Expert Report

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Heating energy and process heat using climate-neutral hydrogen

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A continuously growing number of companies are choosing to reduce their CO_2 footprint or even achieve CO_2 neutrality. For production companies, this often raises the question of how to provide process heat in a climate-neutral way. This challenge also arises when heating large properties or when operating local or district heating grids on a megawatt scale. The use of green hydrogen in boiler systems represents a significant opportunity. As well as generating a high boiler efficiency rate of up to 98 %, its combustion is entirely CO_2-neutral. The following technical report focuses on solutions using hydrogen boilers and on technical measures for safe, clean hydrogen combustion.

Decentralised stand-alone solutions with hydrogen
Experts and gas network operators have been discussing proportionally mixing green hydrogen into the natural gas network for some time. Current opinion states that 10–15 % hydrogen can be mixed into existing networks safely and with little effort or expenditure. However, it must be noted that by volume, hydrogen offers only one third of the net calorific value of natural gas.

In the short- and medium-term, therefore, decentralised solutions with 100 % green hydrogen represent a more attractive alternative for achieving CO_2-neutrality quickly. A number of pilot projects are currently under way on industrial areas and in regions with a high energy density in different locations around the world. In Wunsiedel in Germany, for example, an electrolyser with an electrical power intake of 6 MW in the initial development phase is currently being built. Surplus hydrogen is used in a 5 MW Bosch boiler to provide a heat supply and for drying wood products in a sawmill, among other uses. However, other combinations of district heating with electromobility and decentralised green energy supply, such as a municipality, are also conceivable applications.

But why should anyone choose the complex path of generating their own hydrogen (Figure 1), accepting a loss of efficiency of around 30 % in the process? After all, green electricity can be used directly in electric boilers or hybrid boilers, achieving a high degree of efficiency. It's a plausible response – on sunny or windy days, the electricity is directly available for use in plants and production with a degree of efficiency over 99 %. Due to the fluctuations in the availability of green electricity, which is affected by the weather conditions and time of day, however, an additional CO_2-neutral energy source is required for compensation. This is where the benefits of hydrogen come to the fore: It can be stored at a higher energy density and achieves high degrees of efficiency when used. For these reasons, it is expected that hybrid process heating concepts, such as boilers with multi-fuel burners and electric heaters, will become an ever more attractive option. The majority of these systems are currently operated using green electricity and natural gas due to a lack of readily available hydrogen.

What makes hydrogen combustion different

Green hydrogen is an important energy source for our future and is excellent to be used as a fuel for CO_2-neutral heating energy and process heat generation. However, when comparing its use to that of natural gas, there are certain factors and differences to consider. The flame, which reaches approximately 2000 °C, is significantly hotter, which facilitates the thermal NO_x formation. What's more, this fuel burns and ignites much more quickly – which is why a mixture of hydrogen and oxygen is also known as detonating gas. As the smallest atom in the universe, hydrogen is able to diffuse through a variety of materials and even metals. It is essential that the unintentional formation of detonating gas is prevented.

The hydrogen's net calorific value per unit of volume amounts to around one third of that of natural gas. Correspondingly, it follows that three times the gas volume of hydrogen is required in order to generate the same amount of energy.

Another significant difference is the colourless flame when pure hydrogen is burned – however, the addition of just a small amount of natural gas causes it to change to a blue colour. The heat emission is also different. While a natural gas flame produces a large amount of radiation in the infrared spectrum, a hydrogen flame emits a low, albeit measurable, amount of ultraviolet radiation. In certain combustion systems, this is used as a measured variable for combustion control.

Figure 1: Simplified illustration of green hydrogen production with process heat integration.

