the Institute for Networked Energy Systems of the German Aerospace Centre (DLR) in Oldenburg as part of the 3DnanoMe 2.0 project to optimize the technology of fuel cells. Within three years, a process which ensures increased efficiency of electro catalytic layers on gas diffusion electrodes is to be scaled and validated with the aim of transferring the technology into practice. In a

preliminary project, researchers at the INP have developed a plasma-based process that has since been patented, with which electro catalytic layers with high activities and high stability can be produced. By lowering the activation barrier, these catalytic layers increase the speed of chemical reactions and, when used in gas diffusion electrodes or membrane-electrode assemblies, can be used as common products for electrochemical systems such as fuel cells and electrolysers. (17)

Researchers from the Karlsruhe Institute of Technology and Taiwanese colleagues from the National Dong Hwa University, have been able to show (study) how energy-rich hydrogen can be produced directly with the help of low-energy infrared light, which represents almost 50 percent of sunlight, without great technical effort and power consumption. The scientists from the Karlsruhe Institute of Technology have succeeded in consistently exploiting the synergies between electrolysis and methanisation for the first time. The natural gas substitute generated in the HELMETH project ultimately always contained hydrogen concentrations less than 2 percent by volume and would thus be capable of being fed into the entire German natural gas network without restrictions. (16)

The further development of solar power generation is also important for the production of more and cheaper hydrogen. Here, one of the German Fraunhofer research institutes seems to have succeeded in taking decisive a step. The development of a III-V / Si tandem solar cell grown directly on silicon with an efficiency of 25.9 percent. (18)

But science is also active in the production of hydrogen using completely new methods. For example, a possibility is said to have been found to produce hydrogen from salt water and even polluted water by means of a 3-layer film. (19) One of the obstacles to the economical production of hydrogen in electrolysers is the use of expensive and sometimes toxic precious metals for the electrodes. Researchers from Linz are working on the development of a method for producing hydrogen that does not use precious metals as catalysts. The role of the metal is played by a polymer based on dopamine, a substance that acts as a messenger in the nervous system, which is not only non-toxic but also cheap. (20) But research is also underway in the USA to develop cheaper ways of producing hydrogen. Researchers at Washington State University have found a way to produce hydrogen more efficiently from water: from cheap nickel and iron, researchers developed a very simple method of producing large quantities of a high-quality catalyst within five minutes. This can then be used for hydrolysis to separate hydrogen from water. (21)

Researchers at the Polytechnic University of Lausanne are on the trail of a completely new method of producing hydrogen. They believe that hydrogen can be produced in a fare more environmentally friendly and resource-saving way if only solar energy is used to split water. The researchers led by Michael Graetzel - the inventor of the dye solar cell - have opened a new way to do this. They use two solar cells connected in series as a power source, which consist of the mineral perovskite (the Fraunhofer Institute also works with this - see 18). (22)

The German Aerospace Centre (DLR) together with international project partners presented the largest solar chemical plant for the production of hydrogen to date. In the Hydrosol Plant project, scientists and industrial companies have jointly developed the process of direct hydrogen production using solar radiation. (23) Prof. Rainer Tamme offers an overview of solar hydrogen production techniques. (24)

This foray into the world of hydrogen as an energy storage and energy carrier, as well as the research and development in this sector, should show that it is a very dynamic sector. Although some of the objectives may be very optimistic, it is clear that companies sometimes take a more long-term view than politicians. Indeed, a number of relevant companies have recognized that continued global warming and its consequences will also affect their business interests and that it is therefore better in the long term to take timely action to decarbonise and to develop offers for renewable energy supply and application. This development can be accelerated by appropriate political measures. Not only by

promoting research and development, but also steering measures to the detriment of fossil fuels, making them themselves and their use more expensive and the production and use of alternative forms of energy cheaper.

