



FUEL-FLEXIBLE GAS- TURBINE COGENERATION

**Robin McMillan & David
Marriott,
Siemens Industrial
Turbomachinery Ltd., Lincoln,
U.K.**

**Su, Ri Han, Siemens China,
Shanghai, China**

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Answers for energy.

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1.0 Introduction

In order to counteract the effects of global warming, the pressure to reduce the environmental impact of power and heat production is growing. Reduction of the amount of CO₂ emitted during the generation of heat and power is seen as the key to reducing impacts on the environment. However, it is expected that the demand for power will increase dramatically over the next 10 to 20 years driven by the continuing economic expansion in countries such as China and India

Whilst technologies are now available that emit very low levels of CO₂ or use fuels obtained from renewable sources, these are often uneconomic to install and operate. The challenge is to employ a more pragmatic approach that uses existing proven technologies in a more effective way.

Distributed-cogeneration power plants are an economic way of significantly reducing CO₂ emissions during the production of power and heat. Installing power plants closer to the point of use reduces electrical transmission losses and provides a ready source of heat for the production of steam, hot water and chilling. Optimization of cogeneration facilities can lead to overall useful power-to-heat input ratios of greater than 90%, which can reduce the carbon footprint of an installation by 50%.

The economic and environmental impact of cogeneration can be further enhanced by utilizing waste gases such as refinery and coke-oven gases. It is also worth noting that application of cogeneration-to-waste gases in some regions can qualify for carbon credits.

This paper describes some examples of how gas-turbine cogeneration plants can be configured to operate on high-hydrogen-content refinery gas and coke-oven gas.

2.0 Alternative fuels and applicability to cogeneration

This paper will concentrate on gaseous fuels, with figure 1 below showing the main families of gaseous fuels available for firing gas turbines.

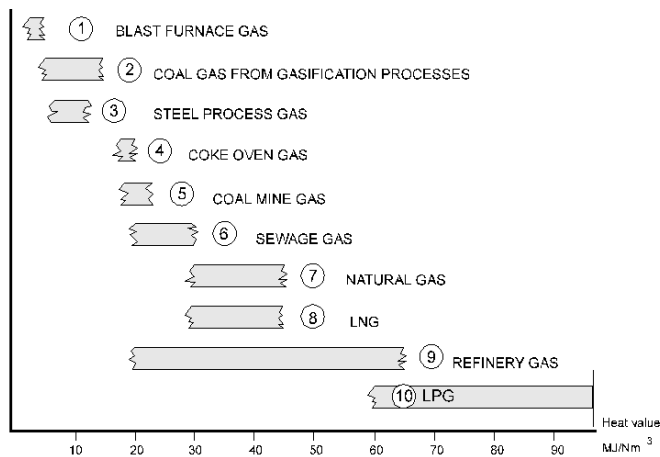


Figure 1. Gaseous fuel types categorized by heating value

As well as a large variation in heating value, and corresponding variation of required volume of gas to be fed into the turbine, the composition of these fuels varies greatly. For example, the lower-heating-value fuels such as those from gasification tend to contain high levels of inert compounds, with the energy coming from hydrogen and carbon monoxide, whereas coke-oven gas contains high levels of hydrogen and little or no inert species. The differences in composition and heating values lead to different challenges in the gas turbine, as discussed in section 3.0.

As well as the technical challenges, the overall economics of the gas-turbine application and the fuel source/supply are critical. For example, the amount of capital investment required to build an integrated gasification and combined-cycle plant currently means that such plants have only marginal viability even at very large scale (>1000MWe).

A good example of where the economics do not add up, despite technical demonstration, is the biomass-fuelled IGCC plant built in Varnamo, Sweden. This plant demonstrated several thousands of hours of successful operation using a gasifier feeding an SGT-100 gas turbine. Despite this technical success, the cost of the electricity produced by the plant was too high for it to operate beyond the demonstration phase.

