DVGW
energie | wasser-praxis
kompakt

October 2022

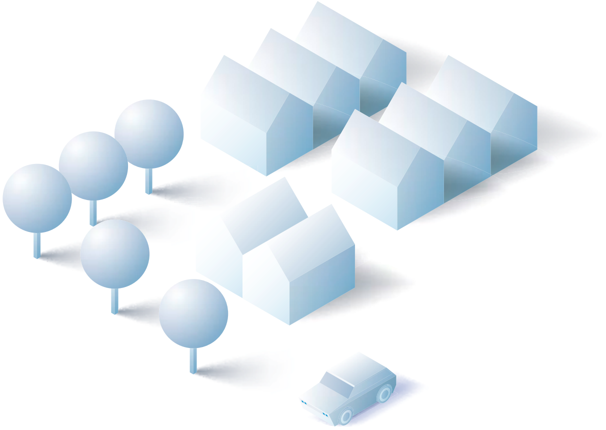
PYROLYSIS

Potential and possible applications of a climate-friendly hydrogen production

DVGW
Hydrogen Europe

PYROLYSIS

POTENTIAL AND POSSIBLE APPLICATIONS OF A CLIMATE-FRIENDLY HYDROGEN PRODUCTION



contents

legal notice

Published by:

DVGW Deutscher Verein des
Gas- und Wasserfaches e. V. –
Technisch-wissenschaftlicher Verein
Josef-Wirmer-Straße 1–3
53123 Bonn/Germany
Tel.: +49 228 9188-5
E-Mail: info@dvgw.de
Website: www.dvgw.de

Hydrogen Europe
Av. De la Toison d’Or 56/60
1060 Brussels/Belgium
E-Mail: secretariat@hydrogeneurope.eu
Website: www.hydrogeneurope.eu

Publishing house and distribution:
wvgw Wirtschafts- und Verlagsgesellschaft
Gas und Wasser mbH
Managing Director: Stephan Maul, M.A.
Josef-Wirmer-Straße 3
53123 Bonn/Germany
Tel.: +49 228 9191-40
E-Mail: info@wvgw.de
Website: www.wvgw.de

Editorial Director:
Prof. Dr Gerald Linke

Editors:
Marcel Pannes (resp.)
Martin Schramm
Tel.: +49 228 9191-451
E-Mail: pannes@wvgw.de

Contributors to this issue:
Dr Susanne Hinz (DVGW), Dr Maximilian Kuhn (Hydrogen Europe), Geoffrey Maddocks

Design:
Angela Goesele (wvgw)

Picture credits:
Page 7: iStock.com/venimo, iStock.com/shoo_arts, ivector – stock.adobe.com, venimo – stock.adobe.com

Printing:
Siebel Druck und Grafik,
ein Unternehmen der Limberg-Druck GmbH

Druckerzeugnis
www.natureOffice.com/DE-610-LY7KX14
klimaneutral
durch CO2-Ausgleich

FSC
www.fsc.org
MIX
Papier aus verantwortungsvollen Quellen
FSC® C017114

We must use all options!

An introduction to the perspectives for transforming the energy supply by **Prof. Dr Gerald Linke**, Chairman of the Board of DVGW e. V. and **Jorgo Chatzimarkakis**, CEO of Hydrogen Europe.


Source: DVGW


Source: Hydrogen Europe

Europe's energy supply is to become independent, diverse and climate-neutral - and that in just a few years. While the climate goals are to be achieved quickly in order to minimise the consequences of climate change, geopolitical risks due to dependence on energy imports from a few supply countries must be taken into account in parallel and the energy supply must be placed on a broad basis.

The resulting necessary restructuring of the energy system can only work if all relevant technologies and options are used that rapidly reduce greenhouse gas emissions - and at acceptable costs and risks.

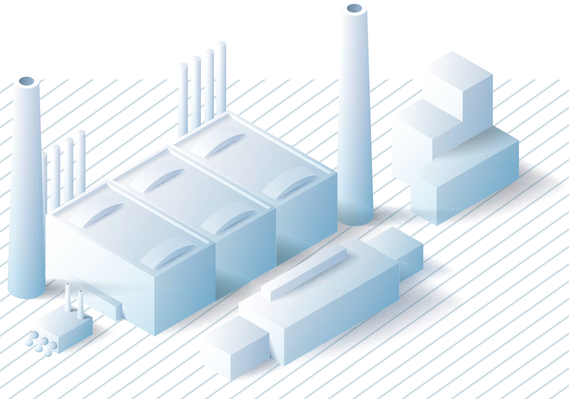
The expansion of renewable energies and the spread of electric solutions are complemented by the ramp-up of climate-friendly molecules: For this is the only way to replace the enormous amounts of energy that are still being generated from fossil raw materials today.

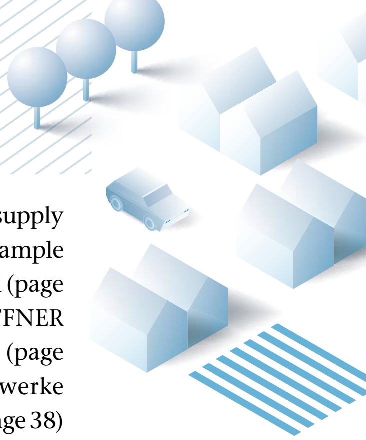
With hydrogen to a climate-neutral society

We should bear one thing in mind: the majority of final energy consumption in Europe is currently covered by molecules - i.e. natural gas, mineral oil or coal - and only one fifth by electricity, even though half of this is now renewable. This means that in the next two decades fossil fuels must be rapidly replaced by climate-friendly molecules. Gaseous energy sources are thus crucial for achieving climate neutrality and for a sustainably secured energy supply.

Hydrogen (H_2) in particular is an energy carrier that can pave the way to a climate-neutral society in all areas - in industrial processes, in mobility, in the centralised and decentralised heat supply of households and as a storage medium. Hydrogen is thus a fundamental building block of the energy transition: It not only burns emission-free, but can also be produced in various ways. Several processes are already available for this purpose, which, depending on the starting material and the type of energy used, leave only a very small or even a negative CO_2 footprint.

Currently, two methods of hydrogen production in particular are common: steam reforming and electrolysis. So-called grey hydrogen is obtained from fossil fuels such as crude oil or natural gas via steam reforming. The disadvantage of this process





is that the CO_2 produced in the process is released unhindered into the atmosphere. In contrast, blue hydrogen is also produced by steam reforming, but the CO_2 produced is directly captured and stored (Carbon Capture and Storage, CCS) and thus does not enter the atmosphere. Hydrogen produced via electrolysis is "green". Renewable electricity is used to split water (H_2O) into its components hydrogen (H_2) and oxygen (O).

Pyrolysis: promising technology for decarbonising energy supply

Another promising process is pyrolysis, the potential of which we examine in detail in this issue of ewp-kompakt. In the pyrolysis process, methane (CH_4) is separated directly into hydrogen and solid carbon at very high temperatures in the absence of oxygen - the latter is much easier to handle than the gaseous CO_2 produced in steam reforming. It can be used in its solid form in various production processes or safely deposited - an overview of the possibilities is provided in the article by Robert Obenaus-Emler on page 16 in this issue.

A special case is "super green" hydrogen. The pyrolysis of biomethane, biomass, waste or wastewater with subsequent storage of the solid carbon is a negative emission technology, since the carbon dioxide previously removed from the atmosphere and neutralised in the biomethane is not released again during the pyrolysis reaction and the use of the hydrogen produced, and thus no climate-damaging greenhouse gas effects are produced.

Ultimately, it should not be the colour that decides whether and which hydrogen is used. Rather, the technologies and processes should be used with which greenhouse gas emissions can be reduced most quickly and effectively. A look at the CO_2 footprint of the different energy sources helps here. In particular, turquoise hydrogen produced with the help of pyrolysis offers great opportunities, as its footprint is significantly smaller than that of natural gas or blue hydrogen. The Engler-Bunte Institute in Karlsruhe has conducted extensive research on this - you can read an excerpt of the results on page 12. The fact that pyrolysis technology is already in use today and can also contribute to decarbonising the energy supply in the future is also shown not only by the example of the Graforce company from a Berlin hotel (page 26), but also by the contributions from HAFFNER ENERGY, ConcordBlue, Plagazi and others (page 32). The future use of pyrolysis at Stadtwerke München (page 36) and Westnetz GmbH (page 38) also demonstrates its many uses and options.

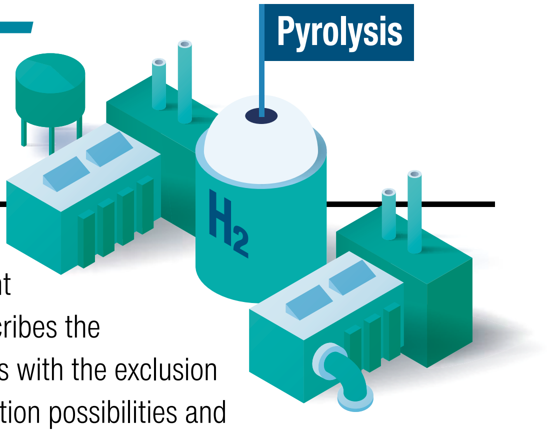
Carbon: an essential building block of the energy transition

Methane pyrolysis does not produce gaseous CO_2, but carbon (C) in solid form, which is the building block in various industries and can be deposited safely and emission-free for an indefinite period. The resulting carbon can be used as an important industrial raw material in the aluminium, steel or construction industries or as a graphite substitute for battery materials. For example, bipolar-plates for stacks are already showing improved efficiency today with this carbon and can thus locally increase work creation in Europe and contribute to a diversification of import dependency. Its potential applications in the agricultural sector (soil carbon) are also particularly interesting and promising. Introduced into the soil, the carbon serves as a water and nutrient reservoir and thus promotes plant growth and increased binding of CO_2 from the atmosphere (6-3 kg CO_2 per kg C). At the same time, the use of chemical fertilisers can be significantly reduced or completely avoided.

> » *In the next two decades we must replace fossil through climate-friendly molecules.* «

All the potentials outlined must now be used and binding framework conditions for this must be developed as quickly as possible. On the other hand, it would be counterproductive - also in the interest of consumers in Europe with regard to social compatibility and security of supply - to strive for a pure electrification of the energy sector. A massive reduction of gas applications in favour of electricity is technically illusory and economically misguided. The decarbonisation of the existing energy supply will only succeed through the prominent use of climate-neutral gases and with pyrolysis technology as a promising technology. ■

“Turquoise” hydrogen from pyrolysis – *what is it?*



The word “pyrolysis” is a combination of the ancient Greek words for fire “Pyr” and solution “Lysis”. It describes the thermochemical decomposition of organic compounds with the exclusion of oxygen. The technology offers a number of application possibilities and is also attractive in environmental and economic terms.

Climate protection is one of the central challenges of our times. As the emission of carbon dioxide in power generation, the heating of buildings, transport and industrial processes is a crucial factor in global warming, we need a comprehensive energy transition. This can be accomplished in two ways: fossil fuels can be replaced at least theoretically in their entirety by electric power – but it is not viable to electrify all areas. In such cases, hydrogen may be considered. Hydrogen can be used for the production of synthetic fuels for vehicles, it can generate electric power in fuel cells or it can heat our homes. The problem is that hydrogen is normally found as a constituent of compounds, especially organic compounds. To use hydrogen as a fuel, it must first be separated from these compounds by energy-intensive chemical processes. Various processes are available, including pyrolysis.

The word “pyrolysis” is a combination of the ancient Greek words for fire “Pyr” and solution “Lysis”. It describes the thermochemical decomposition of organic compounds with the exclusion of oxygen– this means, without combustion! To date, the best-known pyrolysis process has been methane pyrolysis, in which methane (CH_4), the main constituent of natural gas, is split into hydrogen (H_2) and solid carbon (C) in a high-temperature reactor. The advantage of this technology is that there are no emissions of the greenhouse gas CO_2 during the process. The solid carbon produced instead of carbon dioxide can be used in a wide variety of industrial applications. In addition, if biogas or biomethane is used for methane pyrolysis and CO_2 is taken from the atmosphere, the process even has a negative carbon balance.

The two products of methane pyrolysis – hydrogen and carbon – can be used in all sectors. There are already a wide range of possible applications for hydrogen produced by methane pyrolysis across all sectors of industry. The injection of the hydrogen into the gas network is conceivable; in this case, hydrogen could make a contribution to the decarbonisation of the heat energy market. In addition, hydrogen may be used at plants for the combined generation of heat and power; the heat generated can then be used in district heat systems. There are also possible applications in the mobility sector, where hydrogen may be used to power not only trains and ships but also road vehicles.

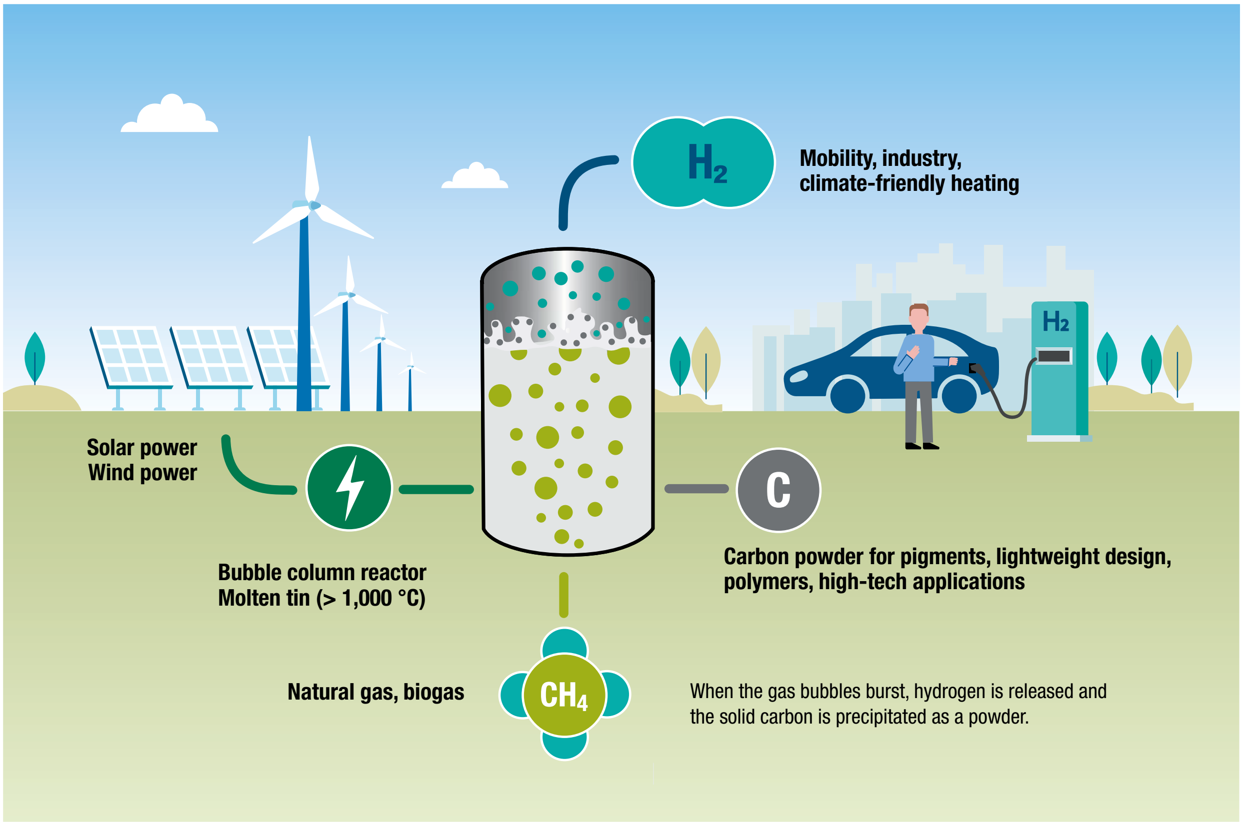
In the industrial sector, methane pyrolysis is doubly interesting. The climate-neutral hydrogen can play a key role in decarbonising CO_2-intensive areas such as steel or cement production. The sol-

id carbon, also known as graphite, may be used in steel making, in battery production or in the semiconductor and solar industry. There is also another positive side-effect: the (synthetic) carbon produced by methane pyrolysis may replace carbon from natural sources in the future, further reducing CO_2 emissions. Following further industrial process stages, graphene can also be produced from carbon nano tubes. Graphene is a relatively new material that features high strength and conductivity and is being used to an increasing extent for applications in the aerospace, automotive, wind power and construction industries.