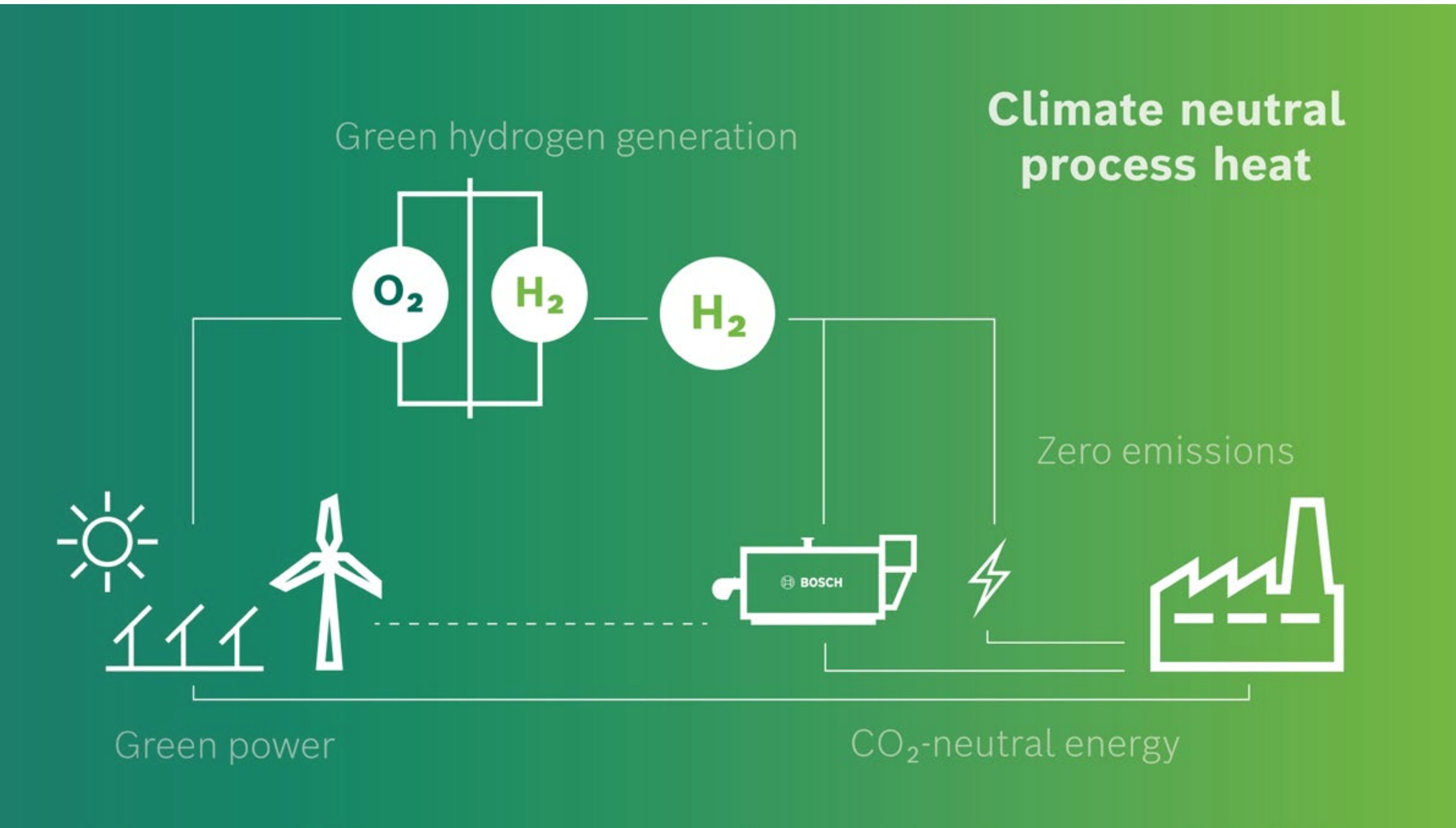

Figure 2: Example of an implemented fuel concept with hydrogen, natural gas and light fuel oil for a Bosch boiler system at a pharmaceutical company.

Technological requirements for hydrogen-powered heating boilers and steam boilers

The use of hydrogen in boiler systems, and the corresponding technology, is commonplace in sectors in which hydrogen is created as a waste product of chemical processes. As a result, there are a range of known technological requirements for safe, efficient handling. Over the past two years, Bosch Industriekessel has manufactured and commissioned a number of systems for customers in the pharmaceutical sector (Figure 2) and plastics manufacturing industry, and for green heat supply.

The following solutions, among others, are suitable for making use of this environmentally friendly gas: The prerequisites include comprehensive technical measures and components that enable triple the fuel volume to be provided and make it possible to control the higher combustion temperatures and faster combustion behaviour. This concerns lines, nozzles, high-temperature-resistant components that come into contact with flames, burner fans and the combustion chamber, in particular. Depending on the project requirements, a 100 % hydrogen boiler can be up to 10 % larger than a natural gas boiler that produces the same output. However, measures can be taken on the flue gas side that mean a larger boiler is not required – for instance, attempting to get as close as possible to the original rated output when retrofitting an existing system and thereby continuing to comply with strict NO_x limits. The hydrogen burner is usually designed as a complex multi-fuel firing unit with a correspondingly demanding control system, in order to enable full flexibility and supply reliability.

The applicable emission regulations regarding NO_x can also be reliably met when using hydrogen firing units. This is generally achieved using flue gas recirculation which reduces the flame temperature. In this process, the flue gas generated by the boiler, which is low in oxygen, is mixed with the combustion air. The partial pressure of the oxygen content is reduced, which delays the reaction between the hydrogen and oxygen, thereby lowering the average flame temperature. This results in an effective reduction in thermal NO_x formation.

