MAN CHP

MAN Energy Solutions
Future in the making

Decarbonizing with combined heat and power for industrial applications

Of all the sectors of energy production to be decarbonized, the production of heat for industrial processes needing high-quality, high-temperature heat and steam are among the most challenging. The decision has been made to stop using coal and to ramp up renewable energy sources (RES). But what will fill the gap in the net-zero scenarios for the energy industry?

Author

Martin Wiedemann
MAN Energy Solutions SE,
Augsburg, Germany

Head of Business Development – Core Business Power Segment
martin.wiedemann@man-es.com

Published in April 2022

Natural gas has been accepted as the transition technology, but it is still a fossil fuel, albeit the least carbon intensive, and it will take time until green hydrogen (green H_2) or derivatives like synthetic natural gas (SNG), ammonia or methanol can take over.

At MAN Energy Solutions, we propose to use our high-efficiency, gas-burning, large engines driving generator sets to kick-start the decarbonization process in this sector.

Large piston engines are already the most efficient converters of fuel into energy and produce roughly equal quantities of electrical and thermal energy. In the past, heat from large medium-speed engines was not sufficient for the industrial applications with the highest thermal demand. Now, by using the electrical output of the GenSets to drive heat pumps, MAN Energy Solutions has devised a method of bridging the thermal gap.

The increase in efficiency and the related reduction of carbon emissions and fuel consumption are ideal starting points for achieving decarbonization as targeted under the European Green Deal.

We looked into industries that have a high demand for heat. The objective is to electrify all sectors in which this is possible and to supply them via RES. Heat is one of these sectors and the heat pump is the technical solution of choice. Now the question is, to what extent can gas-fired reciprocating engines contribute to this scenario?

Reciprocating engines are flexible and can produce base load to meet the demand of a heat pump, but also have dynamic capabilities to provide balancing power in the event that they need to support the RES grid in order to safeguard the security of supply.

In addition, the future-fuel readiness and capability of reciprocating engines make it possible to continue operation toward net zero once fuel from green hydrogen is available.

Efficient solutions for the energy transition

Around 20 years ago, MAN Energy Solutions began adding gas-burning engines to its ranges of large two- and four-stroke combustion engines.