Methane pyrolysis also combines a number of different advantages: for example, in contrast to “conventional” processes for the production of hydrogen from natural gas by steam reforming, pyrolysis does not cause any CO_2 emissions. In addition, pyrolysis is considerably more efficient than other processes, with a specific energy demand of 37.8 kJ/mol H_2 compared with 63.3 kJ/mol H_2 for steam reforming or 285.9 kJ/ mol H_2 for hydrogen production by electrolysis.

New: electron beam plasmalysis

Scientists from Munich University of Technology presented the process of electron beam plasmalysis in May 2021. This process allows hydrogen to be produced considerably more efficiently and in a more environmentally compatible way than with previous methane pyrolysis methods. The new feature is that the methane molecules are separated by accelerated electrons. The efficiency is therefore considerably higher than for any other pyrolysis process. Pyrolysis is also attractive from the economic point of view. With the hydrogen production costs currently predicted, there would be significant cost benefits of methane pyrolysis compared with electrolysis. ■



When the gas bubbles burst, hydrogen is released and the solid carbon is precipitated as a powder.

Source: wvgw mbH

»Nature's heir of residual energy«

by: **Stefan Petters** (Consulting Commitee Member of Green Transformation & Bio Economy Platform Lower Austria Business Agency EcoPlus)

Source: Carbotopia Web Page

You might think, oh, coal? But carbon came to Earth as a space fusion of three helium atoms. Therefore, what we find here either came directly from space, either as part of the Earth's core or through meteorite impact, or it is a secondary form of the transformation processes of an earthly creation. Such as water, which either evaporated from the magma of the Earth's core or melted from the ice of meteorites and formed in space from the abundant hydrogen to H_3O, with our planet's water atoms being up to twice as old as Earth's. Hence, neither water nor carbon are abundantly available on Earth and not fit for linear consummation.

It is also interesting to note that helium itself was formed from the orbital fusion of two hydrogen molecules at a time! So you could call hydrogen the grandmother of our binary biosphere of water and carbon!

On the other hand, given that these two elements of life originated in space, the general assumption that they are infinitely available or regenerable is false. However, both can be recycled by nature and should be kept in terrestrial closed cycles if used anthropogenically. This is because relying on delegating part of the recycling process to the atmosphere can change the conditions that precede what is being relied on.

Nature stores solar energy by building up compounds of carbon and water into so-called carbohydrates, which serve as the basis of the food chain for all living species. All residues eventually break down into gases made up of the same three atoms that make up carbohydrates: Carbon-Hydrogen-Oxygen, while the residual energy is taken over exclusively by methane [CH_4] - the purest and most stable natural hydrocarbon compound as a store of energy-charged hydrogen. While the energy-mass ratio is rebalanced by the formation of H_2O [water(vapour)], CO_2 manifests the conversion losses. Interestingly, nature does not store hydrogen itself, but either allows it to react with oxygen to form water, releasing energy, or carries out an exothermic 65 % efficient equilibrium reaction with CO_2 to form methane, with the 35 % energy losses being balanced by reaction water formation. This also occurs with anthropogenic hydrogen negligently escaping into the atmosphere, which exacerbates greenhouse gas effects. The heat of reaction drives the rise of water vapour and methane into the stratosphere, where the methane reacts with the oxygen atoms of stratospheric ozone, releasing heated CO_2 and hot water vapour. Due to their specific gravity, they must descend into the greenhouse gas layer formed from below and amplify the reflected Earth surface heat, resulting in a multiple effect of CO_2 and rising water vapour.

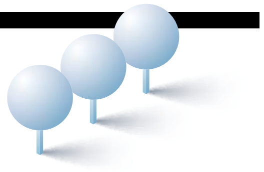
Methane is therefore neither negligible nor eradicable by human concepts. On the contrary, the proper use of methane can be the key to climate neutrality, provided it is used properly and in a controlled manner! Technology allows the dissociation of methane into pure crystalline carbon and hydrogen, recently standardised as turquoise. Regardless of nomenclature, hydrogen turns into water when it is discharged for energy. If this water is collected for reuse, methane can be regenerated along with the carbon derived from methane dissociation, provided energy is made available. More specifically, converting methane from the charged water of a hydrogen fuel cell into so-called green hydrogen is an effective way to convert volatile electricity into storable chemical energy.

Given the readiness of all the technologies required for the circular economy of carbon and water on the one hand, and the still lacking energy storage solutions for volatile electricity on the other, it is proposed to start managing carbon and water in terrestrial closed loops, given the existing infrastructure for storing and distributing methane gas from the natural gas sector. Where this is not possible, the so-called green hydrogen should be hedged by using desalinated seawater to ensure that the water vapour that precipitates over the oceans after use does not further deplete terrestrial water reserves.

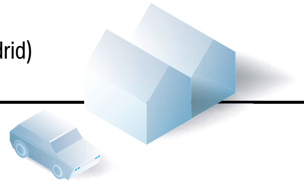
Hopefully, Europe will admit that any other form of enticement to turn water into a new fuel would be counterproductive to climate neutrality. Worse than anything now blamed for climate change is that soil erosion triggered by drought stress through CO_2 respiration irreversibly reduces the metabolic capacity of the biosphere to sequester atmospheric CO_2. ■

You can find a video about hydrogen produced from methane using the following QR code:

» The reaction that would **change** the world «



A conversation with **Prof. Alberto Abánades** (Universidad Politécnica de Madrid)



Source: private

Professor Abánades, what is the problem with the hydrogen economy vision?

Prof. Alberto Abánades: The hydrogen economy requires technologies to produce hydrogen on a large scale from any source available in nature, e.g., water or other hydrogenated molecules such as hydrocarbons. Currently available hydrogen production technologies are mainly fossil fuel reforming and gasification, complemented today by water electrolysis. Biomass fermentation and thermochemical cycles are on the way. In particular, methane steam reforming, naphtha/oil reforming and coal gasification are the main sources of hydrogen today due to their cost-effectiveness and technological maturity.

The challenge is to develop sustainable hydrogen production technologies. Such technologies should be fed from renewable energy sources such as solar, wind or biomass, without excluding nuclear energy. Hydrogen production from wind and solar energy will be done by water electrolysis. Direct thermal energy sources such as solar thermal can use thermochemical processes, either from water or from hydrocarbons as the main raw material. Biomass can be used in two ways in this context: as a feedstock for the production of syngas or biomethane for the production of hydrogen by thermo-chemical processes, or as an electricity generator for the production of hydrogen by electrolysis. In short, hydrogenated compounds will be the feedstock for hydrogen production, with decarbonised energy input to promote hydrogen synthesis and even products other than carbon materials.

Professor Abánades, according to your work, what role should pyrolysis play?

Abánades: The philosophy behind methane decarbonisation is that the carbon in the methane molecule is extracted before any other use. The result is a carbon cycle in which the carbon is reduced or retained without passing from the earth to the atmospheric cycle. In the case of methane decarbonisation through biomethane, the net carbon dioxide in the atmosphere can be negative or contribute to cycles containing CO_2, such as biodiesel production, without increasing the long-term carbon stock. This could be particularly important for the EU at a time when import-dependent oil and gas resources are becoming scarce, as it closes power-to-gas loops in the region.

What advantages do you see in pyrolysis compared to other technologies?

Abánades: From the theoretical analysis of these technologies, it appears that the production of 100 million toe (million tons of oil equivalent) of hydrogen through methane pyrolysis can produce 103.8 million toe of carbon, avoiding the production of 255.18 million toe of CO_2 in methane steam reforming (SMR) or 626.85 million toe of CO_2 compared to coal gasification. Furthermore, the density of supercritical CO_2 is 0.47 kg/m^3. Taking this value as a reference value for storage or sequestration in liquid form, it can be assumed that the production of 100 million toe of hydrogen by steam reforming in combination with CCS processes (carbon capture and sequestration) would produce a volume of CO_2, which would require a suitable storage system in the order of 0.54 billion m^3; in contrast to the 0.054 billion m^3 that would be needed to store carbon (density approx. 1.9 kg/m^3) from the methane pyrolysis process.

The difference in volume would be a factor of 10 resulting from the difference in density (approx. 4) and mass (2.47) between carbon and CO_2. In short, solid carbon is easier and cheaper to manage than carbon dioxide, because it is solid rather than gaseous, which simplifies the infrastructure requirements and of course solid handling is well known and understood.

But doesn't this process have to be powered by heat from natural gas?

Abánades: Certainly, that would be possible, but that would not be the path I recommend. Either by integrating renewable electricity if it is available, by recycling part of the hydrogen produced or by using solar methane splitting. At ETH Zurich, for example, Prof. Aldo Steinfeld has tested a 5 kW prototype solar reactor equipped with black carbon particles as a thermal absorber of solar radiation and a carbonaceous catalyst for the thermal cracking of methane. They reported a maximum methane-to-hydrogen conversion of 95 % with a residence time of less than two seconds, and an experimental solar energy-to-chemical energy conversion efficiency of 16 %.

But there are other examples in Europe. The Solhycarb project, launched by the European Commission, tested a 10 kW reactor. The methane decarbonisation process was tested in the temperature range of 1740-2070 K (1466-1796 °C), showing that as the temperature increases, methane conversion can be increased, and long residence times reduce the production of other hydrocarbons.

How do you see the integration of methane pyrolysis with electrolysis?

Abánades: Water electrolysis and hydrocarbon pyrolysis are complementary technologies, each with their own limitations and advantages. They have different feedstocks, so depending on the presence of water or hydrocarbons at the site, one of the two technologies is more viable than the other. Similar arguments can be made about the availability of energy and the flexibility of integrating different forms of energy. In the past, technologies such as solar thermal or photovoltaics were developed separately, and then hybrid integration was considered, even including wind energy. Now it is probably too early to assess how these technologies can be integrated, as they have yet to prove their mature performance, but I am sure they will do so in the future. One of the clear paths of energy development now is clearly hybridation and integration.

Ammonia is one of the main current applications of hydrogen. How do you see the roleof pyrolysis in this context?

Abánades: When pyrolysis is eventually developed for large-scale hydrogen production, it can play a very important role when integrated into processes for which hydrogen is a fundamental feedstock, such as ammonia production. The Haber-Bosch process, which converts hydrogen and nitrogen into ammonia, produces most of the ammonium fertilizer used in agriculture. This reaction is credited with feeding the population boom of the 20th century. It is so ubiquitous that it is a part of everyone: over 80 % of the nitrogen that enters the tissues of the average person is believed to be the result of the Haber-Bosch process.

Currently, over 95 % of hydrogen is produced by conventional fossil fuels, mainly by reforming natural gas with steam. Fertilizer industry produced equivalent to almost 2 % of total global GHG emissions. Resupplying the Haber-Bosch process with methane-cracked hydrogen could drastically reduce this carbon footprint.

How do you respond to the claim that pyrolysis has a low technology readiness level?

Abánades: There are several players working on this technology worldwide, with much of the know-how and expertise located in Europe. Very active developments are also taking place in the USA, in Canada and other countries. But we already see that there are market players with a TRL level of 8/9, such as Monolith Materials in the US. So the process is on its way to prove itself on an industrial scale. Now we need to invest to bring European start-ups from their TRL between 3 and 6 to the next levels to secure our competitive position. I hope that Europe will not lose its competitiveness in the development of this technology, which I am convinced will contribute to decarbonisation. ■

On assessing the greenhouse gas emissions of turquoise hydrogen: *it's the feedstock that counts!*

By: **Friedemann Mörs, Maximilian Heneka, Dr Frank Graf** (all: DVGW Research Unit at the Engler-Bunte Institute),
Miriam Bäuerle & Jörn Benthin (both: Gas- und Wärme-Institut Essen e. V.)

In order to assess the greenhouse gas reduction potential of turquoise hydrogen (H_2), it is necessary to consider the greenhouse gas emissions of the underlying value stream, i.e. also the so-called "upstream emissions". In this context, the upstream emissions are those created during the production, processing, transport, storage and distribution of natural gas and the supply of electric power.

Against this background, the DVGW research project "Roadmap Gas 2050" considered the supply of turquoise hydrogen with a capacity of 100,000 m^3/h in Germany. You will find a full description of the project data in [1]. However, not only the upstream emissions of the natural gas used have a decisive impact on the greenhouse gas emissions of turquoise hydrogen but also the upstream emissions of the electric power required for the pyrolysis process.

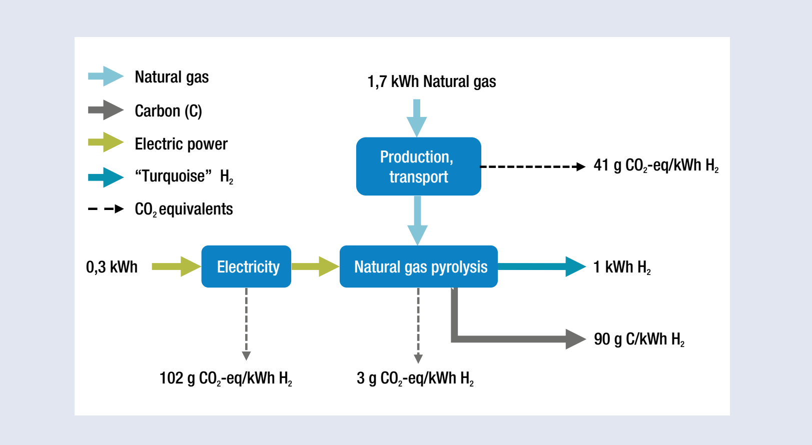
The direct emissions caused by the use of natural gas at the production plant must also be taken into account. In contrast, the greenhouse gas emissions created by the construction of the plant can be neglected as such plants are operated for long periods at high natural gas flow rates [2].

