Expert Report

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Process heat supply in the context of decarbonisation – how will the industrial boilers of the future look?

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Almost every product that is used on a daily basis in industrialised nations – whether foodstuffs or vehicle components, clothing or medicines – is manufactured using thermal energy. Most of the time, this heat originates from energy generators such as steam boilers, hot water boilers and CHP plants, although occasionally it can also come from thermal pumps, waste heat or solar thermal energy. Until now, in the context of process heat, decarbonisation has been understood to refer to the firing-side removal of carbonaceous coatings in the boiler. With regard to discussions surrounding CO_2 as a driver of climate change, the topic is somewhat different: Here, decarbonisation refers to the conversion of production processes to CO_2-neutral technologies. Particularly with regard to process heat, this topic is somewhat more nuanced and must be considered accordingly. It constitutes larger technical challenges than with pure heating applications. Many industrial processes require high temperatures and pressures as well as large connected loads of up to several hundred megawatts.

An economic and global consideration

Energy prices vary significantly by region. While in Saudi Arabia, it is possible to hear statements such as "for us, diesel is cheaper than water", someone elsewhere could be trying to squeeze out the last tenth of a percent of efficiency from their process heating systems. Even within Europe, prices vary greatly. For example, you can compare the electricity prices for non-household customers in France (nuclear power, €0.09 per kWh) or Sweden (hydro-electric power, < €0.07 per kWh) with those in Germany (€0.16 per kWh). However, one thing is common among a number of nations: Natural gas is affordable in the majority of countries at €0.025–€0.035 per kWh. The supply of natural gas and the processes involved in its combustion are particularly reliable and produce comparatively low emissions with a simultaneously high degree of primary energy efficiency. This is indeed also a reason why there is still plenty of savings potential through modernisation measures that is yet to be taken advantage of in the majority of existing plants today. Alongside components for waste heat utilisation and more efficient process heat consumers, new digital efficiency assistants provide the opportunity to reduce losses through optimisation of operating methods.

While the use of heating oil is continually on the decline, natural gas is enjoying ever-increasing popularity when it comes to industrial process heat supply. The tax on CO_2 emissions, that has been introduced to some countries lately, is going to have direct impact on the gas preis. Experience from previous decades shows that, in the event of increasing energy prices, measures to increase efficiency are implemented by the industry first. Only once these have been exploited will a shift in technology or a conversion to a different fuel be considered. It is therefore a likely assumption that industrial enterprises will be one of the last sectors to completely branch off from the use of natural gas as an energy source. In general, the changeover here entails higher investments without the usual associated outcomes, e. g. an increase in production volume. For many decision-makers, the choice is therefore economically driven. Experience shows that decisions regarding investments are then often only made if a return on investment capital is achieved within a maximum of two to three years and significant reductions in costs are to be expected in the long term. Otherwise, decisions regarding large investments for the replacement of thermal large-scale plants are much less likely to be implemented.

Which applications and processes are affected?

If thermal applications for industrial and commercial enterprises are considered according to different groups, they can be roughly distinguished as follows: Heating applications, processes with lower temperatures up to 110 °C and high-temperature processes that mostly fall between 110–300 °C. In special cases, such as in the manufacturing of fuels, or with direct heating, e. g. in metal production, significantly higher temperatures are also encountered.

Whether hot water or steam is used as a heat carrier medium in a range above 110 °C is hardly a matter of significance in the context of decarbonisation. Much more important is the required temperature level. For heating applications (< 110 °C), there are some alternative technologies that can be used individually or in combination with one another. Examples include

"We are taking responsibility for climate change and therefore choosing to act now," explains Dr Volkmar Denner, Chairman of the Board of Management at Robert Bosch GmbH. "Climate protection is feasible and can be implemented quickly with the necessary course of action," he emphasises. "Our investments do not just benefit us at Bosch; rather, they are of benefit to the whole of humanity."

An immediate conversion of all fossil fuel-powered process heat generators in Germany to electrical operation would likely overstrain both the electricity generation capacities and the electricity grids.

high-temperature thermal pumps or solar-thermal systems for support. These areas are most likely to undergo a technological transformation. A sharp rise in the price of gas and falling prices for these technologies would provide the necessary circumstances for this. In addition to heating applications, cleaning or CIP (clean-in-place) processes can fall within this temperature range.