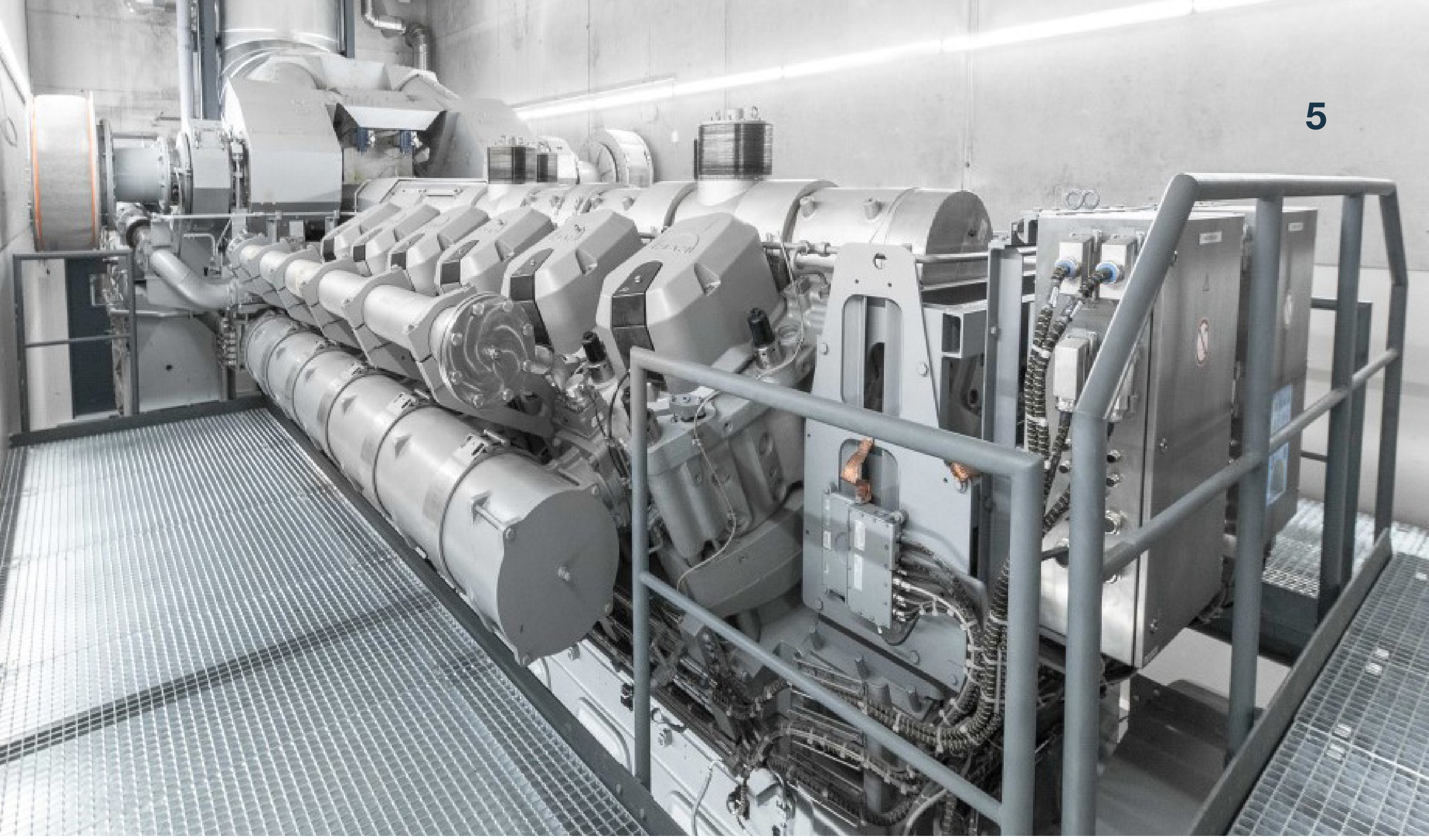
Reducing emissions and consumption

Initially, MAN's aim was to make very low emissions of nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM) possible with engines, burning available natural gas in much higher power ranges, between 7.4 and 20.7 MW based on the V35/44G and V51/60G spark-ignited gas engines. These low-emission engines are the basis for generating electrical and thermal energy while complying with strict environmental legislation. MAN's range of engines, designed primarily to run on natural gas, have since taken on a new and urgent significance. With highly flexible dual fuel technology, the engines can also run on gas and switch to liquid fuel operation at any time in case of an interruption in the gas supply. As the global community begins to implement strategies to reduce greenhouse gas emissions (GHG) with the aim of slowing and ultimately eliminating global warming and climate change, engines burning natural gas offer immediate and ongoing improvements. These are based on the fact that natural gas is around 80 – 85 % methane (CH_4), the simplest combination of carbon and H_2. It is thus the hydrocarbon fuel which produces the lowest carbon dioxide emissions (CO_2) per unit of energy produced.

Moreover, MAN's gas engines are highly efficient converters of fuel into energy, especially when there is a use for their thermal output, and they are designed for wide fuel flexibility. They represent a suitable starting point for progressive further reductions in carbon emissions and the likelihood of large gas engines becoming stranded assets is remote.

Among the most pressing challenges in the global decarbonization process is producing high-temperature, high-quality heat and steam for industrial processes. Currently much of this demand is covered by coal-fired boilers or combined heat and power plants based on gas turbines with their high volumes of high-temperature exhaust gases.

Comparing these two methods of high-temperature process heat production, emphasizes the two most important aspects of CO_2 emissions reduction – the carbon intensity of the fuel and the efficiency of its combustion.



The high efficiency of reciprocating gas engines

In addition, the above comparison also emphasizes the CHP potential for MAN's large gas-burning engines powering generator sets. Replacing energy producing plants with gas engine CHP plants also enables more efficient energy production from the fossil fuel with the lowest CO_2 emissions per kWh.

Large piston engines produce electrical and thermal energy in roughly equal amounts and in CHP contexts, the total electrical and thermal energy extracted from the combusted fuel can be as high as 95 %. Even in industrial CHP plants with high thermal energy demand, they hold the potential for a further significant reduction in CO_2 emissions, below the levels achieved by gas turbines.

MAN Energy Solutions has addressed this field of applications and devised a suitable way of extending the thermal output of its gas engines. Using the electrical output of gas engine generator sets, a heat pump can be driven to further raise the temperature of water heated by the engine heat sources (e.g. charge air cooler, oil cooler, cylinder coolant, exhaust gases). The input of waste heat from the industrial process adds to the efficiency of the method via additional waste heat recovery and by eliminating the need for cooling the process water.

In a case study application, a gas engine genset plus heat pump plus process waste heat recovery without cooling was used to replace a gas boiler. The needs of an industrial process with demand for large quantities of high-temperature steam were met while gas consumption was reduced by over 40 %.

A further benefit of MAN's concept is that it is based on the V35/44G and V51/60G gas engines with rated mechanical outputs between 7.4 and 20.7 MW. In multiple engine installations, generator sets can be brought on and offline individually as demand for electrical and thermal power varies. The engines operate in their optimum power range and electrical output can be directed to the heat pumps, the local grid or industrial processes according to demand.

Raising efficiency

Benefits of CHP

CHP or cogeneration plants based on gas engines have existed for decades and have gradually grown in size. They supply electrical energy to households and other private consumers or for industrial processes, and thermal energy for space heating (district heating) and, again, industrial processes.

The advantages of gas-fired CHP

Aside from their potential for the efficient production of thermal and electrical power with reduced carbon emissions, gas-engine-based CHP plants boast a range of advantages.

- In contrast to coal-burning thermal power stations, whose economic size starts at around several hundred megawatts, CHP plants based on gas engine GenSets from MAN Energy Solutions employ the V35/44G and V51/60G gas engines, whose mechanical outputs cover the power range from 7.4 to over 20.7 MW per engine.