The upstream emissions shown in Table 1 were assumed for the German power mix. For 2030 and 2045, the emission factors given by the software package GEMIS (Version 5.0) [3] were used. These are based on the target scenario of the German government's National Energy and Climate Plan (NECP). The NECP is submitted to the EU Commission by the EU member states at regular intervals and contains information on the national energy and climate policy for a period of 10 years. The current German NECP was submitted to the EU Commission on 10 June 2020 [4]. The German climate targets (greenhouse gas neutrality by 2045) revised in August 2021 on the basis of a decision of the Federal Constitutional Court in Germany are therefore not take into consideration. The greenhouse gas footprint for the German power mix used here for 2030 and 2045 must therefore be regarded as a conservative forecast. For the natural gas used, the average upstream emissions of the German natural gas mix were used (24 g CO_2eq/kWh (LHV)). This value includes the carbon dioxide and methane emissions caused by production, processing, transport to Germany and distribution in Germany. The upstream emissions for biogas are based on the well-to-tank analyses of the Joint Research Centre (JRC) [5]. A reduction of up to 40 percent in the upstream emissions of biogas from energy crops up to 2040 was not taken into consideration in this study [6].

	Germany 2020	*Germany 2030*	*Germany 2045 (2050)*
Power mix g CO_2eq/kWh (el) [9–11]	*352*	*261*	*30*
upstream emissions g CO_2eq/kWh (LHV)			
Natural gas, average for Germany	*24 [12]*		
Biomethane from maize	*86 [5, 13]*		
Biomethane from residual waste	*25 [5, 13]*		

Source: the authors

Fig. 2 shows the results of an analysis of the greenhouse gas emissions of turquoise H_2 for a production plant in Germany. For the reference year 2020, power purchased from the public grid would account for about



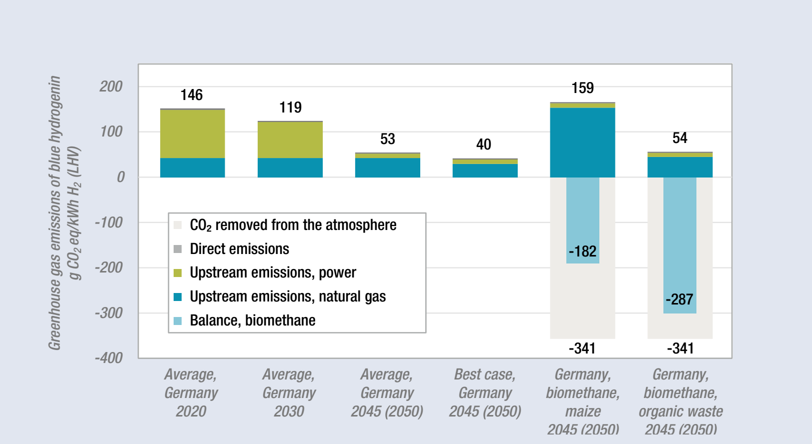
Source: the authors

Mass and energy flows (referred to the lower heating value, LHV) and greenhouse gas emissions of hydrogen production by natural gas pyrolysis for the reference year of 2020

two-thirds and the upstream emissions of natural gas for about one-third of the total greenhouse gas emissions concerned. In the constellations investigated, direct emissions are only of secondary importance. With the expected expansion of renewable energies, the upstream emissions of the German power mix are expected to fall to 30 g CO_2eq/kWh(el) by 2045 (2050) (Table 1). As a result of the considerable influence of the upstream emissions for electric power, the greenhouse gas emissions of turquoise H_2 will therefore fall from 146 g CO_2eq/kWh (LHV) in 2020 to 53 g CO_2eq/kWh (LHV) in 2045 (2050). Compared with the use of grey hydrogen from steam reforming (approx. 310 g CO_2eq/kWh) or the combustion of the natural gas used in Germany (approx. 222 g CO_2 eq/kWh), this will therefore represent a reduction in greenhouse gas emissions.

A decisive consideration in the analysis is the fact that the greenhouse gas emissions of turquoise hydrogen are strongly affected by the natural gas used or rather its upstream emissions [7]. And the upstream emissions of natural gas become even more crucial as the upstream emissions of the electric power used are reduced. This is why it is necessary to consider the specific locations and the upstream emissions of the natural gas used when analysing the greenhouse gas emissions of turquoise H_2. This also confirmed by the best case analysis.

In line with the plans of the EU Commission, methane emissions in all sectors are to be reduced by 30 percent by 2030 [8]. Assuming that the upstream emissions are also reduced by up to 30 percent, it will therefore also be possible to further reduce the greenhouse gas emissions of turquoise H_2. Although the limited availability of biomass must be taken into consideration, the use of biogas from maize (energy crops) or organic waste may even allow negative greenhouse gas emissions for turquoise hydrogen despite the high upstream emissions. Why is this the case? The growing of crops for biomass removes carbon from the atmosphere in the form of CO_2. Following the pyrolysis process, the carbon can be stored in solid form. The analyses show that the greenhouse gas emissions of hydrogen can be reduced compared with the state of the art using natural gas pyrolysis. The decisive factors are the location-dependent upstream emissions of the natural gas and electric power used and the storage of the carbon produced with a view to avoiding greenhouse gas emissions during carbon utilization. ■



Source: the authors

Greenhouse gas emissions of turquoise hydrogen for various reference years, with a reduction of 30 percent in upstream emissions from methane (best case) and for biogas from maize and organic waste in 2045 (2050)

INFORMATION

A full bibliography for this article is available at www.energie-wasser-praxis.de.

Production of hydrogen from methane-containing gases without CO_2 emissions

by: **Dr.-Ing. Jörg Nitzsche, Alexandra Müller & Michael Kühn** (all: DBI – Gastechnologisches Institut gGmbH Freiberg)

The production of hydrogen with zero or very low greenhouse gas emissions has considerable potential for the future. However, methane pyrolysis, a possible production process, posses considerable technical challenges. Therefore DBI – Gastechnologisches Institut gGmbH Freiberg is developing an innovative approach that avoids the general disadvantages of methane pyrolysis by splitting the entire process into two stages.

While global H_2 demand continues to grow, most of the hydrogen is produced from fossil fuels, chiefly by reforming hydrocarbons (such as natural gas) or the gasification of coal and heavy fuel oil. These processes cause considerable CO_2 emissions which can be reduced by carbon capture and storage (CCS). In comparison, the by-product of methane pyrolysis, solid carbon (reaction (3)) is easier to separate, transport and store and can be used for a variety of applications. However, challenges include the energy demand of the high-temperature reaction (T > 1,000 °C) in combination with the uncontrolled deposit of solid carbon on the reactor walls and catalysts as well as the possible formation of undesirable gaseous by-products.

> » *The disadvantages of pyrolysis can be avoided by splitting the process into two stages.* «

To avoid these disadvantages, DBI is developing an innovative process with the steps of “hydrogen production” and “carbon deposition” separated into two reactions. The first reaction is dry reforming (reaction (1)) in which the methane is converted in appropriate catalytic converters together with CO_2. This also allows the direct use of biogas (without previous separation of the CO_2 and treatment to produce biomethane). The second step is then the Boudouard reaction (reaction (2)) in a moving bed reactor. The carbon deposited on the bed material can be discharged and stored, used or, partly, reused as a bed material. This prevents both the possible deactivation of the catalyst and undesirable carbon deposits on the reactor walls. The overall reaction of the process is methane pyrolysis (reaction (3)).

Process structure – stage 1 (dry reforming)

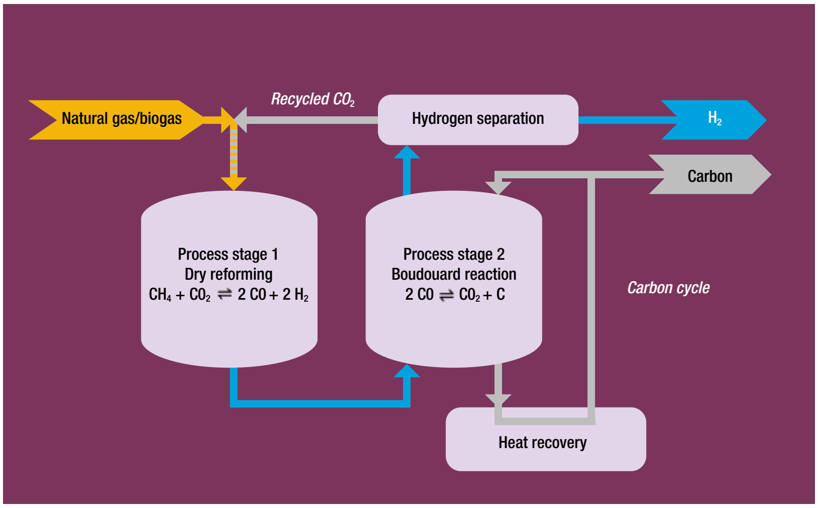
In the first stage, dry reforming (reaction (1)), the main focus is on a high rate of conversion of methane into hydrogen and oxides of carbon and the avoidance of carbon deposits on the catalyst sur-

$$CH_4 + CO_2 \rightleftharpoons 2CO + 2H_2 \quad \Delta_r H^0 = 247\,kJ/mol \qquad (1)$$

$$2\,CO \rightleftharpoons C + CO_2 \quad \Delta_r H^0 = -173\,kJ/mol \qquad (2)$$

$$CH_4 \rightleftharpoons 2H_2 + C \quad \Delta_r H^0 = 74{,}9\,kJ/mol \qquad (3)$$

Source: DBI



Schematic diagram of the two-stage process under investigation

faces. If the thermodynamics of the reaction are considered, it becomes clear that not only high reactor temperatures and low pressures but also a carbon dioxide excess in the reagent flow are advantageous to prevent carbon deposition. At a reaction temperature of 800 °C and atmospheric pressure, an operating range without carbon deposition can only be reached in thermodynamic terms with a CO_2:CH_4 ratio higher than 1.2. Reaction temperatures which are as high as possible are associated with high reforming rates and low risk of carbon formation, which generally leads to the same requirements for process conditions.

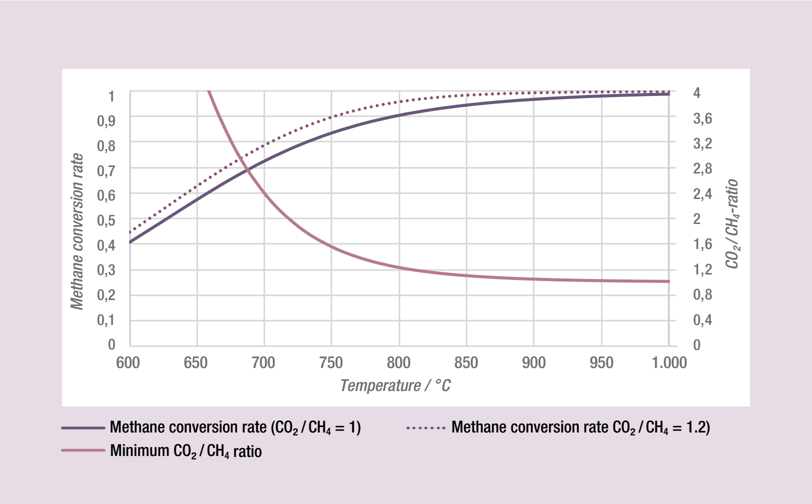
Process structure – stage 2 (Boudouard reaction)

In the second process stage, the Boudouard reaction, the main focus is on the targeted deposition of carbon on a moving bed. The carbon separated from the bed may either be reused or stored while the CO_2 formed is recycled to stage 1. In thermodynamic terms, the Boudouard reaction is almost fully completed (carbon yield >99 %) at temperatures up to 500 °C. At higher temperatures, the balance shifts increasingly towards the reagents. The reaction is therefore carried out at temperatures which are as low as possible. Secondary reactions which reduce the hydrogen yield, especially water gas shift reactions and methanisation reactions, are possible. These must be prevented by the design of the process or by kinetic inhibition.

Process structure – linking the stages

The two process stages pose considerably lower challenges as regards implementation than pyrolysis but must be implemented at different temperature levels. In order to reduce the overall energy demand, it is necessary to link the two process stages in thermal aspects. In addition, process-internal recycling should be implemented through the preferential use of the carbon produced as a moving bed material, allowing the operation of the process without additional material. The development of the process and the investigation of the two process stages are key aspects in the R&D project that is currently in progress, funded by the Federal Ministry for Industry and Climate Protection supported by DVGW hydrogen innovation programme. ■

Source: DBI



Obtainable methane conversion rate and minimum CO_2/CH_4 ratio required to avoid carbon deposition in the first reaction stage (dry reforming)

Gefördert durch:
Bundesministerium
für Wirtschaft
und Klimaschutz
aufgrund eines Beschlusses
des Deutschen Bundestages

Unterstützt durch:
DVGW

Multiple applications for carbon from *methane pyrolysis*

by: **Robert Obenaus-Emler** (University of Leoben)

Source: University of Leoben

In addition to pure hydrogen, methane pyrolysis also produces solid carbon. Depending on the allotrope concerned and the degree of purity, this carbon may be used in many different applications – there are a variety of possibilities.

Hydrogen that is produced with in a CO_2-free process or with a low CO_2 footprint will play a key role in a future energy system based solely on energy from renewable sources. Currently, hydrogen is chiefly produced by the steam reforming of natural gas, a process that releases CO_2 and is mainly used in the chemical and petrochemical industries.

If the quantity of hydrogen required in the future were to be produced solely by water electrolysis, several thousand terawatts-hours of electric power from renewable sources would be required in Europe alone. One of the possible alternative production processes for renewable hydrogen is methane pyrolysis. Compared with other alternative processes, methane pyrolysis offers a very high hydrogen yield combined with the lowest energy demand (less than a quarter of the energy needed for water electrolysis is required). Hydrogen from methane pyrolysis is therefore considerably superior to hydrogen from all other processes in terms of the environmental impact caused by energy utilization.