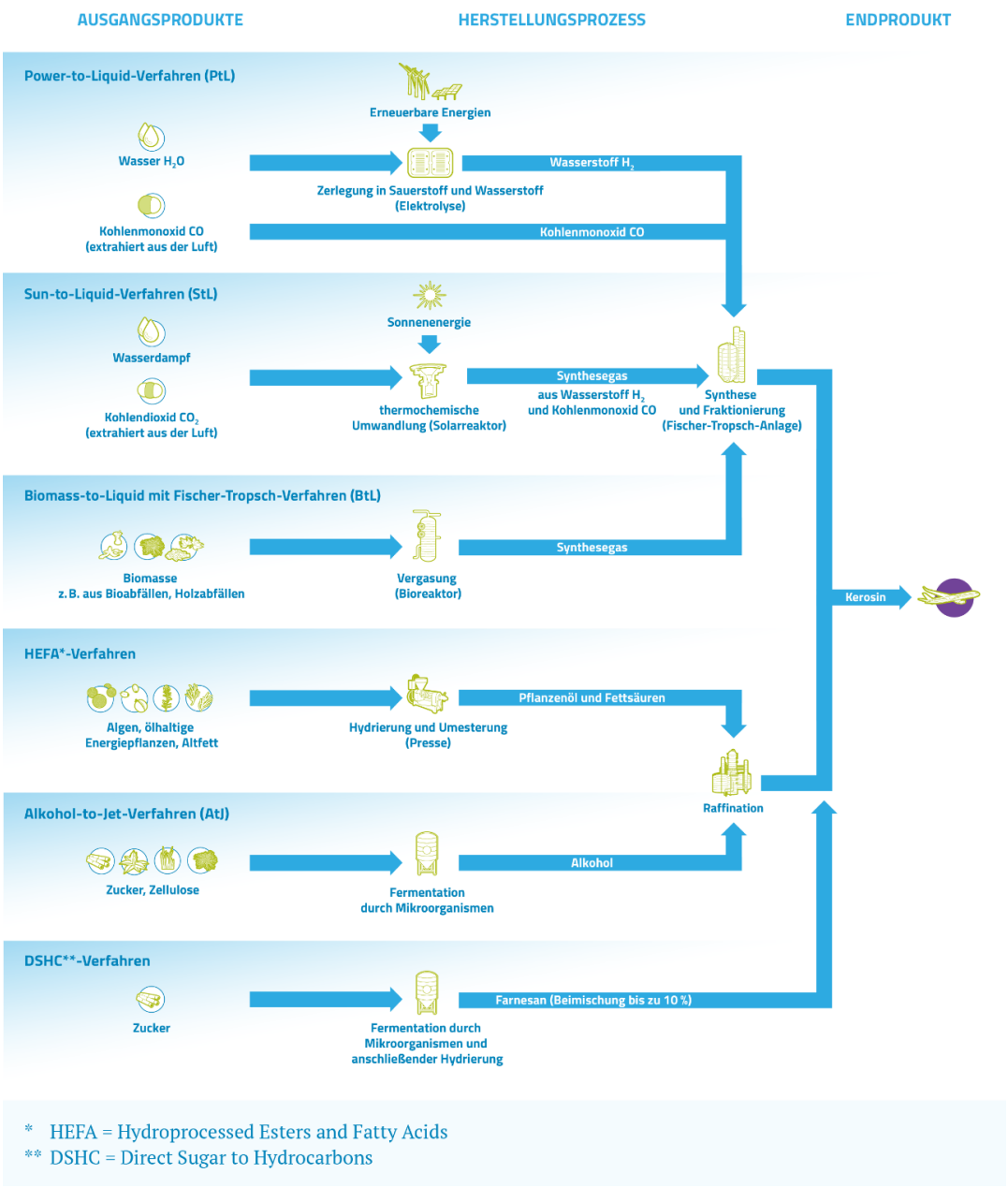
There is such a broad field for the application of hydrogen that the main problem will be to provide sufficient quantities of green hydrogen. (25) With regard to the use fuel cells, there is a heated debate under way as to whether it makes sense and is economical. (26) But here too, an enormous dynamic can be observed. It seems that for light vehicles, from the passenger cars downwards, the battery electric propulsion will prevail, for heavy vehicles, i.e. buses, trucks, trains without overhead lines and ships, the fuel cell has advantages. The direct use of hydrogen in combustion engines is also gaining in importance. (27) The fuel cell will also find its place in stationary applications. The fact that the fuel cell in vehicle propulsion is expected to have a future is also shown by the fact that a racing series with fuel cell powered vehicles is in preparation, which is scheduled to start in 2023. (28)

Hydrogen in the aviation industry

In aviation, hydrogen has only a limited direct application. (29) For large passenger planes, the batteries are too heavy for a battery electric drive. This is only conceivable for small aircraft, also supported by the ongoing development of more powerful batteries. Hydrogen and fuel cells are considered to be more feasible for medium-sized aircraft. However, research is also underway here. (30, 31, 32)