- Gas engine CHP plants can be built and deployed on relatively short timescales, allowing a rapid, progressive shift of the production of electrical and thermal energy away from solid and liquid hydrocarbon fossil fuels to gaseous fuels.

- Gas engine CHP plants can thus be very flexibly configured and operated. Given their rapid start-up capability, engines can be brought on and offline individually as demand for electrical and thermal power varies. Each engine operates in its optimum efficiency range and electrical output can be directed to the heat pumps, the local grid or industrial processes according to demand.

- Gas engine CHP plants are ideal for decentralized electrical power generation while producing electricity and heat close to consumers in industrial as well as municipal and utility applications.

- Natural or renewable gas will be available in sufficient quantities for the foreseeable future to implement this strategy.

- Gas-burning engines make it possible to achieve very low noxious emissions. The combustion of natural gas produces very low quantities of PM and no SO_x. At the same time, the lean-burn combustion technology widely used in large gas engines with the Otto combustion process enables fuel-efficient combustion.

- Modern gas engines are designed for fuel flexibility and thus reliability in case of a shortage of one fuel type, and plans call for a continuous switch to gaseous fuels with progressively lower carbon intensity on the way to full carbon neutrality. Hence, gas engine CHP plants represent the first step toward reduced carbon emissions that are unlikely to become stranded assets. A possible progression is shown in Fig. 1.

- Gas engines will easily cope with the addition of a proportion of green H_2 from renewable energy sources into their fuel supply.

- CHP plants enable a reduced carbon footprint for a given requirement of heat and electricity, demonstrating social responsibility, doing away with the need to purchase carbon emissions certificates and the like, and fulfilling sustainability goals and commitments.

- The further progressive, stepwise reductions in GHG emissions based on gaseous and liquid fuels burnt in fuel-flexible engines is core to the strategy of MAN Energy Solutions. The strategy is based largely on synthetic fuels made from green hydrogen. This conversion of renewable energy via green hydrogen into synthetic, carbon-neutral fuels will produce gases and liquids that can be readily stored, transported and handled. As well as H_2 itself in the longer term, SNG, ammonia and methanol are the leading contenders for short- and medium-term use.

- Crucially, MAN's engines will be progressively equipped to burn new fuels as required as they become available. If necessary, engines can be retrofitted to run on blends of fuels during transitional periods.

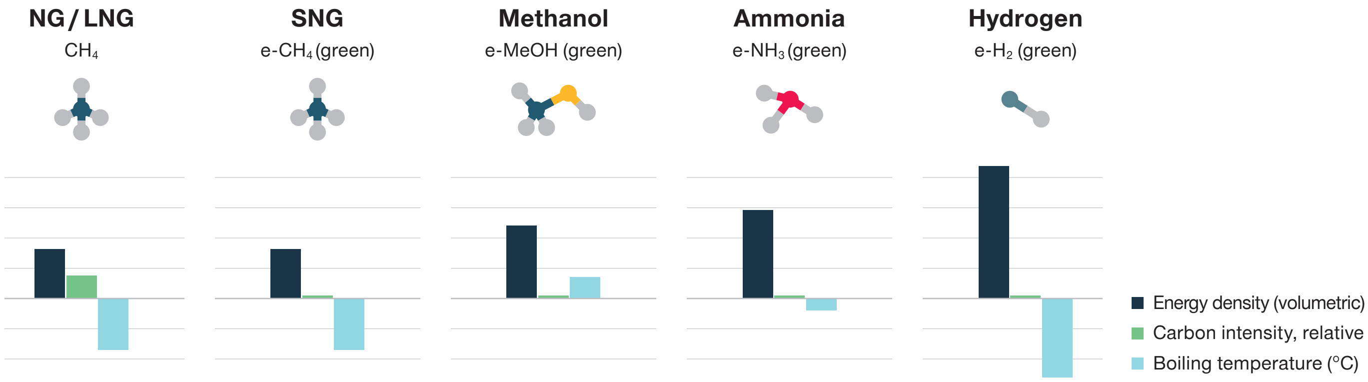


Fig. 1: Fuel overview and comparison

The details of gas engine CHP

Internal combustion engines driving electrical generators produce usable electricity and heat in roughly equal quantities. In the applications served by gas engine CHP plants, there is a range of uses for the thermal as well as the electrical energy produced by each gas engine generator set. For example, the heat can be used for space heating, or air conditioning, in buildings, or as heat for manufacturing operations, known as process heat. In fact, where there are uses for the thermal as well as the electrical energy from generators driven by combustion engines, it is possible, depending on the application, to utilize over 95 % of the energy in the fuel burnt either as heat or electricity.

The electrical output of a gas engine CHP plant is produced by the mechanical output of the engine driving a generator. The thermal output is the part of the energy content of the fuel which cannot be converted into mechanical energy. In some applications, this heat cannot be used and must be transferred into the ambient air, for example in engine-powered vehicles where the radiator dissipates heat to reduce the temperature of the engine coolant before it returns to the cylinder block. As a result, an engine's thermal output is often referred to as waste heat.