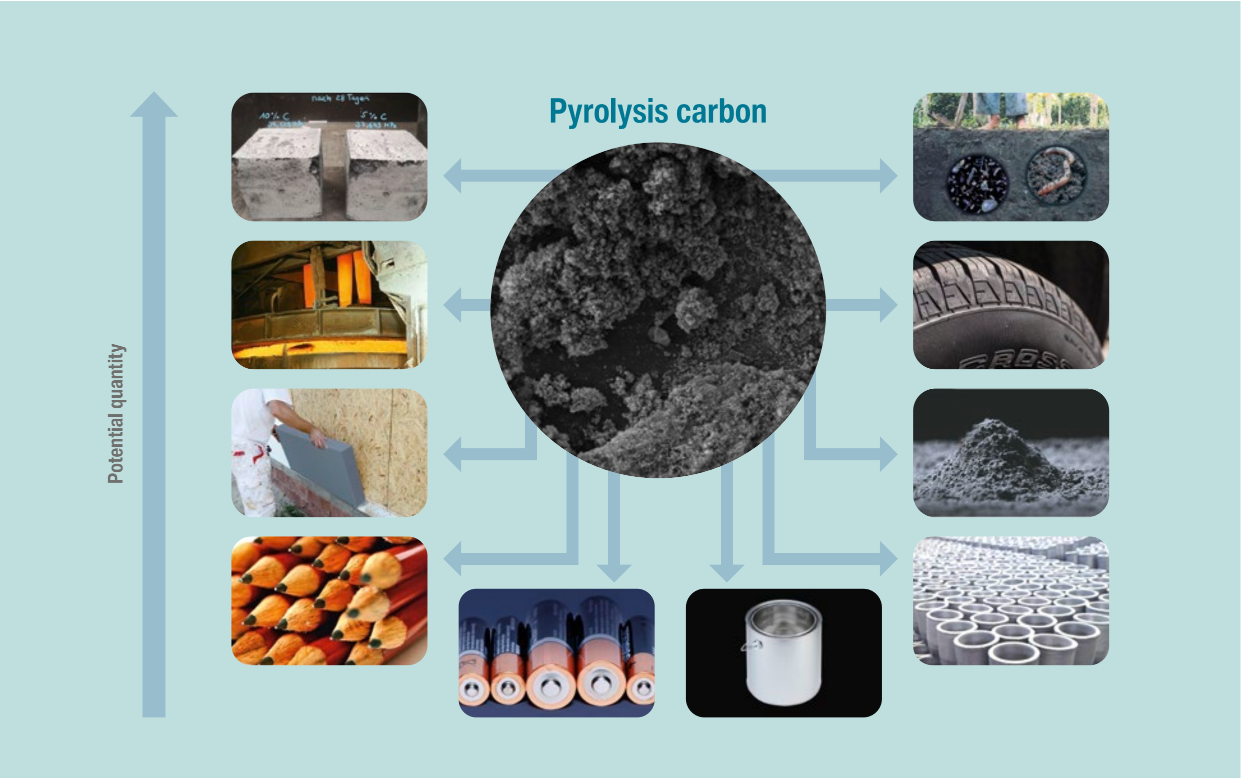
As methane pyrolysis results in a by-product of solid carbon, the hydrogen produced is CO_2-free. Per kilogram of H_2, about 3 kg of solid carbon (C) are produced. In terms of the full utilization of resources, the sustainable use of this elementary carbon is extremely important. The scientific investigations carried out at the University of Leoben confirm the correlation between the carbon morphology produced and the pyrolysis process or the catalyst material used. It is therefore possible to set the quality of the carbon produced to the technical parameters required for the application process as regards allotrope and particle size.

Depending on the allotrope (graphite, graphene, soot, carbon tubes, turbostratic carbon, etc) and the purity of the carbon produced, it may be used for a variety of different applications. The possibilities available include both high-tech applications such as carbon nano tubes, high performance materials, supercapacitors and microporous carbon tanks for energy-efficient hydrogen storage on the one hand and use as a raw material for rubber and plastic products and in the asphalt and ceramics industry, as an additive for lubricants, casting powders and electrode materials for the metallurgical industry and as a feedstock for batteries and storage systems for electric power on the other hand.

In view of the high yield of solid carbon in methane pyrolysis, large-volume carbon applications are particularly important. Carbon may for example be used in the building industry as an aggregate for insulation materials and to modify the physical properties of construction materials. It may also be used for soil amelioration in agriculture, with properties such as positive effects on the nutrient and water storage capacity of the soil, the targeted development of humus and a positive contribution to reducing soil emissions with a harmful impact on the climate. In addition, it may be used as an additive for composting and for the production of organic fertiliser pellets. Although the purity requirements for the use of carbon in agriculture are high, these applications are especially interesting because of the possible environmental benefits.

Especially in the case of large-volume applications for carbon, it must be assumed with reference to marketing that further use of the carbon produced is possible at low cost. In the ideal case, carbon from methane pyrolysis may be used directly as a product without any further complex processes. As a result, with respect to the development of pyrolysis technology and future implementation in commercial-scale plants, the main focus must be on the selection of the pyrolysis process route and the definition of relevant process parameters. Furthermore, the economic and environmental significance of possible applications for hydrogen and carbon should be considered in the context of sustainable technology development. The objective of ensuring the full use of all the material and energy flows created by pyrolysis should not be neglected. ■

> »
> *In order to ensure that resources are utilised as fully as possible, the use of all material and energy flows created by methane pyrolysis, where possible, is a key consideration.* «



Source: Montanuniversität Leoben/pixabay.com/Wikipedia Commons


Source: ralph-richir.fr

»A world without CO_2 emissions from human activities is not utopian«

A conversation with **Gérard Gatt**, President at Sakowin Green Energy, about how to scale up hydrogen production.

Mr Gatt, why is hydrogen indispensable in the future?

Gérard Gatt: The IPCC warns of the acceleration of global warming and states, as well as companies and communities have committed to achieving CO_2 neutrality between 2050 and 2070. This is a major challenge, given that human activities generated no less than 36.4 billion tons of CO_2 in 2021.

If we must produce energy while not emitting CO_2, hydrogen is the best way to do this, at least for the foreseeable future. Reaching net zero emission means converting 85 % of our current energy (combustion of oil, gas and coal) to hydrogen. This would equate to 10 billion tons of hydrogen that need to be produced, which is an order of magnitude significantly higher that current objectives. Imagine a world where the combustion of hydrocarbons would no longer be the main source of energy – imagine a world without CO_2 emissions from human activity. This vision is not utopian. It is now a reality thanks to the next generation of sustainable hydrogen without CO_2 emissions.

> »*The methane molecule (CH_4) requires 7 times less energy than a water molecule (H_2O) to produce the same amount of hydrogen.*«

To scale up hydrogen production to such a level, what primary energy should we use in addition to solar, wind, hydraulics and nuclear?

Gatt: The last untapped scalable renewable energy source we can use is methane (CH_4), ideally produced from biomass. But, instead of today, it must be used in decomposition without oxygen and not in combustion, to avoid CO_2 emissions. However, currently, most of the available hydrogen production solutions have either a high CO_2 balance or costs that are burdened by their high energy consumption, storage or transport. If we want to be cost competitive, wouldn't it be safer to use a molecule that will require the least amount of energy? The methane molecule (CH_4) requires 7 times less energy than a water molecule (H_2O) to produce the same amount of hydrogen. To meet this challenge while respecting the energy economic constraints, Sakowin Green Energy is innovating by proposing a solution for the future: the production of sustainable hydrogen, at a competitive cost, from methane, i.e. biomethane or natural gas.

What does the solution look like from your point of view?

Gatt: Sakowin has developed and patented a disruptive solution able to overcome these limitations. We use microwave plasma to dissociate methane into gaseous hydrogen and solid carbon, a process called Plasmalysis. Our equipment is compact, modular and stackable and can be installed at the end of a gas line, allowing us to produce hydrogen on-site and on-demand utilizing existing gas infrastructures.

We use a mature and proven microwave plasma to dissociate methane into hydrogen gas and solid carbon. Our equipment avoids the buildup of new infrastructure for transport and storage of hydrogen, utilizing gas infrastructure, valorizing existing assets and allowing current heavy emitters to transform their industries with minimum changes.

What role does biomethane play in this context?

Gatt: The most sustainable route is using biomethane as the input. This coupling creates a CO_2 negative energy solution, allowing to accelerate the energy transition and industries to better offset residual CO_2 emissions. While biomethane is developing, natural gas can be decarbonized as an intermediate solution to produce hydrogen in large volumes at a competitive cost.

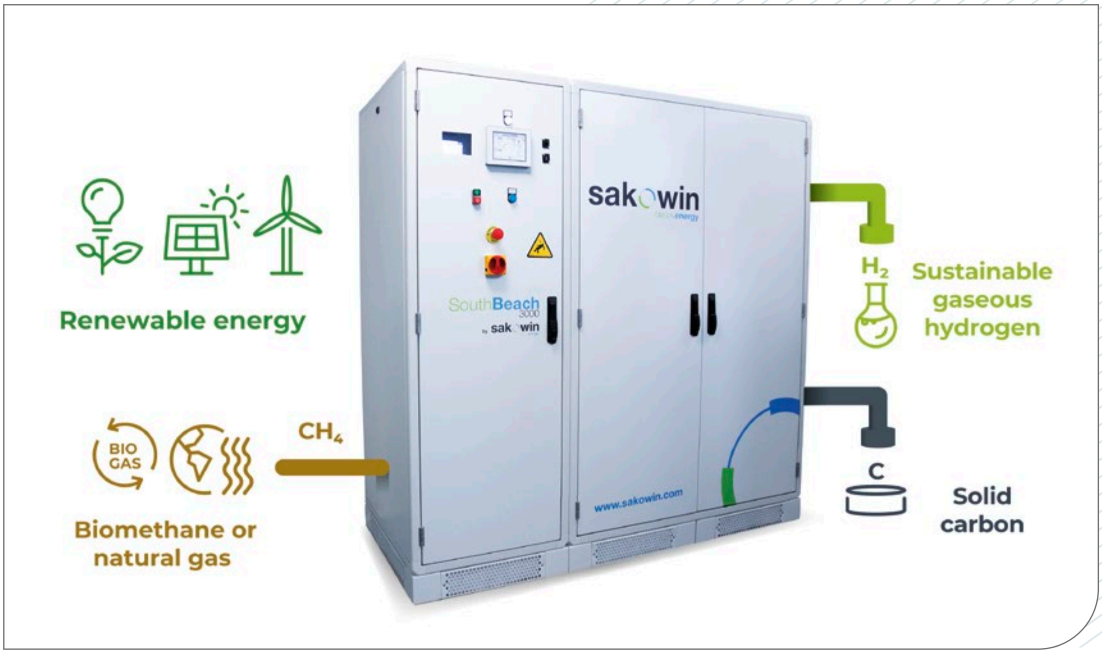
Compared to our competitors and thanks to our patented technology, we use 5 times less energy than an electrolyzer to produce hydrogen. The result: a cost-competitive hydrogen regardless carbon value. The cost-competitiveness of our technology and its capacity to be CO_2 negative will significantly accelerate the development of the $2.500 billion hydrogen market.

How can the solid carbon that is also produced be used?

Gatt: There are several potential applications of the co-produced solid carbon that also have a positive environmental impact. For example, it has been shown that by partly replacing portland cement with solid carbon, the concrete industry could lower their CO_2 emissions by 10 %.

Another environmental application is in agriculture. Carbon enrichment of soil can help improve its composition and capacities to retain more water.

Therefore Sakowin's technology will create an opportunity with a positive environmental impact for new Carbon markets to emerge (building materials, agriculture), going from a current demand market to an offer market, and therefore encouraging the invention of new and more environmentally friendly processes. ■



Source: IDEACTIS

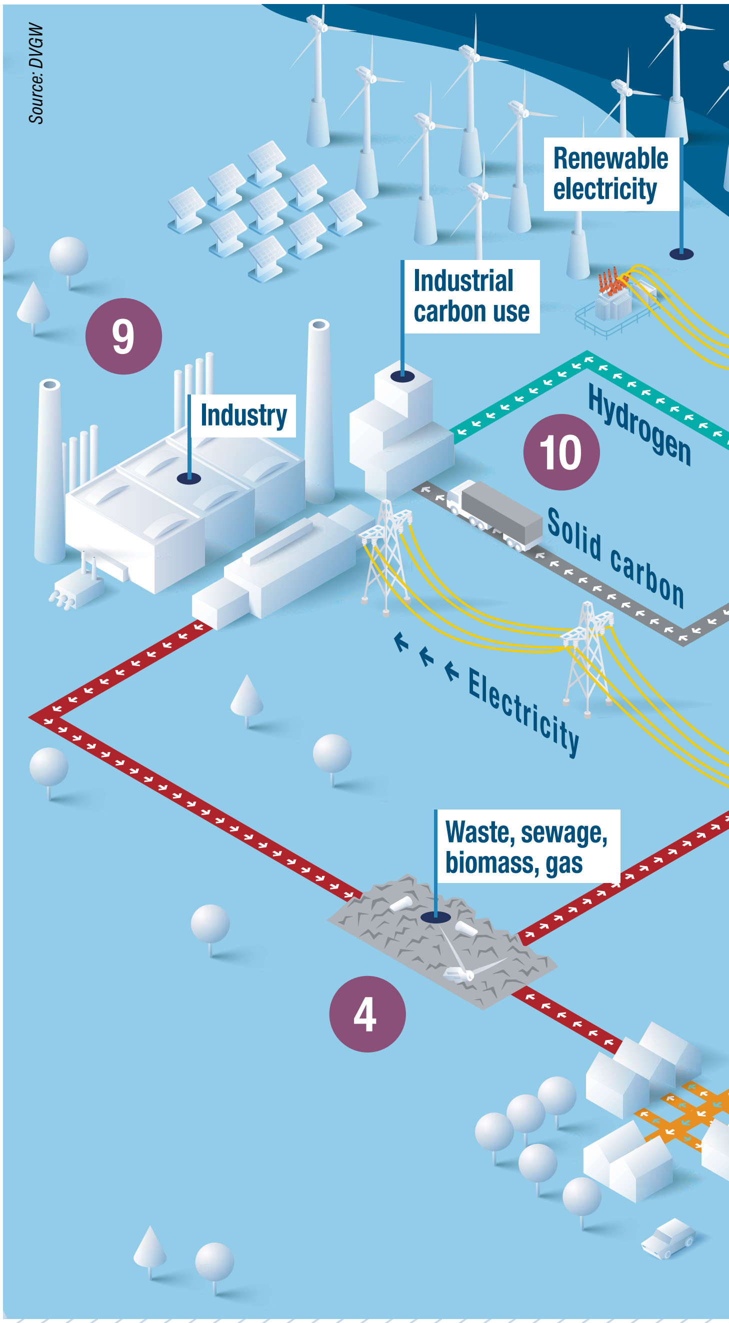
Sakowin South Beach Module 100 kW

The world of **methane pyrolysis** at a

Methane is everywhere in our lives either by natural processes - such as the decay of organic material or the digestion of food by livestock - or by human activities - such as agricultural, energy production or wastewater treatment. Methane pyrolysis **(1)** neutralizes unabated methane emissions and integrates renewables **(2)**. Gasification **(3)** converts all carbonaceous materials, from biomass or fossil (e.g. plastics or waste), into gases to feed the pyrolysis process.