To prevent reignition of the hydrogen firing unit in the fuel supply line, the combustion system features a flame arrestor upstream. This can be designed either statically, e. g. as deflagration or detonation arrestor, or dynamically. The dynamic variant causes a significantly higher gas escape speed from gas ring or gas lances than the flame speed. Regulations or binding rules describing hydrogen burners in industrial boiler plants are not yet available. Even though standardisation relating to hydrogen has gained momentum over the past year, it is currently the case that every system must be subjected to an individual inspection. This inspection must take into account issues such as specific explosion protection specifications (ATEX level), materials selection, the suitability of the equipment used, and operational aspects.

In the flue gas technology sector, established design rules and technologies can be used like in natural gas firing units. The hydrogen present in the form of methane in the natural gas is finally also combusted to produce water vapour. This results in the significantly lower CO_2 emissions of natural gas compared to that of coal, which primarily consists of carbon. The high specific thermal capacity or enthalpy of the water vapour in the flue gas enables condensing technology to be used when combusting hydrogen, as well. During the phase change from water vapour in the flue gas to liquid water, significantly more energy is released than during the pure temperature reduction in waste heat usage. The flue gas temperature can be reduced from 130 °C to 60 °C using condensing heat exchanges, resulting in fuel savings of up to 7 %. However, this requires a heat sink, for instance to pre-heat the process water or to heat production halls and offices. In practice, the overall efficiency of systems of this kind is up to 103 % relative to the net calorific value, or 98 % from a primary energy perspective. When using condensing technology in combination with hydrogen combustion and flue gas recirculation, there are additional aspects to consider, particularly in the case of warm/hot water boilers with low return flow temperatures.

Why not use green electricity directly?

The use of purely electrical steam and hot water generators in commercial and industrial processes seems very attractive from a technological perspective. The boiler house no longer needs a chimney, which makes it more future-proof with respect to emissions. Economically, however, this solution is less often suitable in countries like Germany. Compared to the same quantity of natural gas, the costs of purchasing electricity for most operations in Germany are around four times higher. What's more, each kWh of electricity that is supplied to the end user still involves around twice as much CO_2 as natural gas. Nevertheless, electrical steam generators do have their strengths – e. g. in small businesses or in hospitals with a steam demand of only a few hours each week. Additionally, the natural gas network has not been extended to cover rural areas comprehensively. Similarly, some businesses own photovoltaic systems and can use electric boilers or hybrid boilers (Figure 3) with electrical heater rods and burners to increase the proportion of green electricity they use by a significant amount. Decisive factors for "power-to-heat"

Figure 3: Hybrid boilers with electrical heater rods generate up to 5 MW of CO_2-neutral process heat with regenerative energy usage. The burner of the Bosch boiler reliably covers any additional demand.

Ready for the future: Process heat solutions from Bosch for the use of hydrogen, biofuels or green electricity – both for new systems and for retrofitting existing systems.

include energy prices and the underlying policies in the corresponding country. In regions with low energy prices and correspondingly well-established network infrastructures for large consumers, the use of electric boilers is already on the rise.

Other alternatives, such as the integration of heat pumps, are typically only profitable in production companies when they are used for low-temperature applications like heating. In contrast, many production processes require steam and hot water, often at temperatures far exceeding 100 °C. At these high temperature levels, the efficiency (more precisely, the Coefficient of Performance) of heat pumps is lower – as a result, they cannot be operated cost-effectively. Furthermore, there is often no sufficient source of waste heat available to supply the heat pumps, since the achievable increase in temperature is usually less than 50 Kelvin, e.g. from 15 °C to 65 °C.

Establishing a sustainable energy supply

What is the current recommended course of action for commercial and industrial companies with respect to their future heating energy and process heat supply? It is not currently possible to predict whether hydrogen will become the energy source of the future. The same goes for the timescale in which businesses will be offered the opportunity to completely eliminate CO_2 emissions from their chimneys through the use of energy sources such as natural gas, oil or wood. While green energy sources with annual CO_2 fixing (biogas, bio-oil) are only available to a limited extent, green electricity and hydrogen represent a chance to comprehensively replace this avoidable CO_2 load. In some cases, it is possible to modernise existing boiler systems for an acceptable cost. Currently, the limiting factors are still availability and economic feasibility – the technology itself, in contrast, is fully developed and ready for the use of hydrogen. As a result, it is advisable to include interfaces for later retrofitting in new systems, for instance by including a blind flange for an electrical heating rod, or by sizing boilers/combustion chambers to include enough space for later conversion to hydrogen. In any case, checking existing systems to assess their future suitability is a practical step. This process frequently uncovers many potentials to save CO_2, which can be used, for example, through heat recovery equipment – resulting in not just a decrease in fuel costs, but a sustainable reduction in the company's CO_2 footprint.

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