On the engine of a CHP plant, a typical heat recovery setup includes heat exchangers to progressively capture heat from the engine's lubricating oil, its cylinder coolant, its charge air cooler and, the hottest source, the engine's exhaust gases. The thermal energy is thus generated in the form of heated (warm or hot) water or steam.

Mature and future-proof

The built-in sustainability of CHP

Due to its high efficiency, CHP plays an important role in decarbonization plans. This is also reflected in the European Green Deal, which favors gas-driven power and, especially, CHP as an important bridging technology on the path toward RES.

Step by step towards net zero

Looking further ahead, as stated, this initial move to fossil natural gas is planned to be the first step in a gradual transition to synthetic, carbon-neutral gas fuels, including green H_2 and SNG, and ammonia made from green H_2. Modern gas engines will be adapted to consume each of these fuels. For example, gas engines will be able to burn natural gas mixed with H_2, or SNG, produced by the power-to-X process, i.e. from the electrolysis of water powered by renewable energy from wind, solar, and hydroelectric sources.

Above all, the technology of producing CHP (cogeneration) from combustion engines is mature technology which is already making major, reliable contributions to energy efficiency throughout the world.

There are hundreds of CHP plants around the world. In recent years, the size and energy output of gas engines have increased considerably and thus their scope has been extended to larger industrial process heat applications.

Competing with gas turbines

Looking at the history of gas engine CHP, in the early days the majority of plants were based on smaller, high-speed engines serving applications involving heating individual buildings, district heating, swimming pools or other municipal functions. Many such plants were based on larger high-speed engines of around four litres per cylinder and mechanical outputs from around 1 to 1.5 MW. However, when MAN Energy Solutions introduced its large, medium-speed gas engines it became possible overnight to cover outputs up to 20,700 kW of mechanical energy with a single engine. This paved the way for CHP solutions for far larger applications – and especially industrial plants where power demand is often much higher and process heat, rather than electricity, is often the priority.

In this way, MAN's gas engines entered a range of mechanical and thermal power outputs which had previously been the domain of gas turbines. These much larger gas engines enabled industrial CHP plant operators to enjoy the benefits of the higher fuel efficiencies achievable with reciprocating engines, compared to gas turbines. Now, with its latest developments, MAN Energy Solutions intends to further extend the scope and type of thermal energy requirements that can be covered by its gas engine generator sets.

In many industrial CHP applications, a central question is whether the focus is on electricity production or heat production. In this area, the electrical power-to-heat ratio of the energy source is an important criterion in meeting the demands of the specific application. Reciprocating engines were intended for power-to-heat ratios of 0.8 to 1, whereas gas turbines focus on heat production and power-to-heat ratios of < 0.8 due to the higher heat content in their exhaust gases. As a result, reciprocating engine CHP was typically used in low-temperature applications, such as district heating, which limited the market to countries with a demand for space heating.