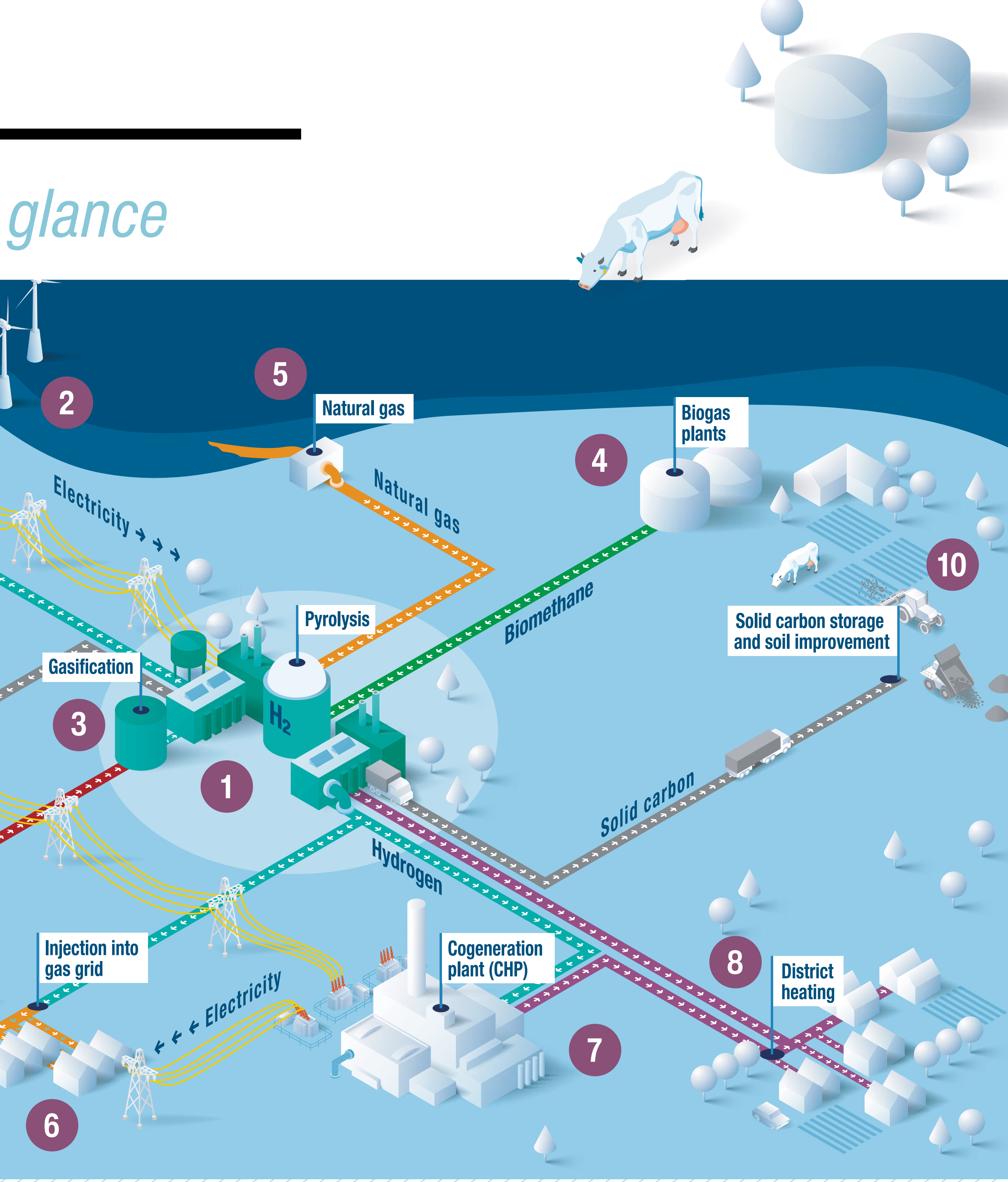
Pyrolysis splits methane (CH_4) into hydrogen (H_2) and solid carbon (C) **(1).** In contrast to steam reforming, pyrolysis does not produce CO_2 but solid carbon that can be used as an industrial building block. Feedstocks for pyrolysis can be either methane from biogenic sources (e.g. biogas, landfill gas and/or waste gasification) **(4)** or natural gas in the form of LNG/pipeline gas **(5)**. There are a variety of applications for hydrogen from pyrolysis in industrial sectors. For example, hydrogen can be fed into the gas grids **(6)**, contributing to the decarbonisation of the thermal energy market. In addition, hydrogen can be used in combined heat and power plants **(7)**; the heat generated by the power plant or the pyrolysis plant can then be used in district heating systems **(8)**. Other possible applications include the mobility sector, to power trains and ships, but also road vehicles. For Industry **(9)**, pyrolysis is attractive for sectors that are hard to abate. The climate-neutral hydrogen can play a key role in decarbonising these sectors.

Solid carbon, such as synthetic graphite, activated carbon, is a critical raw material used as a clean substitute for industries such as battery production, bipolar plates for fuel cells and electrolyzers, or in the semiconductor, wind and solar industries **(10)**. Its use for soil improvement **(10)** brings various climate benefits: higher water retention, less soil erosion, higher CO_2 uptake by plants, less fertiliser needs. Excess amounts of solid carbon can be safely stored underground for an indefinite period (e.g. in abandoned coal mines) **(10)**.



Source: DVGW

glance


2
5
Natural gas
Biogas
plants
4
Electricity
Natural gas
10
Pyrolysis
Biomethane
Solid carbon storage
and soil improvement
Gasification
3
H_2
1
Solid carbon
Hydrogen
8
Injection into
gas grid
Cogeneration
plant (CHP)
District
heating
Electricity
7
6

»Graphene and hydrogen – two materials **to power** the decarbonization«

by: **Ian Hopkins** (CPO Levidian)

Source: Source: Levidian

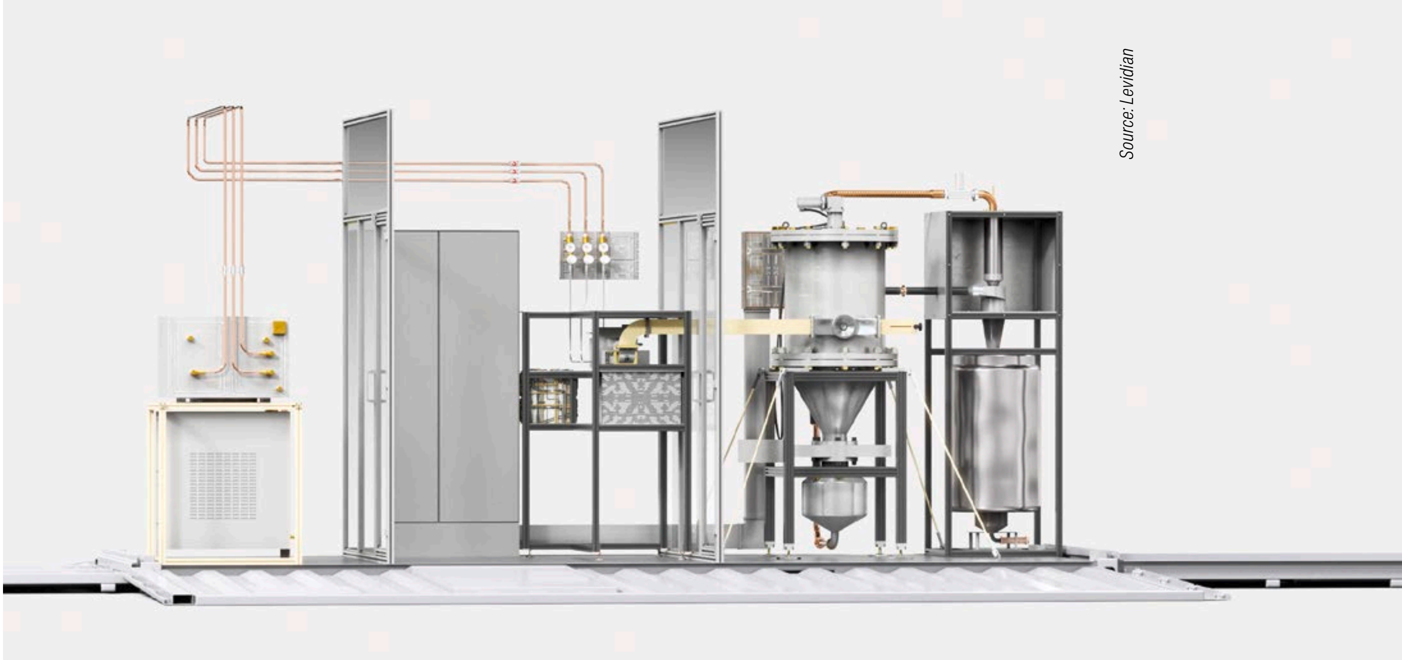
Hydrogen is the lightest element, and it is destined to power the future of our societies. Moreover, it is the most abundant element in the universe – all the hydrogen in the universe comes from the first moments after the Big Bang. Hydrogen has the atomic number “1” in the periodic table and is the third most abundant element on the Earth's surface.

Against this background, it may come as a surprise that carbon is the second most abundant mass in the human body and the fourth most abundant element in the universe (by mass), after hydrogen, helium and oxygen. This makes carbon the chemical basis of all known life on Earth and graphene a potentially environmentally friendly, sustainable solution for an almost unlimited number of applications.

Graphene is the thinnest compound known to man at one atom thick, the lightest material known (with one square meter weighing around 0.77 milligrams), the strongest compound discovered (between 100 to 300 times stronger than steel with a tensile strength of 130 GPa), the best conductor of heat at room temperature (at (4.84 ± 0.44) × 10^3 to (5.30 ± 0.48) × 10^3 W·m–1·K–1) and also the best conductor of electricity known (studies have shown electron mobility at values of more than 200,000 cm^2·V–1·s–1). Despite the hype surrounding said applications of hydrogen and graphene, these two offer amazing possibilities.

Putting carbon to work

The British company LEVIDIAN is behind the LOOP system, which uses a patented low-temperature, low-pressure process to split methane down into its constituent hydrogen and carbon without the need for catalysts or additives. This process uses focused microwaves to directly ionize the methane gas and create a plasma without CO_2 emissions. The high-frequency electromagnetic microwaves excite the electrons in the gas and promote collisions with other molecules, breaking them apart and creating more free electrons and positive ion radicals. In this way, a cascade of reactions occurs, providing a sustained plasma state as long as microwave energy is applied. This plasma "soup" of electrons and ions is not to be confused with plasma torches such as those used in other pyrolysis applications, where plasma is used to generate reactor heat. In the LOOP process, the methane is the plasma, and most of the energy contained in the microwaves is delivered directly to the electrons and ions of the gas. As these excited electrons and



Source: Levidian

The Levidian LOOP

ions leave the plasma region, they cool and combine to produce: Hydrogen gas and solid carbon, in the form of graphene.

Compared to other processes, the LOOP process is much more energy efficient. The energy needed to break the bonds is transferred directly to the molecules. In addition, it works optimally at near ambient pressure because the energy comes from the microwaves and not from conditions in the system.

The LOOP system can utilise methane from various sources, including natural gas and biomethane. Levidian is currently identifying the full range of input sources from which hydrogen and graphene can be generated. LOOP technology could provide a route to decarbonisation and hydrogen generation for customers ranging from industrial heat and power users to landfill or flare gas sites.

LOOPs can be deployed in standard shipping containers or in permanent infrastructure as single units or larger arrays. Levidian is currently expanding this technology to deploy LOOP1000+, each of which will remove more than 1.000 t of CO_2 equivalent per year. The hydrogen produced by LOOP can be used immediately as drop-in fuel, allowing industrial energy users to decarbonize their existing natural gas consumption with minimal infrastructure changes. With an additional hydrogen separator, LOOP can deliver hydrogen for a variety of applications directly at the point of use.

Levidian graphene is the second product from the patented LOOP system. Carbon produced by our process is bonded into "atomic" graphene with minimal batch-to-batch variation. Levidian graphene is unadulterated, has only a few layers and is not functionalized. Because of its unique properties, it can be used in its original form or functionalized for numerous applications. The graphene produced by LOOP is sustainable and, when produced using waste gas, is carbon-negative. As was announced recently, over 500 shipping containers equipped with the LOOP system shall be shipped and deployed to United Arab Emirates over the next years, to contribute to the decarbonization. Levidian's vision is a decarbonized future powered by hydrogen and built on graphene. European policy and decisionmakers need to be ready for it. ■

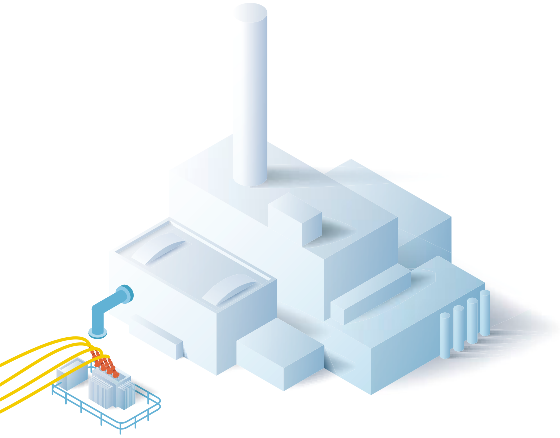
» Levidian's vision is a decarbonised future powered by hydrogen and built on graphene. «

Joining the rainbow: turquoise hydrogen

by: ***Raimondo Giavi*** (Vice President – Hydrogen Growth Area, Baker Hughes)


Source: Baker Hughes

Hydrogen can be produced in a number of ways. It is categorized by color based on the underlying type of raw material, forming what we call the hydrogen rainbow. At Baker Hughes, we are focusing our efforts on developing low-carbon production technologies to scale up the hydrogen economy: be it green, blue, and turquoise. All of them display some clear advantages and some disadvantages, thus making them suitable for different applications and user-case around the world.



Blue and green hydrogen are well-known technologies with a high degree of maturity. On the other hand, turquoise is quite a novel and still undiscovered technology. We believe that we, as society, will need all of them to meet the Paris Agreement goals.

Turquoise hydrogen – or pyrolysis – converts gases into hydrogen and solid carbon, which can be used in many industries as well for soil improvement, increasing its ability to absorb CO_2. The pyrolysis reaction to produce hydrogen can also be powered either by gas (when the direct CO_2 emissions are relatively important) or by renewable electricity. When using renewable electricity to power the reaction, the resultant hydrogen is zero-carbon in nature, subject to addressing fugitive methane emissions. When the reaction is powered by renewable electricity, if the methane used as feedstock is carefully sourced and traced, such fugitive methane emissions are very limited and could easily be offset, especially as capture technologies improve. If that occurs, the resultant hydrogen should therefore be considered zero-carbon in nature.

Finally, producing 1 kg of zero-carbon hydrogen will in all likelihood require far less energy when produced via pyrolysis than through electrolysis, because the chemical reaction used for pyrolysis requires the equivalent of 13 to 26 % of the energy needed by the reaction used

in electrolysis. This means that less renewable energy will need to be built, meaning less raw materials are needed. This technology, therefore, is an important option for zero-carbon hydrogen in the future however, additional R&D and demonstration investment is required before it's scaled up.