Synthetic kerosene

The use of synthetic paraffin will be necessary to promote decarbonisation in large aircraft. This is a liquid fuel produced by combining green hydrogen and CO_2 (from the air or industrial exhaust gases). When it is burned, the CO_2 contained is released again, but this is not an additional emission, but a cycle, because this CO_2 was taken from the air during the production of this synthetic paraffin. The methods that can be used to do this have been known for a long time. The following diagram shows these methods. (33)



However, as with all methods of alternative energy, it is also important here, as with all methods of alternative energy, to use the energies used or applied as efficiently as possible, i.e. with the highest possible degree of efficiency and consequently with the highest possible economic efficiency. (34)

It is therefore not surprising that intensive research and development is also being carried out here. At ETH Zurich, a system has been developed that uses solar energy, produces hydrogen, separates CO_2 from the air and combines it into synthetic fuel in one device. (35) Another way of producing hydrogen namely by means of artificial photosynthesis, is being researched by a team of researchers from the USA and the Federal Republic of Germany. (36)

The Institute for Combustion Technology of the German Aerospace Centre (DLR) has studied the combustion properties of synthetic paraffin and found that synthetic fuel is not only climate-friendly and meets the legally prescribed combustion properties, but also releases 30 to 100 times less soot precursors than conventional paraffin. This means that synthetic fuels can make a significant contribution not only to minimizing CO_2 emissions but also to minimizing pollutants in air traffic. (37, 38) The Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) has

developed a process which extracts the necessary raw material CO_2 more efficiently and cheaply than before directly from the air. (39)

Nature knows a method to produce carbon from the air using sunlight and CO_2. The plants do this by photosynthesis using the green plant pigment chlorophyll. However, this natural method has a very low efficiency. Only about 1% of the incident sunlight is used. Researchers are now trying to develop artificial photosynthesis with a higher degree efficiency using methods from bionics, the implementation of processes in nature using technical means. One of these experiments is underway at the University of Vienna. (40) A major step I this direction appears to have been successful in Marburg. (41)

The importance of synthetic paraffin is increasingly recognized and acknowledged. It is not only relevant NGOs, such as T&E in Brussels, that point this out and show how the introduction could be accelerated. (42) Airlines are also becoming active in this direction. The Lufthansa Group, for example, has concluded an agreement with ETH Zurich to promote the Synhelion system developed there (see 35). (43) British Airways are also moving in this direction. Alex Cruz, CEO of British Airways, has stated the development of a green jet fuel refinery on the South Humber Bank remains a priority. This leading figure in British aviation has underlined the commitment to a greener future for the industry and has supported the call for an acceleration of aviation investment. (44) The German Federal Ministry of Transport and Digital Development has also highlighted the importance of this development in a study. (45) The German Federal Ministry of Education and Research also points out the importance of synthetic fuels for the transformation of energy systems. (46) ADAC, the German automobile club, also sees synthetic fuels as a future and economically competitive energy source. (47)

Summary

Global warming and its consequences are an indisputable and increasingly undisputed scientific fact. It is also an indisputable and increasingly undisputed scientific fact that in order to limit global warming, the emission of greenhouse gases must be drastically reduced. CO_2 is a significant proportion of these greenhouse gases. In order to limit and minimize CO_2 emissions, it is essential to massively restrict the burning of fossil fuels in industry and transport. The Paris Climate Convention lays down a roadmap for this emission limitation. More and more governments, and most recently again the EU Commission, want to tighten and accelerate their measures to curb CO_2 emissions. To achieve this, the energy transition from fossil fuels to renewable energy sources must be accelerated. In this process, hydrogen is becoming increasingly important.

The above expedition through numerous sources on this topic does not claim to be exhaustive. Not all sources could be recorded, as new ones are constantly available. However, it clearly shows the trend. Hydrogen is on the way becoming an important and indispensable energy carrier. (48)

Some policy and research and development goals may also be ambitious and take some time to achieve. If research and development is carried out intensively and the necessary financial resources are available, the objectives will be achieved. A look at the history of technology provides this impressive proof of this.

Postscript:

The collection of material for this work was completed on 31 August 20. It is therefore no longer entirely up-to-date with regard to the sources available and used. Because every week new sources are available on this topic. The tendency shown in this thesis that hydrogen is at the beginning of a

development to an important energy storage and carrier material in the course of the climate and energy turnaround is confirmed by the new predominantly sources.

Attachment

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