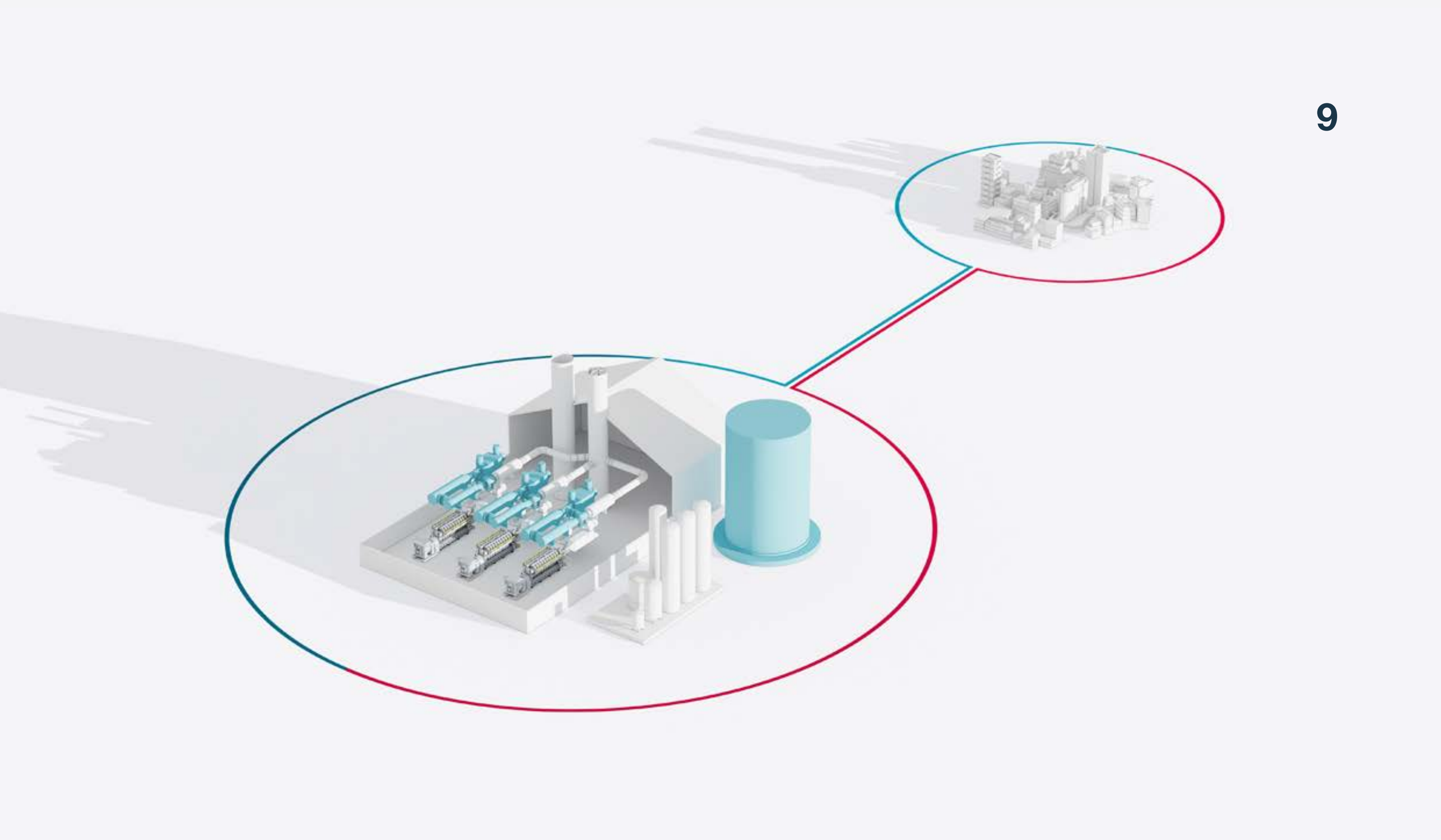


Fig. 2: MAN engine-based combined heat and power

High-temperature CHP challenge

The challenge for MAN Energy Solutions has thus been to find ways of extending the thermal energy reach of reciprocating engines to bring the benefits of their high electrical efficiency to those CHP plants needing high-quality, higher-temperature thermal energy. Clearly, as well as reduced fuel bills, the advantages for the industrial processes also include reduced carbon footprints.

Typically, the industries in question have a demand for heat at high levels but also produce waste heat that, under normal circumstances, needs to be destroyed. Enterprises with high demand for process steam were investigated by MAN Energy Solutions, with the aim of providing a solution for industrial customers such as dairies and breweries (disinfection), the paper industry and refineries.

In these types of operation, electricity is typically taken from the grid, heat is produced in boilers, and waste heat after the industrial processes is dissipated in radiators, cooling towers, etc.. In the concept developed by MAN Energy Solutions, in contrast, a gas-engine-powered generator set replaces the fired boiler as the basic source of thermal energy and the grid as the source of electricity. The thermal output of the gas engine is then raised by means of an electrically-driven heat pump up to the levels required by the industrial process or processes in question.

This solution is both highly efficient and flexible. The heat pump is able to meet the high level of heat demand, and depending on the circumstances, it can be powered primarily using the gas engine generator set, or using the local grid or both. This gives the operator of the industrial processes attractive options such as switching to grid power for the heat pump when electricity prices are favourably low or feeding electrical power into the grid when offered prices are favourably high.

In order to enhance the efficiency of the heat pump, the temperature on the suction side needs to be optimized to increase the coefficient of performance (COP). With the boiler replaced by a heat pump, the electricity supply from the grid is replaced by a highly efficient reciprocating gas engine genset, the cooling device is omitted, and the waste heat will feed the heat pump. This setup, in which the generating sets act as the driver of the heat pump, makes it possible to reduce the gas demand compared to the fired boiler/grid power setup. It therefore reduces the owner's gas costs and, critically the plant's carbon emissions (as shown in the following case studies).