For applications above 110 °C, the established technology for generating high temperatures is the combustion of fuel in solid, liquid or gaseous form. Occasionally, systems based on electrical energy are also used. Should gas or oil prices rise sharply, it is anticipated that alternative energy sources will become increasingly more attractive in terms of cost. In the event of a change in the high price difference per kWh for natural gas in comparison to electricity, hybrid or electrical systems could become a more enticing prospect. Namely, this concerns boilers that possess an electrical heating element in addition to the conventional burner. However, these solutions are only conducive to decarbonisation when the electricity does not originate from coal-fired power stations or similar plants. At present, every kilowatt hour of electricity in Germany still results in roughly twice as much CO_2 as the same quantity of energy from natural gas, up to the point where it reaches the house connection.

Connected load: A threat of blackouts when starting up plants?

Currently, a total of approximately 545 terawatt hours of electricity is generated by power plants in Germany each year. At the same time, the installed capacity of commercial/industrial boiler systems (only gas-fired systems) amounts to 340 terawatt hours. Even in the medium term, an expansion of the electricity generation/distribution by this amount (approximately 60 %) appears to be an unrealistic prospect. Nevertheless, let’s imagine a purely electric scenario in which all steam, hot water and shell boilers are converted to electrical boiler systems. We can take the example of a paper factory or a power plant with a steam turbine, which starts its steam boiler system with a capacity of 100 tons of steam per hour. At full load, the system draws a load that corresponds to that of approximately 75,000 vacuum cleaners at full capacity (since 2017, this has been limited to 900 watts). In some places, however, there are a multitude of such large boiler systems within the same electricity grid, and many companies begin production at similar times of the morning. Today’s electricity grids and power plants are quite simply overstrained by these high capacities and dynamic fluctuations on the part of consumers. If we also take into account the increasing fluctuation of the availability of electrical energy from wind and solar power, blackouts would be hard to avoid.

The pure electrification of larger boiler systems in the short or medium term is therefore unlikely. If the price of gas were to rise sharply and at the same time the price per kilowatt hour of electrical energy were to remain at the current level, hybrid solutions with burners and an additional electrical heating element would be more of a conceivable option. Up to now, these have only been used very occasionally owing to the high costs for electrical heating elements in the megawatt capacity range. Current application examples encompass in-house electricity generation with insufficient feed capabilities, modern participation in the energy balancing market a few years prior or application in Scandinavian countries with extremely low electricity prices.

Biomass – renewable, but with a concerning level of exhaust gases

For systems that use biomass such as wood, or alternatively industrial waste of natural origin, significantly higher permitted limit values have always applied for climate-detrimental greenhouse gases and particulate matter in exhaust gas. Technically, even better values are possible, yet this would require more expensive filter and catalyst technology. Seemingly green energy from the combustion of biomass is therefore accompanied by significantly increased exhaust gas emissions. In addition to particulate matter, the values for nitric oxide and carbon monoxide are also significantly higher than for the combustion of natural gas. For the most part, the higher exhaust gas temperatures additionally result in lower levels of efficiency. Nonetheless, there is justification for biomass combustion: In many cases, particularly with regard to the combustion of combustible biomass waste (e.g. wood residues, nutshells, rice husks), there is often a lack of alternative usage options. It should be mentioned that when it comes to total CO_2 balance, even wood is not completely climate-neutral. If we consider, for example, the complete process of wooden pellet production with regard to CO_2, the effects can actually be contrary in nature. Approximately 10 % of the energy contained is expended on the drying and manufacturing processes alone, and the means of transporting raw material and pellets only adds to this.

Biomass emissions balances are often spared of quantities of CO_2 that trees have absorbed from the atmosphere during their growth. However, the quantity of CO_2 that the tree could still absorb in its future life cycle is unfortunately not taken into account. At the end of the day, one factor is decisive: The exhaust gases that are emitted from the chimney of a plant. Additionally, there is a question of scalability when it comes to the topic of biomass. The required cultivation areas for the worldwide substitution of today's gas-fired/oil-fired process heat systems would be enormous (or rather, enormously unrealistic) and the resulting logistics would also entail several challenges.

Biofuels/biogases: A genuine alternative?