Turquoise hydrogen displays a series of advantages that makes it suitable for small, medium and large applications:

- It can be installed at the point of use wherever there is methane, therefore avoiding large CapEx in expensive infrastructure,
- Minimal electricity consumption makes it more competitive than green hydrogen in a high electricity price environment,
- the by-product of the process is solid carbon with significant potential in the circular economy.

Baker Hughes has invested in turquoise hydrogen by collaborating with Ekona Power, a Canadian start-up with a promising technology. Ekona's methane pyrolysis solution uses combustion and high-speed gas dynamics in a reactor to separate feedstock methane into hydrogen and solid carbon, drastically reducing carbon dioxide emissions versus the traditional and prevalent steam methane reforming process. The innovative solution is designed to easily integrate with standard equipment for gas and hydrogen applications including carbon separation and hydrogen purification, thus simplifying industrial process integration.

Ekona and Baker Hughes have joined efforts to accelerate the scale up and industrialization of the technology by identifying suitable pilot projects and leveraging Baker Hughes' leading turbomachinery portfolio as well as established technical expertise in providing modular and scalable solutions for global hydrogen and natural gas projects. Through the adoption of this technology, the industry can leverage existing and abundant natural gas reserves to produce low carbon hydrogen and accelerate its use across the energy value chain.

A healthy hydrogen economy will require coordinated efforts from all stakeholders to enable a meaningful scale up. At Baker Hughes, we develop and build technologies that support the full value chain, from production through transportation and utilization: compression, hydrogen gas turbines, valves, flex pipes, and finally different low-carbon production technologies. We believe turquoise hydrogen will find a particular spot in the hydrogen economy due to its particularly appealing characteristics:

> » *Turquoise hydrogen displays a series of advantages that makes it suitable for small, medium and large applications* «

- leveraging of existing gas infrastructure
- low use of electricity
- carbon as a solid by-product
- scalability

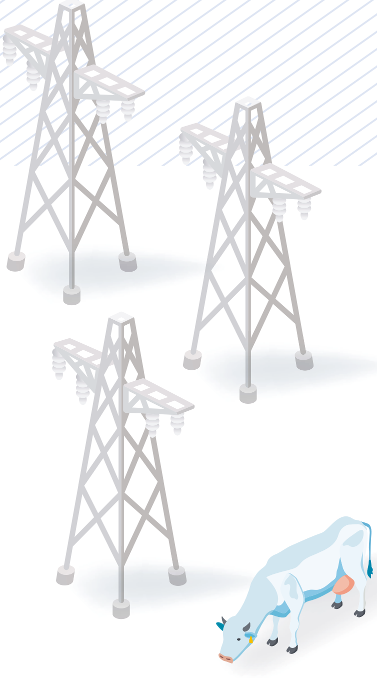
Achieving the Paris Agreement goals will require a wide range of solutions to meet various application requirements. Turquoise hydrogen promises solutions to specific set of challenges and end-use applications. ■

»Methane plasmalysis can already be integrated into solutions fit for everyday use«

The editorial team talked to **Dr Jens Hanke**, founder and CTO of Graforce GmbH, concerning the potential of plasmalysis and first possible practical applications.

Source: Graforce GmbH

Dr. Jens Hanke is the founder and CTO of Graforce GmbH.



Dr Hanke, what is plasmalysis precisely?

Dr Jens Hanke: Plasmalysis is an electrochemical technology that can produce hydrogen from methane, sewage treatment plant wastewater or liquid manure with high energy efficiency, without carbon dioxide production, at low cost and with high yield. The technology is based on the use of green electricity to generate a high-frequency plasma field. This field splits the high-energy nitrogen, hydrogen and carbon compounds in the feedstock into atoms which then combine to form molecules of hydrogen and other industrial gases in the plasma field.

What is the difference between this process and pyrolysis?

Dr Hanke: Pyrolysis is a thermo-chemical process in which methane is split into hydrogen and solid carbon at high temperatures with the virtual exclusion of oxygen. Apart from this, the two processes are very similar. In comparison with electrolysis, they only need about one-fifth of the energy to generate the same quantity of hydrogen. The carbon-hydrogen bonds in methane (CH_4) are considerably easier to break than the hydrogen-oxygen bonds in water (H_2O). Currently, pyrolysis is not sufficiently mature for industrial use although the first demonstration plants are planned in Germany.

What is a carbon sink and to what extent does this term play a role in connection with methane plasmalysis?

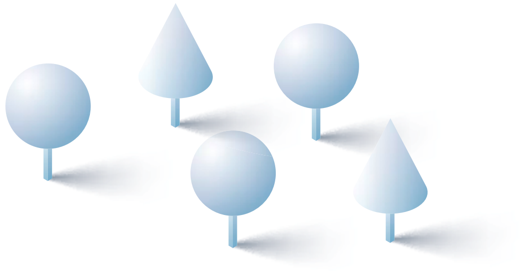
Dr Hanke: In process engineering terms, we talk about a carbon sink if sustainable biogas is used for methane plasmalysis. Green hydrogen can be used directly for CO_2-free heat and power generation in hydrogen-powered CHP plants, heating boilers or SOFC fuel cells. Elementary carbon can be used as an industrial raw material, e.g. for asphalt, concrete or cement production, or for soil amelioration. This means that CO_2 is removed from the cycle in the long term, resulting in an exemption from the carbon tax. Viewing the process as a whole, CO_2 is taken from the atmosphere and the overall carbon balance of the process is negative.

To what extent is the plasmalysis technology already market-ready and is work on the first practical applications already in progress?

Dr Hanke: We are currently implementing an innovative energy solution based on methane plasmalysis for the Mercure-Hotel MOA in Berlin. To date, the hotel has used five natural gas boilers, producing up to 800 t of CO_2 per year. Initially, two of the five boilers are now to be operated using a mixture of natural gas and up to 20 percent hydrogen generated by the system. The H_2 share will then be successively increased until all the boilers are operated solely on hydrogen, reducing the CO_2 output to zero.

In what fields can such plants be used in general? What other examples are there?

Dr Hanke: The methane plasmalysis plants should be rolled out fast. In the course of the year, we will already be converting a city district of 40,000 m^2 to CO_2-free heating. The system consisting of plasmalysis, hydrogen-powered compact CHP plant and heating boilers will be the first solution fit for everyday use for the implementation of the heat energy transition. It will not take any electricity from the public grid as the electric power required for hydrogen production will be generated by the CHP plant.



» Methane plasmalysis allows the sustained, long-term removal of CO_2 from the cycle. «

And what applications are there for the solid carbon?

Dr Hanke: Carbon can be used in building materials for example. In that case, the CO_2 is no longer released but durably integrated in asphalt or bricks. This market-ready CO_2 reduction technology can already be used throughout the energy system.

Why do you predict that plasmalysis will be a less costly solution than electrolysis in the long term?

Dr Hanke: If hydrogen is produced by water electrolysis using green power, the process currently needs more than 50 kW-hours of power per kg of H_2, as the hydrogen-oxygen bonds in water are stronger. Plasmalysis uses alternative biogenic sources which have weaker bonds. This reduces the cost from an average of between €6 and €8 to between €1.5 and €3 per kg H_2. ■

» Thermo-catalytic hydrocarbon decomposition technologies for hydrogen production «

by: **Klaus Mauthner** (Carbotopia) **& Matti Malkamäki** (Founder, Chairman of the Board, Hycamite TCD Technologies Ltd.)

The thermocatalytic decomposition of methane simultaneously produces clean hydrogen solid, high quality carbon products. The methane can be obtained from various sources such as waste gasification, biomass, biogas, natural gas, or chemical synthesis of imported LNG from green hydrogen. It has been shown that the catalysts used can also separate other light hydrocarbons, e.g., from side streams of the petrochemical industry, as feedstock.

As already known, hydrogen can be used, for example, in the chemical industry, for climate-neutral fuel production, or as an emission-free fuel to compensate for fluctuations in power generation from wind and solar energy.

» *TCD hydrogen enables quick switch to clean hydrogen and can have an essential role with green methane.* «

Proprietary, scalable technologies enable sustainable hydrogen production without any greenhouse-gas emissions borne from the process. The technology has been promoted as a proper "last-mile hydrogen solution" – it enables companies to switch quickly to hydrogen-use without waiting for other hydrogen production or infrastructure to be finished. The Thermo-Catalytic Decomposition (TCD)-plant units can be placed close to the end-user, or over the fence, and can even provide excess waste heat subsidizing the hydrogen cost. Saving carbon as a resource during the production of hydrogen lowers the costs and, even more, can ease foreign supply dependencies for several, critical declared carbon products, such as graphite.

The quality of the co-produced carbon can be for example graphite or nanotubes and -fibres, thus enabling demanding industrial use at lower filling rates than state-of-the-art carbon black. A range of these carbon products is ideal for bipolar plates in stacks for electrolyzers, battery manufacturing, new materials, additives in cement products, and other industrial use. According to a recent analysis of Benchmark Mineral Intelligence, an additional 3,100,000 t of synthetic graphite is already needed for 2035 to meet the demand from electric vehicles and energy storage batteries. For a wide variety of applications, nano carbon typically further improves existing products and significantly lowers the carbon footprint. The catalysts used are recyclable, and there are no rare earth metals needed. In Europe, several companies are leading the development of this cost-competitive technology:

In Austria, Carbotopia builds on its nearly 30 years of experience in developing unique catalyst systems for the continuous co-production of hydrogen and crystalline carbon. The demonstration reactor fits into a shipping container and produces hydrogen and nanocarbon at high conversion rates and efficiency of 95 Vol.-% H_2. This carbon has been processed into the first samples of carbon composite bipolar plates for initial testing, promising high efficiency and longer life for bipolar plates in fuel cells or electrolyzers, forming an important pillar for the European green electrolyzer strategy and envisioned cost reductions and efficiency gains. The planned scale-up to a standard vertical reactor with ultimately 800 t/y of hydrogen (equivalent to a 20 MW electrolyzer with 2,200 operating hours per year) plus three times the nanocarbon production has successfully passed all feasibility tests and is ready for technical implementation. At future sites, such standard reactors could be arranged in up to fivefold parallel multiple setups, as needed, to meet on-site hydrogen demand.

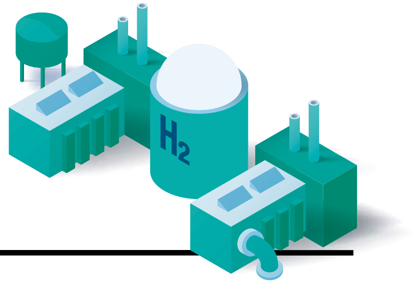
In Kokkola, Finland, Hycamite has an operational pilot plant and is preparing to begin construction of an industrial-scale demonstration plant in the Kokkola Industrial Park (KIP) later this year, building upon long-term catalyst research from the University of Oulu. The industrial-scale demonstration plant will have two functions: First, to produce and demonstrate the technology for producing clean hydrogen and second, to provide carbon samples for high-value carbon customers. This plant will have an annual nominal capacity of 2,000 tons of clean hydrogen, comparable to a 20 MW electrolyser with 5,500 hrs annual operation. Yet, the power consumption of the site will be around 2.6 MW, approx. 13 % of the same-capacity electrolyser. Similarly, the plant can produce 6,000 tons of solid carbon. As the plant will use biogas as feedstock, the plant will act as a carbon sink, almost 22,000 t of CO_2 are stored when only the hydrogen use is counted for. As solid carbon can be used to further reduce the footprint of other products, depending on the application, the total CO_2 removal can be significantly more and, in most cases, above 100,000 t per annum.

Following the success of the demonstration plant, together with its various partners, Hycamite is planning to deploy numerous sites both in industrial applications and on vessels within the maritime industry. The target is to deliver multiple plants and to scale up the technology to have an annual output of more than 100,000 t of hydrogen from the largest facilities. ■

Source: Hycamite

Hycamite plant at Kokkola industrial park, Finland

» H_2-Innovation and H_2-ramp up – **technology development** in the Ruhr valley «



A conversation with **Bernd Meyer**, Dortmund

The CleanPort-Dortmund is an ideal location for the development and industrialisation of innovative processes for the CO_2-friendly production of hydrogen. Looking at the full H_2-value-chain from production to transport/storage and application, Cleanport is supporting innovative solutions ranging from green to turquoise hydrogen. The city of Dortmund is promoting the development of future-oriented technologies since decades. Incorporated in 1984 the TechnologieZentrum Dortmund today is amongst the major centers of innovation and development in Germany. To fund this success story the city of Dortmund has established a special fund called "Sondervermögen Verpachtung Technologie-Zentrum Dortmund" (SVTZ), bundling years of experience in the development of technology incubators.

As a contractual partner of the SVTZ, Bernd Meyer, with more than 30 years of experience in the high-tech sector, is supporting the SVTZ in structuring and setting up CleanPort to open doors for startups in 2024.

Mr Meyer, what can Dortmund offer to these companies?

Bernd Meyer: As a location for start-ups and spin-offs, the CleanPort-Dortmund will offer the provision and leasing of the necessary premises, custom pilot facilities and infrastructure as well as the networks for raising the equity capital needed to cover the burn rate during the phase of technology development.

Why is CleanPort focusing on start-ups based on pyrolysis instead of electrolysis?

Meyer: Well, first of all we are not dogmatic. Committed to contribute to a sound migration path from hydrocarbon to hydrogen we are open for every smart, efficient and cost competitive solution helping to speed up and establish Hydrogen as a commodity until 2045. The main challenge on this path is that production, transport infrastructure and consumption have to be built in parallel – mainly from scratch.

Therefore, today all technological options are worthwhile to look into. Most important will be efficiency. Realizing today's gap between market price for green H_2 and the economical facts of potential H_2-Consumers we should better bet on pragmatic innovation rather than waiting for the government to close this gap by grants and subventions. If we take this as a benchmark which applies to both, domestic H_2 production and H_2 imports, it has the potential to pay off in the creation of a prospering hydrogen industry in Germany.

What experience does Cleanport have with carbon handling?

Meyer: Ruhr valley and carbon are synonymous terms. Carbon will stay a major feedstock for a multitude of applications. That's why CleanPort – located in the heart of the Ruhr Valley – has set a focus on carbon innovation. For example, the anchor tenant of CleanPort already has gained a remarkable position in the carbon farming market. With this know-how and market position the company is a valuable local development partner for our future tenants and their innovative solutions for methane pyrolysis and comparable process technologies.

A pre-condition for CO_2-free hydrogen from methane pyrolysis is to maintain a neutral CO_2-footprint for pyrolysis carbon over the entire application cycle. Therefore, CleanPort will initialize joint development projects for large-scale application of carbon with other competence providers in industry and science.

How do you see the integration of methane pyrolysis with electrolysis?