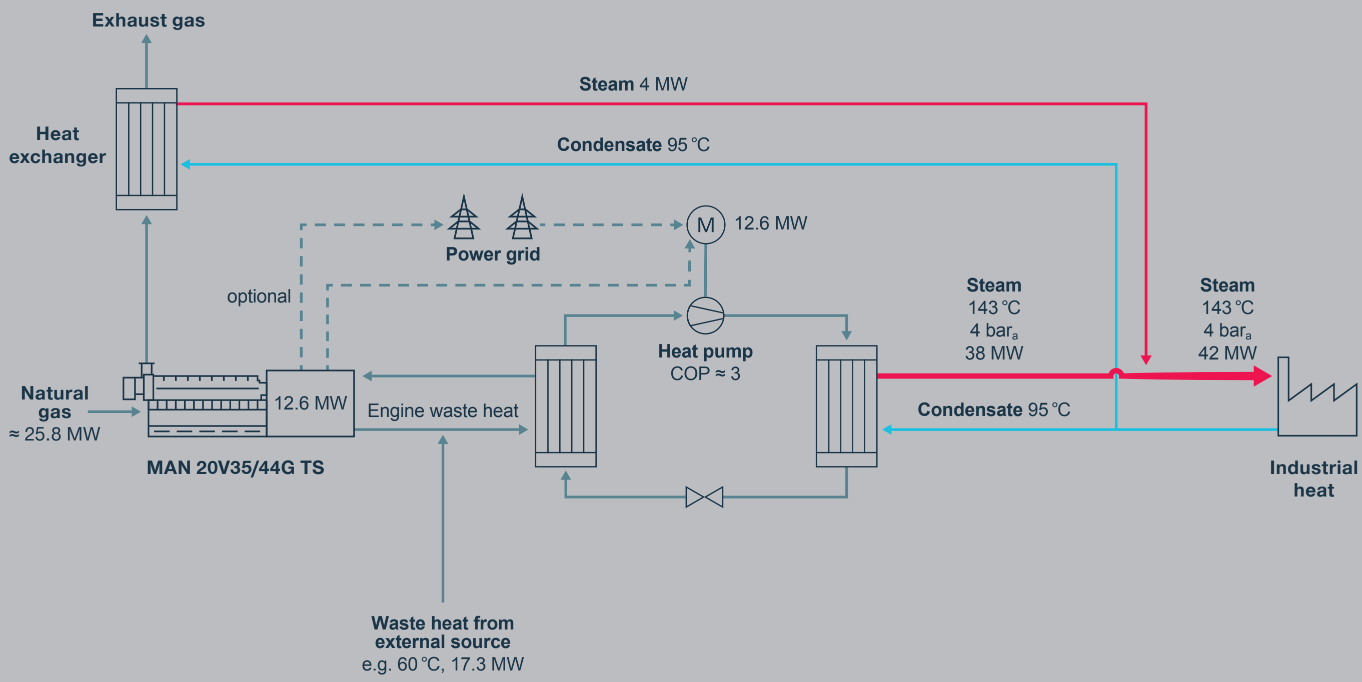


Fig. 3: MAN engine 20V35/44G TS, heat pump and heat storage replacing gas boiler

Case study 1

Fig. 3 shows an example of an application where the gas engine genset plus heat pump configuration, based on an MAN 20V35/44G TS spark-ignited gas engine with 12.6 MW electrical output, replaces a gas-fired steam boiler (92 % efficiency). As shown, the configuration would fulfill the needs of an industrial process with demand for large quantities of high-temperature steam. The use of the engine and heat pump plus external waste heat configuration can result in at least 41 % savings in gas consumption.

Business case

Shown below are the major business case elements for an MAN 20V35/44G TS engine in combination with an MAN Combination Compressor line (Brüden Compressor) operating in the paper, food and chemical industries.

The scenario is a plant with:

- 18 MW of cooling water capacity from waste heat at approx. 60 °C
- Annual steam demand of approx. 40 MW peak, 8,500 op/year
- Gas price approx. € 100/MWh incl. CO_2 emission tax
- Total annual gas costs of approx. € 39 M/year

By contrast, the fuel economics of a plant based on an MAN 20V35/44G TS gas engine with a gas input of 25.8 MW and MAN combination heat pump with COP 3, are:

- Total annual gas costs of € 22 M/year
- Total gas savings of approx. € 16 M/year
- Total CO_2 reduction approx. 42 %