Already, many cultivation areas are used on the basis of subsidies for the generation of biomass for biogas production or of vegetable oil as an energy source. This has a significant effect on the ecology and availability of the cultivation areas for food production. Similar to biomass, the challenges here lie in scaling this to meet the global energy demand of the industry. In addition, they are more difficult to combust and have a higher level of exhaust gas emissions. A longterm, globally dominant proportion of biofuels can consequently hardly be anticipated.

Manufacturing procedures for hydrogen

- Reaction with metals
- Steam reforming
- Thermal water splitting with thermochemical cycle processes
- Electrochemical water splitting
- Water electrolysis
- Steam electrolysis
- Biological water splitting (formation of biomass)
- Photolytic water splitting (direct hydrogen formation)

Hydrogen: A cleaner alternative, but with pitfalls

The principle is as ingenious as it is simple: Water is separated via electrolysis into its component parts and then recombined via combustion. Instead of CO_2, water vapour is produced as an exhaust gas. At first glance, hydrogen as an energy source seems to be an attractive long-term solution as a primary energy source for process heat generators. In practice, however, this results in several long-term challenges – though admittedly, these can be resolved.

They occur as early on as the hydrogen production stage: In its pure form, hydrogen presents issues for storage and safety risks, since there is a risk of oxyhydrogen reactions in the event of leakages. Even today, proportional admixing into the existing gas infrastructure is practised though in a very small percentage range (< 2 %). An increase is likely in the event of increased availability; however, it will require adaptations with regard to infrastructure and consumers. "Reversible" fuel cells, as they are known, promise higher levels of efficiency than electrolysis, but primarily serve the use of hydrogen for electricity generation. Even when it comes to the combustion of hydrogen, new technical challenges are emerging that practically do not occur for the current combustion methods for oil and gas. These result in new requirements for both the burner and the boiler as well as for distribution and safety equipment. Bosch has already implemented multiple systems with hydrogen, some of which are operated with pure hydrogen.

For industrial customers, the use of pure hydrogen as a fuel is still more practicable than for domestic heating purposes, for example. For industrial process heating systems, the acquisition costs play a comparatively much smaller role (on average, approx. 2% of the total operating costs over 15 years).

To increase the tradeability of hydrogen, there are several technical procedures that nonetheless all have one thing in common: They reduce the total efficiency of the generation of the actual medium. In the production of hydrogen with electricity and subsequent methanation for the grid feed with 80 bar, around 36–50% of the originally supplied energy is lost. Taking into consideration the additional technology that is required, the price per megawatt hour becomes considerably more expensive. An unresolved issue here is also the cost-effective extraction of CO_2 from the air, since an insufficient amount of pure hydrogen sources are available on a large scale. (Currently, the extraction of CO_2 from the air costs several hundred euros per ton.) A similar factor that is insufficiently economically feasible for the replacement of natural gas as a fuel is the extraction of hydrogen from natural gas to avoid CO_2 in the combustion process. Over the coming decades, progress in hydrogen technology is to be expected.

Modernisation of existing systems for increasing efficiency or use of regenerative fuels are short-term effective measures for reducing CO_2 emissions in industry.

Summary

Even in the industrial sector, organisations are beginning to abstain from the use of fossil fuels for thermotechnical plants. As soon as it becomes economically feasible, it is likely that many processes below 110 °C and heating applications will be converted to alternative technologies or fuels. The conversion process for process heating systems will last significantly longer. Taking into account the high savings potential for existing systems, comprehensive modernisations of energy systems are to be initially expected in this regard. In the long term, questions remain as to whether hydrogen or electricity-based systems will prevail, and how these are to be distributed regionally.

For most applications, shell boilers will continue to be used for the safe generation of steam or as a hydraulic system component in closed systems. Water tube boilers, on the other hand, are almost only encountered in existing/large-scale plants or in special applications (temperatures > 300 °C) in the long term. Manufacturers of boiler systems and burner manufacturers will likely have to prepare for an increasing number of special combustion projects in the medium term. In this respect, there are a number of existing systems that represent potential opportunities for conversion. The energy generators themselves can often still be operated for many decades with modified fuel, provided that the increasingly stricter exhaust gas limits are adhered to.

Since boiler systems that are well maintained from time to time have a long service life and can be operated for multiple decades, their subsequent use should be taken into consideration early on. If, in the long term, a system with hydrogen or alternative fuels is conceivable, this can already be constructively taken into account today, since these boilers will, in principle, require a slightly different design.

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