Meyer: All energy- and cost efficient H_2-Production Technologies will be needed on the way to a CO_2-free 2045. So where is the point to skip one and narrow the options. As long as the prime energy and mobility markets are not sufficiently decarbonized by renewables one should consider that methane pyrolysis compared to electrolysis by physics consumes app. ⅐ of renewable energy per H_2-molecule. Along with the options arising from a smart carbon innovation management, methane pyrolysis can be more an enabler rather than only a bridge technology to supply CO_2-free hydrogen as a commodity to the German-European Industry.

Beyond H_2-Innovation what else activities are you pursuing to promote the H_2-rampup?

Meyer: Together with strong industrial partners we are part of H_2-Ruhr. This is an initiative to support the production, logistics and application of hydrogen as a commodity in the Ruhr Valley Area. In order to reduce CO_2 emission and balance H_2-demand and -supply from an economic and ecologic point of view we very much believe in local clusters to be established in the surroundings of out use NG-pipes which can be repurposed to H_2-Pipes at low administrational efforts and low cost. Such local clusters than will be interconnected to regional cluster and finally connected to the emerging national H_2-grid. Together with local partners actually we are structuring such first local clusters.

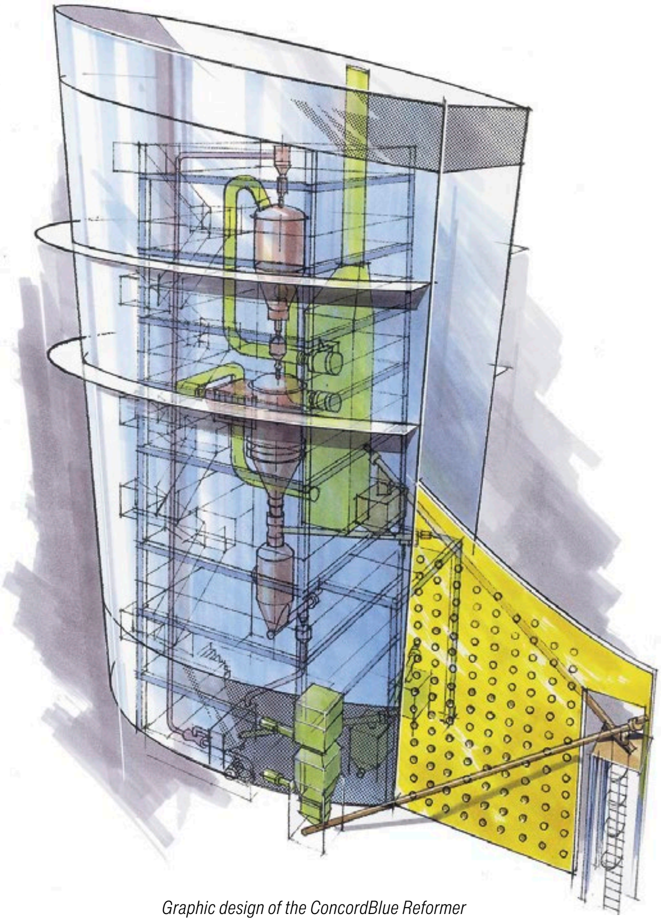
Furthermore, supported by advisors with expertise in Global Climate Finance and Funding & Sustainability Services we are actually working to develop and establish H_2-Ruhr Fonds. This Fonds is planned as an instrument enabling the global financial community to effectively invest into CO_2-reduction and H_2-ramp in the Ruhr Valley Area. ■

Source: BAUART GmbH & Co.KG, Dortmund

»Decarbonised hydrogen from waste – a regulatory framework to **climate neutrality**«

by: **Dr Maximilian Kuhn** (Advisor, Hydrogen Europe)

Worldwide, there is a waste problem. Pictures of polluted oceans and micro plastics found at most remote areas come into our mind. At the same time, we still incinerate waste or deposit at landfills and cause harmful emissions. In Europe this applies particularly to a wide variety of organic and non-organic residual and waste materials from industrial and municipal environments as well as agriculture and forestry. A solution to this waste problem is the thermochemical conversion of residues to produce regenerative gases such as hydrogen.



Source: ConcordBlue

Graphic design of the ConcordBlue Reformer

Especially for the decarbonisation of the economy, renewable hydrogen is on everyone's lips. However, taking European policies into consideration, this refers mainly to hydrogen produced from water electrolysis using renewable electricity. Other production methods are mostly neglected in current European policies. Due to the limits of renewable electricity local deployment in Europe, the demand for renewable hydrogen to decarbonise European mobility and industrial sector can hardly be fulfilled in the medium term. Therefore, a technology-open approach is required that also takes other routes of renewable hydrogen production into account in order to contribute to the ambitious targets set by the Commission, in line with the REPowerEU strategy.

Today, in the EU alone 200 million tons of non-recycled waste are either landfilled or incinerated, each year. Additionally, a wide variety of sustainable waste fractions of biomass are available as organic residues in large quantities and are currently either under-valued, landfilled or thermally utilised in waste incineration plants to generate electricity. Various companies, such as HAFFNER ENERGY, ConcordBlue, BHYO, INDELOOP or PLAGAZI, have developed their unique technology where non-organic residual and waste materials or biomass is exposed to high temperature, within a closed system that results into the production of a syngas which, thanks to separation technology, will be converted into hydrogen. Such hydrogen with high industrial purity, can be used from fuel cells to industrial processes, at 25 % of the cost compared to other green hydrogen production processes. And even more: While renewable gases offer an excellent alternative to fossil fuels for our industries and the mobility sectors, more needs to be achieved. According to the IPCC, the world and the EU must implement large-scale permanent carbon removal to keep global warming within the targets set by the Paris Agreement. Thus, it requires to go beyond net-zero goals and actively remove Carbon Dioxide from the atmosphere.

This is what some of these technologies do, using sustainable waste of biomass, and co-producing Biochar when producing renewable gases during the thermolysis process. Biochar is the transformation of biogenic carbon (naturally contained in the biomass) into a stable form of carbon which can then be stored in soils (when used as a soil amendment) or incorporated into materials (such as cement), thus being considered as a permanent carbon sink.

These thermochemical conversion processes, such as thermolysis, pyrolysis and gasification, convert organic residues, non-organic residual and other waste materials into synthesis gas to produce hydrogen at an unsubsidized cost of appr. € 2-3/kg H_2 and with significantly lower specific greenhouse gas emissions than the current fossil benchmark (steam methane reforming). On a full life cycle analysis and taking the potential of the Biochar to sequester CO_2 based on its final use, the thermochemical conversion of sustainable waste of biomass would even allow to produce hydrogen with a negative CO_2 footprint. Of the approximately 308 million tons of waste produced annually in the EU that is suitable for hydrogen production, at least 31 million tons of hydrogen could be produced in the EU, reducing Europe's dependence on fossil imports from overseas.

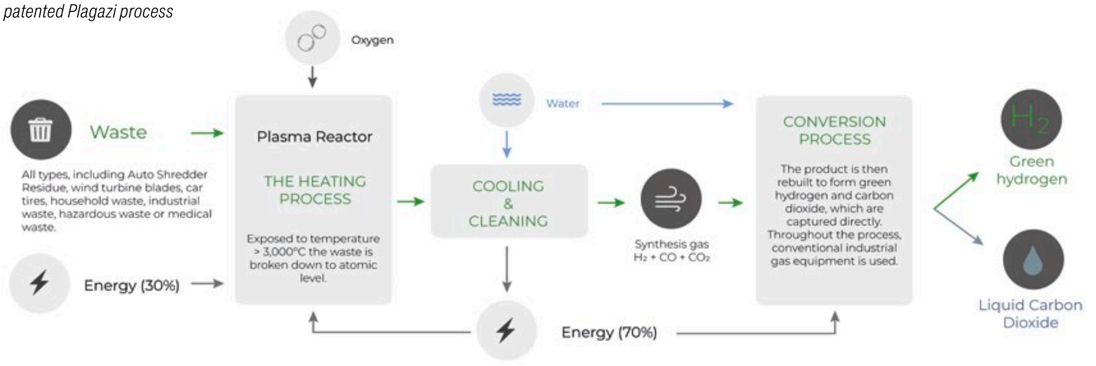
Reintroducing waste into the circular economy

The advantage of these processes lies in their high flexibility regarding the feedstock, which makes it possible to thermochemically convert a wide variety of solid and liquid waste into a high-quality synthesis gas that is then available for various utilisation routes. Also, some of these processes could also allow for the recycling of previously unrecyclable waste such as wind turbine blades, plastic scrap or Auto Shredder Residue into low carbon hydrogen, solving two European problems at the same time. The direct thermochemical conversion of organic residues, non-organic residual and waste materials into a hydrogen-rich synthesis gas, from which hydrogen is separated, allows two to three times higher hydrogen yields per kilogram of residue compared to waste incineration plants via combustion and subsequent electricity use for electrolysis. The hydrogen produced in this way thus has a significantly greater decarbonisation potential, while solving a universal waste problem. Additionally, by giving value to sustainable waste of biomass from agriculture or forestry, these technologies are supporting a local and circular approach, strongly enhancing the value of the territories and contributing to their energy independence. Already today, this technology is present in several countries in Europe:

Plagazi's contribution to circular economy

For instance in Sweden, at the Köping Hydrogen Park, PLAGAZI will annually produce 12,000 tons of green hydrogen, 51 MW annually, from 66,000 tons of unrecyclable waste and provide the municipality with 10 MW of district heating. The Köping Hydrogen Park will be one of the largest green hydrogen production sites in Sweden, laying the foundations for a sustainable hydrogen future while fully eliminating the CO_2 emissions from the nearby incineration plant, Norsaverket.

Furthermore, Project Havelstoff, located in Premnitz, Germany, aims to produce 8,000 tons of green hydrogen, or 35 MW annually, by recycling 44,000 tons of non-recyclable waste and reducing 100,000 of CO_2 emissions per year. The Patented Plagazi Process requires less than 10 kWh/kg H_2 of external energy consumption since the process



The patented Plagazi process

Source: Plagazi

uses the energy content inside the waste itself. For example, an annual production of 35 MW of hydrogen via the patented Plagazi Process requires only 7 MW of electricity, while an average electrolysis plant would need about 50 MW of electricity for the same amount of green hydrogen production. Thus, these projects create opportunities by converting previously non-recyclable waste into hydrogen at a fraction of the cost of an electrolyser, paving the way for Europe's new circular economy, and road to CO_2 neutrality and energy independence.

HAFFNER ENERGY: production of hydrogen with negative carbon balance

In France, the company HAFFNER ENERGY already supplied a first industrial unit to R-HYNOCA, a R-GDS group company (operator of the gas distribution network in Strasbourg). This unit has been started-up in June 2021 with the production of hypergas (hydrogen rich syngas) and will deliver pure hydrogen from the second quarter of 2023 onwards as soon as the hydrogen refueling station from McPhy is commissioned. The HYNOCA process is following a modular approach, designed to minimize ground space and facilitate export. Each HYNOCA module requires 10.8 tons of sustainable biomass per day at 30 % humidity, which can in most cases be sourced locally in a 50 km area. One HYNOCA module allows to produce 120 tons of renewable hydrogen per year or 4,440 MWh PCI of renewable syngas. Additionally, each module will co-produce 660 t/year of biochar, which has the potential to sequester 1,440 tons of net CO_2.

When as an example talking about mobility, this means a standard hydrogen refueling station based on two HYNOCA modules will provide renewable hydrogen to fuel either 72 Buses travelling an average of 40,000 km/year, 900 light utility vehicles travelling an average of 20,000 km/year each or 1,700 light vehicles travelling an average of 15,000 km/year. Additionally, the 2,880 tons of CO_2 potentially sequestered would be equivalent to the CO_2 emissions of 1,595 light vehicles travelling an average of 15,000 km/year. The overall energetic efficiency for an HYNOCA module is 70 %, and the process only requires a fraction of its own gas to provide the required energy and the hydrogen can be produced with a negative carbon balance of 12 kg (net) of CO_2 per kg of hydrogen produced, based on full life cycle analysis.

ConcordBlue: scalable modular solutions to produce decarbonized hydrogen

In Germany, ConcordBlue, a Düsseldorf-based tech company, is building scalable modular solutions that can be as small as 250 kW, and as large as 400 MW. Using a staged reforming process based on water steam thermolysis, it can convert numerous types of waste into decarbonized purity 5.0-hydrogen, syngas, electricity, heat and biofuels. Since 2002, the company has completed ten facilities in Germany, India, Japan and the United States. The Omuta plant in Japan was the first commercial biomass-to-hydrogen facility in the world. The plant in Pune, India, has produced 10 MW_{th} of syngas since 2012. At its site in Herten, Germany, ConcordBlue can process 28,000 tons of biomass and waste per year, producing 2,624 tons of decarbonized hydrogen. Long-term supply contracts with local waste companies have already been executed.

BHYO: sustainable hydrogen from regionally produced biomass

Another example from Germany is BHYO GmbH, which is producing sustainable hydrogen from regionally produced biomass and biogenic residues with decentralized plant concepts for regional recycling and supply. Here, the primary raw material for the BHYO plants is biomass and biogenic residues without further use, which are usually generated in the economic cycle as a waste product at the end of a value chain. Various otherwise difficult to use biomass and biogenic residues such as sewage sludge, biowaste or landscape pruning would also qualify. The hybrid gasification process developed of BHYO has technological advantages over other gasification processes and enables the economical production of hydrogen from biomass and biogenic residues and is particularly suitable for decentralized plants of medium size (50 to 100 kg/h of hydrogen) and within the framework of regional concepts, where the feed radius of the biogenic residual currents used defines the plant size.

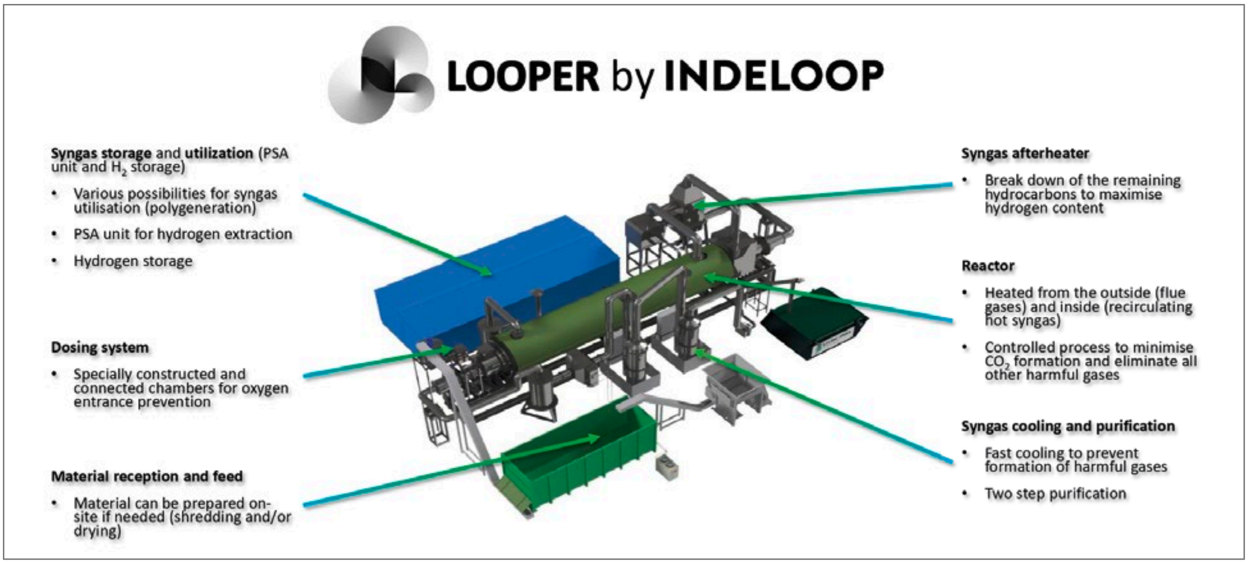
Hydrogen production via Looper from Croatia

Also, a highly innovative company in Croatia, Indeloop Ltd. has developed two testing systems located at the company's headquarters in Zagreb. These systems, can process 1 and 2 t of organic material per day, showing promising results regarding systems efficiency, sustainability and hydrogen production. Today the company is working on the scale up these systems and is now constructing a Looper that will be able to process 6 t of organic material per day and is planning soon to start construction of a Looper that will be able to process 25 t of organic material daily. Initial testings showed that, on average, from 1 t of organic material, 40 kg of hydrogen can be produced. In 2023 the company expects a production of an additional 5 to 10 t of hydrogen per day in Europe alone from its Loopers.