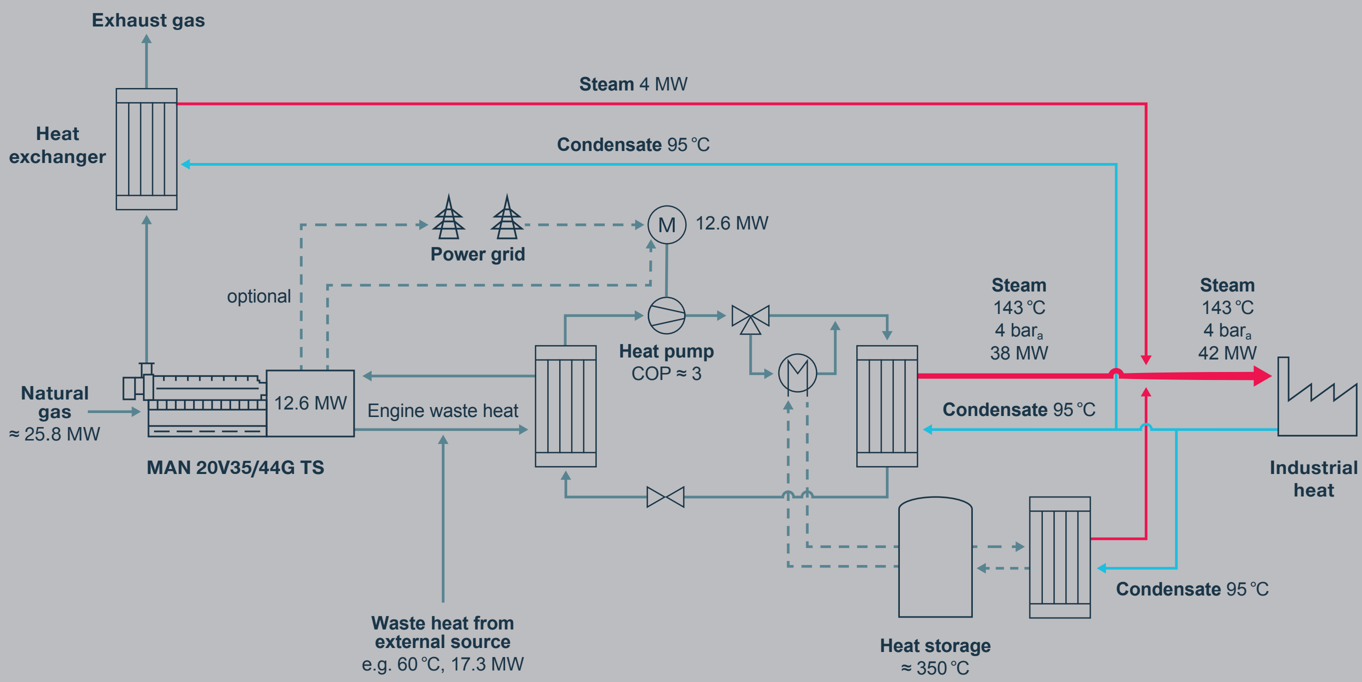


Fig. 4: MAN engine 20V35/44G TS and heat pump replacing gas boiler

Case study 2

A further refinement of the MAN gas engine GenSet and heat pump concept is shown in Fig. 4, where the engine and heat pump replace a gas boiler and the system is supplemented by heat storage. Heat storage enhances the flexibility of the system, as it allows the user to temporally decouple electricity and steam generation, for instance to run the engine in peaker mode and sell electricity to the grid. It will also allow the user to utilize low-priced electricity from the grid or renewable sources and, in doing so, optimize the steam generation cost. And it helps to balance a fluctuating demand for process steam.

Scalability and flexibility

Both case studies 1 and 2 represent plants relying on a single MAN gas engine GenSet.

To achieve higher electrical and thermal energy capacities, multiple engines can be installed, resulting in an installation that can be flexibly operated. Based on their rapid start-up capability, individual engines can be readily started up and shut down as demand for electrical and thermal power varies. With the number of operating engines matched to the power demand, engines operate in their optimum ranges for fuel efficiency, power and emissions.

Likewise, electrical output can be flexibly directed on an engine-by-engine basis to the heat pumps, to the industrial processes or to the local grid, according to actual demand.

Energy in the balance

Time for change

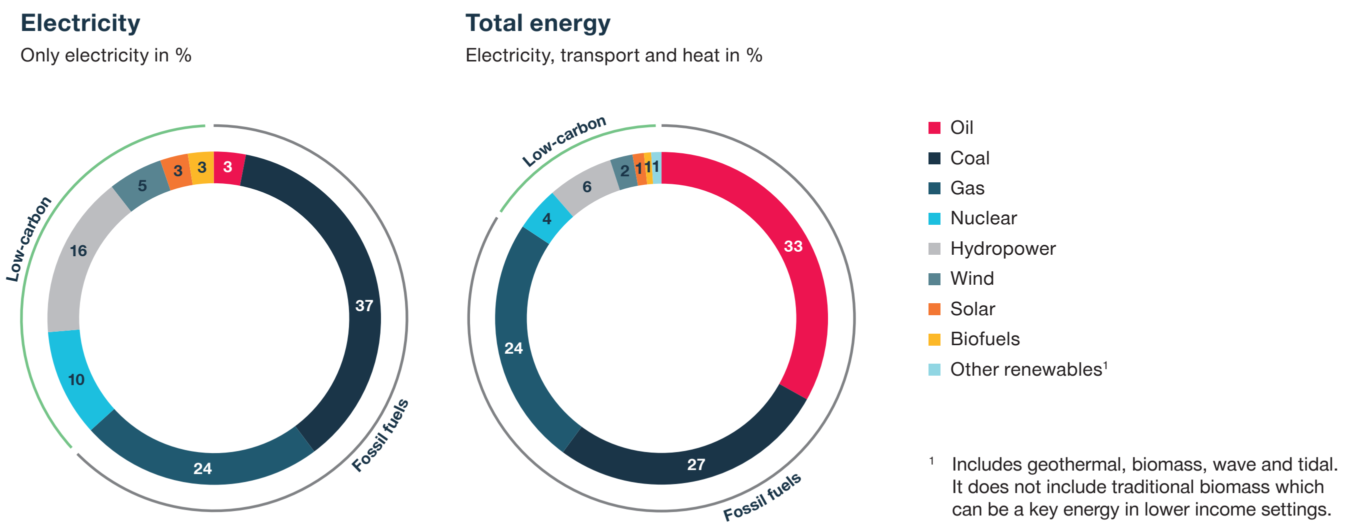
The energy transition away from fuels that produce emissions of the greenhouse gas CO_2 is now underway and has taken on a new urgency.

Coal heats up the planet

As well as a virtually indisputable body of evidence gathered over several decades, recent extreme weather events have emphasized the fact that the problems of climate change caused by human activity are already affecting us. Global warming may be approaching a tipping point at which large-scale negative impacts on ecological systems are unavoidable.

Countermeasures to drastically reduce the emission of GHG into the earth's atmosphere are a priority. Clearly identified among the causes is the contribution of energy plants burning coal or heavy and distillate fossil fuels to produce electrical and/or thermal power.

As shown in Fig. 5, burning coal and oil accounts for around 60 % of global energy production, including thermal energy for industrial processes. And, as shown in Fig. 6, these high proportions of global energy production are compounded by the comparatively high emissions of CO_2 from coal and oil, making fossil hydrocarbon fuels the biggest contributor to climate change caused by humans.



[1] Includes geothermal, biomass, wave and tidal. It does not include traditional biomass which can be a key energy in lower income settings.

Fig. 5: More than one-third of global electricity comes from low-carbon sources; but a lot less of total energy does

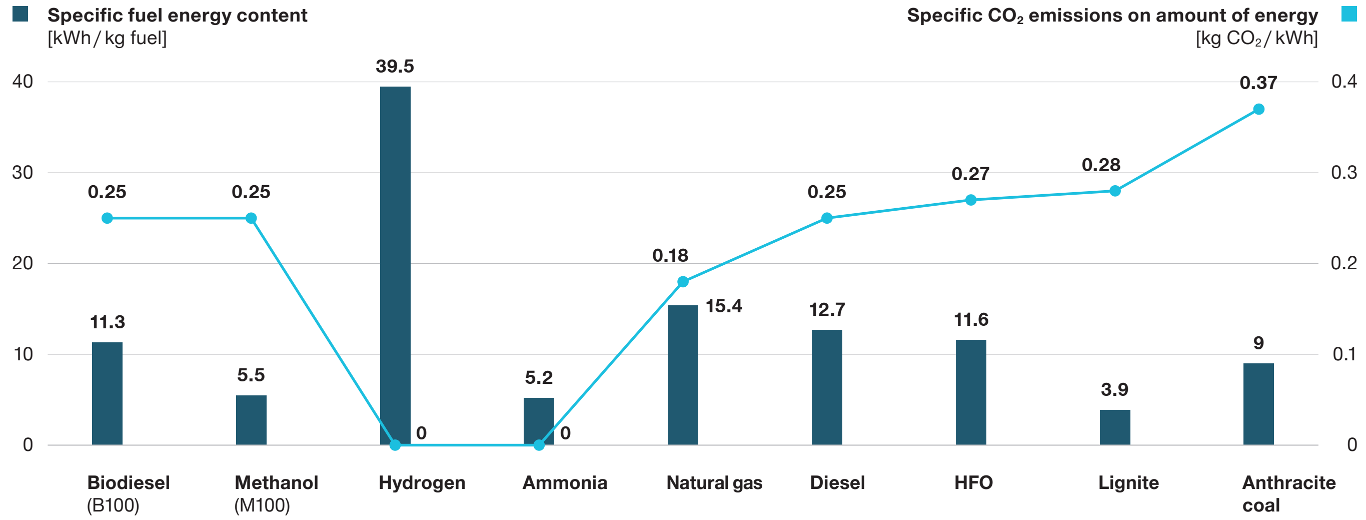


Fig. 6: Energy content and emissions of CO_2 from combustion of common fuels

Accordingly, at the most recent United Nations Climate Change Conference, COP26 held in 2021 in Glasgow, Scotland, there was a strong focus on solid fuel, with 65 countries pledging to phase out coal, while all major coal financing countries committed to ending international coal finance by the end of 2021.

Gas for efficiency

The elimination of coal and oil from the global energy mix will, naturally, leave a large void to be filled by carbon-neutral, low-carbon, and renewable energy, but help is at hand. For years, large combustion engines have been capable of burning natural gas and other gaseous fuels, and the climate benefits of switching to gas-burning reciprocating engines for the production of electrical and thermal energy are twofold. On the one hand, as we see in Fig. 6, natural gas is the least carbon-intensive hydrocarbon fossil fuel, and its substitution for coal can achieve immediate reductions in carbon emissions of up to nearly 50 % per unit of energy produced. On the other hand, combustion engines are efficient converters of fuel into energy, especially when there are uses for both the electrical and thermal outputs of a gas-engine-driven electrical generator (gas engine generator set).

Figures

Fig. 1 MAN Energy Solutions (2022): Fuel overview and comparison. Augsburg: MAN Energy Solutions SE.

Fig. 2 MAN Energy Solutions (2017): MAN engine-based combined heat and power. Augsburg: MAN Energy Solutions SE.

Fig. 3 MAN Energy Solutions (2022): MAN engine 20V35/44G TS and heat pump replacing gas boiler. Augsburg: MAN Energy Solutions SE.

Fig. 4 MAN Energy Solutions (2022): MAN engine 20V35/44G TS, heat pump and heat storage replacing gas boiler. Augsburg: MAN Energy Solutions SE.

Fig. 5 Ritchie, Hannah / Roser, Max (2021): More than one-third of global electricity comes from low-carbon sources; but a lot less of total energy does [online]. Available at: https://ourworldindata.org/energy [accessed March 31, 2022]

Fig. 6 MAN Energy Solutions (2022): Energy content and emissions of CO_2 from combustion of common fuels. Augsburg: MAN Energy Solutions SE.

MAN Energy Solutions
86224 Augsburg, Germany
P + 49 821 322-0
F + 49 821 322-3382
info@man-es.com
www.man-es.com