Outlook: we need a regulatory framework

The development of guidelines for the classification of the hydrogen produced from this and comparable technologies would significantly accelerate their market penetration in Europe. It is necessary to define suitable approaches for balancing the greenhouse gas emissions for this hydrogen production pathway and thus to determine the CO_2,eq footprint of the hydrogen produced in this way. Currently a European Guarantee of Origin system is under development, within ISO 16325 at European level, or with voluntary schemes for "Low-Carbon Hydrogen" from CertifHy. Within the framework of certification and standardisation, a uniform certification system should be archived. Here, politicians are called upon to set a framework that is technology-neutral and oriented towards the real-life cycle emissions in order to evaluate its potential for decarbonisation.

The companies mentioned have recognized the potential of waste-to-hydrogen for the circular economy and hydrogen future and is contributing to the achievement of European climate targets with its proprietary European technologies. Now it is up to politicians and decision-makers to recognize the societal value of novel technologies contributing to the hydrogen economy. ■



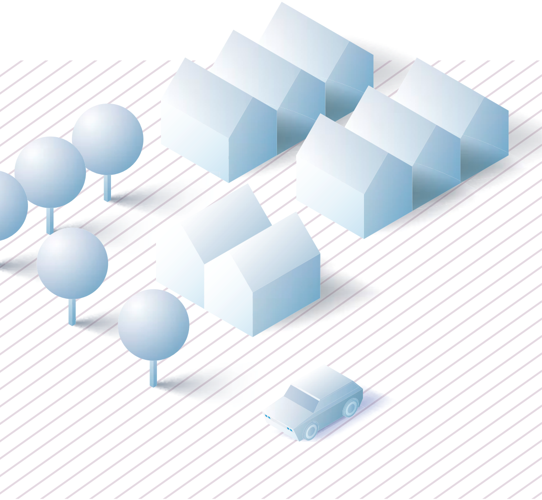
Source: indeloop ltd.

Looper, Croatia

»Pyrolysis-based island solutions could become established in Bavaria«

The editorial team talked to **Dr Gregor Neunzert**, Head of Gas Participations of Stadtwerke München, concerning island hydrogen solutions in Bavaria and the benefits of pyrolysis technology.

Source: SWM



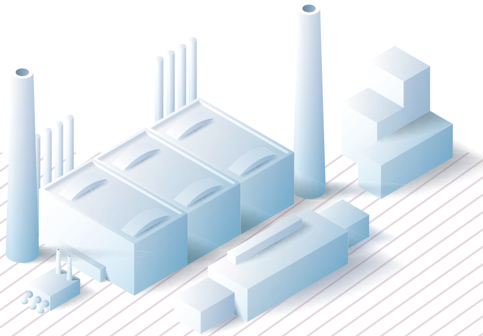
Dr Neunzert, what strategies and plans are being pursued by Stadtwerke München with respect to the decarbonisation of energy supplies in general and the development of a hydrogen market in particular?

Dr Gregor Neunzert: The city of Munich has set itself the target of becoming climate-neutral by 2035. In this connection, Stadtwerke München, the municipal utility of Munich, already launched a renewable energy offensive in 2008. The objective of this offensive is for the city to cover its entire annual power demand – about seven terawatt-hours – with 100 percent green power from its own facilities by 2025. Currently, we have reached about 90 percent of this target. In addition, district heat is supplied to about one-third of the population of Munich. The fossil fuels currently being used for this purpose are to be replaced, especially by geothermal energy, by 2040 at the latest. As regards the energy transition in the mobility sector, we are not only massively expanding our offering of bus and rail services but also intend to convert the entire bus fleet to battery-electric drive systems by 2035. In contrast to some other cities in Germany, we have opted for electric power and not hydrogen in this sector.

In the energy generation sector, we are now working on a hydrogen utilization strategy and are in the process of producing a database for this purpose. The targets of the strategy could be similar to those mentioned above for the electric power sector. Certain specific measures have already been taken. Some gas turbines at our new plants are already designed for the addition of between 10 and 20 percent hydrogen. In the course of modernisation work over the next few years, further turbines are to be modified.

To what extent do the conditions for hydrogen utilization by a company in southern Germany differ to those that apply to companies in the North or West of Germany?

Dr Neunzert: The plans of gas transmission system operators are based on the European H_2 Backbone, a European transmission system for pure hydrogen currently in the process of development. In view of the development stages now planned, it seems that Munich will



probably only be connected to the Backbone at a very late stage, probably after 2035. Until then, we will have to rely on island solutions, i.e. on renewable energies generated on a decentralised basis, and we expect that such solutions will be adopted throughout Bavaria. In addition, Bavaria has relatively few onshore wind farms for the generation of renewable power, which will be essential for the production of green hydrogen. Pyrolysis for the production

What benefits are connected with pyrolysis?

Dr Neunzert: The benefits of pyrolysis are self-evident: compared with the production of green hydrogen by electrolysis, the production of turquoise hydrogen requires about 80 percent less electric power. The reason is that the chemical bonding of the water molecule is significantly stronger than that of methane, which is used in pyrolysis. The solid carbon produced by pyrolysis can, depending on the quantity and quality, be used to replace graphite as a feedstock in the chemical industry and generate potential income. Larger quantities would certainly be interesting for tyre manufacturers. However, action will need to be taken to ensure that the carbon is not returned to the atmosphere at some point, for example if used tyres reach waste incineration plants. In the case of very large quantities, it might not be possible for them to be absorbed by the market, in which case they would need to be disposed of on a landfill.

How do you assess the prospects for a market ramp-up of pyrolysis technology?

Dr Neunzert: VOne advantage of turquoise hydrogen is its scalability. In the USA, hydrogen burners for domestic use are to be offered in the near future, virtually allowing pyrolysis in the home. This is a very interesting idea because the existing gas infrastructure in Germany could very easily be used. Medium-sized installations for businesses and hotels are already in use and major producers such as BASF are operating large pyrolysis pilot plants. However, for a robust market ramp-up, we will also need clear, binding rules on the definition of green or low-carbon hydrogen. Only then will this technology have genuine long-term prospects. ■

> *» Munich will probably only be connected to the H_2 Backbone after 2035, which is why we are opting for island solutions. «*

INFORMATION

The Burghausen/ChemDelta Bavaria pilot project

The objective of the Burghausen/ChemDelta Bavaria pilot project is to change chemical industry processes over to non-fossil carbon sources and to establish hydrogen refuelling infrastructure in the Burghausen region. Another focus is on creating a nucleus for the Bavarian hydrogen economy. The project pursues a holistic approach to leveraging the industrial potentials of hydrogen technology in the chemical industry and possible platform and linked products for mobility, industrial applications and regional development.

Source: Westnetz GmbH

»Pyrolysis is a transitional technology that can be rolled out rapidly«

The editorial team talked to **Dr Andreas Breuer,** Head of Hydrogen with Westnetz GmbH, concerning the design of the project "HydroNet – the Sauerland model region for climate protection" and the associated use of pyrolysis technology for hydrogen production.

Dr Breuer, what objectives are you pursuing with HydroNet, the Sauerland climate protection model region?

Dr Andreas Breuer: With the Sauerland climate protection model region, we are planning the energy system of the future. Our objective, together with our partners, is to make the Arnsberg region climate-neutral using advanced hydrogen technologies. Over the next few years, industry, medium-sized companies and the mobility sector are to embark on the use of hydrogen. The key element of the project is a natural gas pipeline with a length of 11 kilometres which is to be converted to hydrogen and to serve as an energy storage facility. We have quite deliberately decided to call the project "climate protection model region" and not "Sauerland hydrogen project", for example because we want to show how a region can develop sustainably with respect to climate protection goals.

What has been the response of the companies and partners participating in the project?

Dr Breuer: In many discussions concerning a variety of hydrogen projects, I have found that companies are already working very intensively on this topic – both on their own initiative and in response to the wishes of their customers. Customers are now calling for products to be manufactured on a carbon-neutral basis in the future, for example in the automobile component sector. Companies now face the challenge of transferring their theoretical plans to the real world. This is where we see our task as a network operator at Westnetz. We will support the entire region by starting to develop hydrogen infrastructure and connecting companies to this infrastructure. We will be doing even more: the development of the Arnsberg region towards climate neutrality could serve as a blueprint for other regions. One example is the neighbouring district of Soest, which has already indicated that it is interested.

Why will you also be using turquoise hydrogen within the framework of the HydroNet project? What are the benefits?

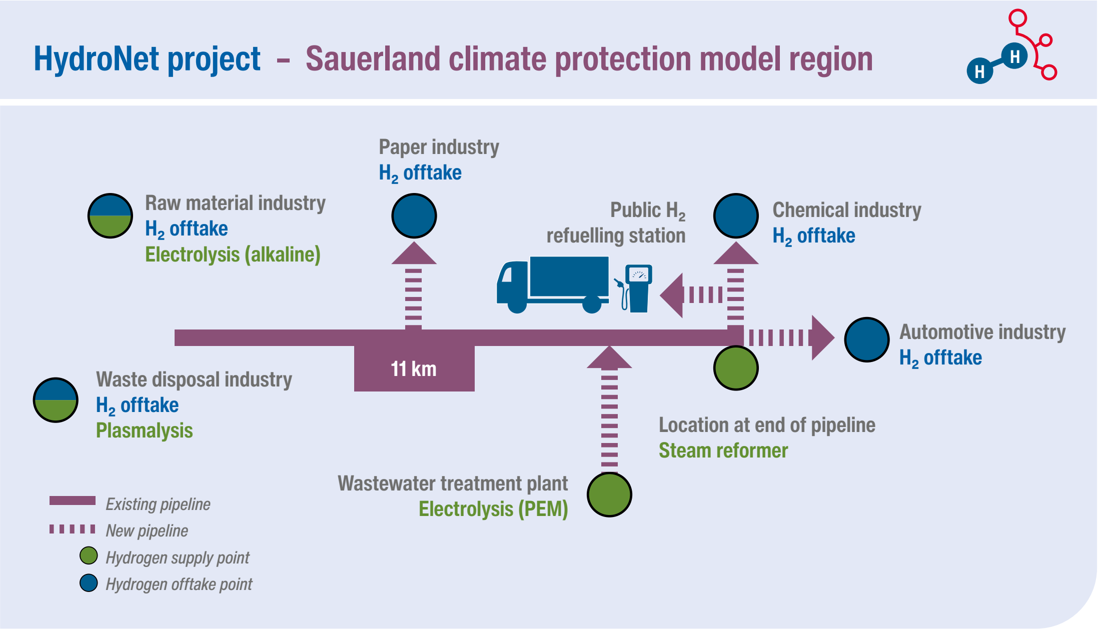
Dr Breuer: In addition to electrolysis, we have decided to opt for pyrolysis technology because we want to show companies what is feasible today. We consider pyrolysis to be a transitional technology that can be used very soon because we will be unable to cover energy demand directly and solely using green hydrogen. The conditions are favourable: one of our partners, a waste disposal company from Arnsberg, already has a raw material, residual waste, which is very well-suited for pyrolysis, available at its waste incineration plant. This means that a raw material, in this case methane, cannot only be utilised but can also form the basis for climate-neutral energy generation. The solid carbon produced by the process is by no means waste but is rather a valuable raw material which we will be making available for road construction within a partnership arrangement. Depending on the quantities produced, we could also supply carbon to a nearby tyre manufacturing plant in Dortmund. In order to obtain subsidies for the project, it will be essential to provide evidence of the sustainable use of all components.

What is the current status of the project and when is production due to start?

Dr Breuer: In February 2022, we submitted the project outline to the regional authority in Arnsberg and hope that it will now be possible to submit the funding application by the autumn. If our application is approved, we could officially start work on the project at the beginning of 2023. We expect that the preparation of the project, including the approval procedure and a further infrastructure review, will take between two and three years. We will be carrying out comprehensive burner tests and 3-D combustion chamber simulations before companies are changed over to hydrogen. On this basis, we plan to start hydrogen supplies in 2026.

I feel that it is important to emphasise that we will be effectively supporting the entire region with this project. It is true that we will be starting with an island solution, but there will be a possibility of connection to the hydrogen backbone currently being planned by transmission system operators in the future. We could transfer this project to virtually any region in Germany. One thing is clear: companies throughout the country face more or less the same challenge. They want to reduce CO_2 output and to use hydrogen but they do not know how they can obtain this raw material. Although we cannot simply flick a switch and change all the companies concerned over to 100 percent hydrogen immediately, we have made a start and are taking the first steps, with prospects of transferring the project to many other regions. ■

> »*Our project is not intended to be unique but can be transferred to many other regions.*«



Source: Westnetz GmbH

Overview of the basic structure of the Sauerland climate protection model region

For more information, please visit:

www.dvgw.de

www.hydrogeneurope.eu

www.energie-wasser-praxis.de

About DVGW

The DVGW, Deutscher Verein des Gas- und Wasserfaches e.V. (German Technical and Scientific Association for Gas and Water), is a recognised rule-setter for the gas and water industry, a technical and scientific know-how provider, and an initiator and promoter of industry-related research projects and innovations. The DVGW is the institution designated in the German Energy Industry Act for hydrogen infrastructures. The DVGW is also member of Hydrogen Europe Research.

About Hydrogen Europe

Hydrogen Europe is the European association representing the interest of the hydrogen industry and its stakeholders and promoting hydrogen as an enabler of a zero-emission society. With more than 400+ members, including 25+ EU regions and 30+ national associations, Hydrogen Europe encompass the entire value chain of the European hydrogen and fuel cell ecosystem.