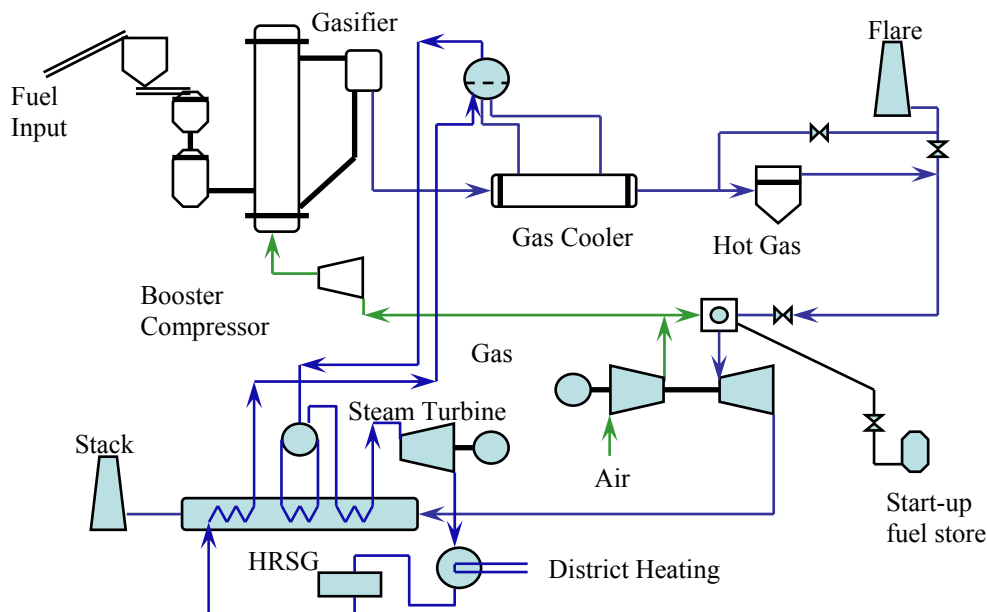


Figure 2. Flow chart for IGCC-plant in Varnamo. Note that, as well as the plant operating in combined cycle, waste heat from the HRSG was used to provide district heating.

In contrast, a process-waste gas can provide a huge financial opportunity for a user who can use or sell on the heat or electricity available through installation of a cogeneration plant. One example of a waste gas that provides a viable opportunity is coke-oven gas. In general, in China, coke-producing plants are located away from steel production facilities. This means that, instead of using the gas as part of the steel production process, in a large number of cases, the gas is simply flared or, even worse, vented. Table 1 shows typical sizes of coke plants and the volume of waste gas produced.

Coke Plant Size, coke output K Tonne/year	COG produced mNm ³ /year	COG available for power generation Nm ³ /s
400	100	1.84
500	125	2.30
700	175	3.23
900	225	4.14
1000	250	4.61
1500	375	6.92

*assumptions, 250 Nm³ of COG/tonne coke, 50% of COG used for other purposes e.g. oven-firing, 8,000 operating hours per year, COG heat value is around 16 kJ/Nm³ – data is approximate.

Table 1

Table 2 shows various options for implementing GT solutions to produce electricity and steam at an efficiency of up to 95% (GT plus fired boiler plus steam turbine plus waste heat).

GT Power plant format	Electrical Output MW	Natural gas input Nm3/s	Equivalent COG input Nm3/s
SGT-200 S.C.	6.62	0.6	1.31
SGT-200 CHP unfired	9.65	0.6	1.31
SGT-200 CHP fired boiler	12.74	0.9	1.96
SGT-500 S.C.	16.3	1.48	3.22
SGT-500 CHP unfired	24.3	1.48	3.22
SGT-500 CHP fired boiler	32.1	2.78	6.05

Power output at ISO conditions, data is for guidance only.

Table 2

Burning waste gases, as well as being financially attractive, can also benefit the environment by producing power and heat that would otherwise be produced by the burning of premium fuels, resulting in a net reduction of CO₂ produced. As such, installation in China can be entitled to carbon credits.

Another example is using refinery gases where a hydrogen-rich off-gas is produced and is used to fire a gas turbine and heat recovery system providing both process steam and electricity. These gases can contain very high levels of hydrogen (>80%).



Figure 3: SGT-200 unit operating on high-hydrogen fuel at an oil refinery in the U.K.

Another application that takes the term “waste” to an extreme is operating a gas turbine on landfill and sewage gas. In an application using sewage gas, heat is recovered from the gas-turbine exhaust and used to accelerate the anaerobic digestion of sewage, producing a medium-calorific gas consisting of methane and carbon dioxide that is then used to fire the gas turbine. In addition to heat supplied to the digester, a steam turbine can be applied to increase the overall electrical efficiency of the plant in applications where process steam is not required.

3.0 Fuel considerations

In order to understand the impact of a fuel on the gas turbine it is important to recognize the key combustion and flow characteristics of the various fuels discussed. Figure 4 below attempts to map out the fuels in terms of the key influencing properties of volume flow, hydrogen content and extinction characteristics. These three parameters have strongest impact on how the gas turbine is adjusted to cope.

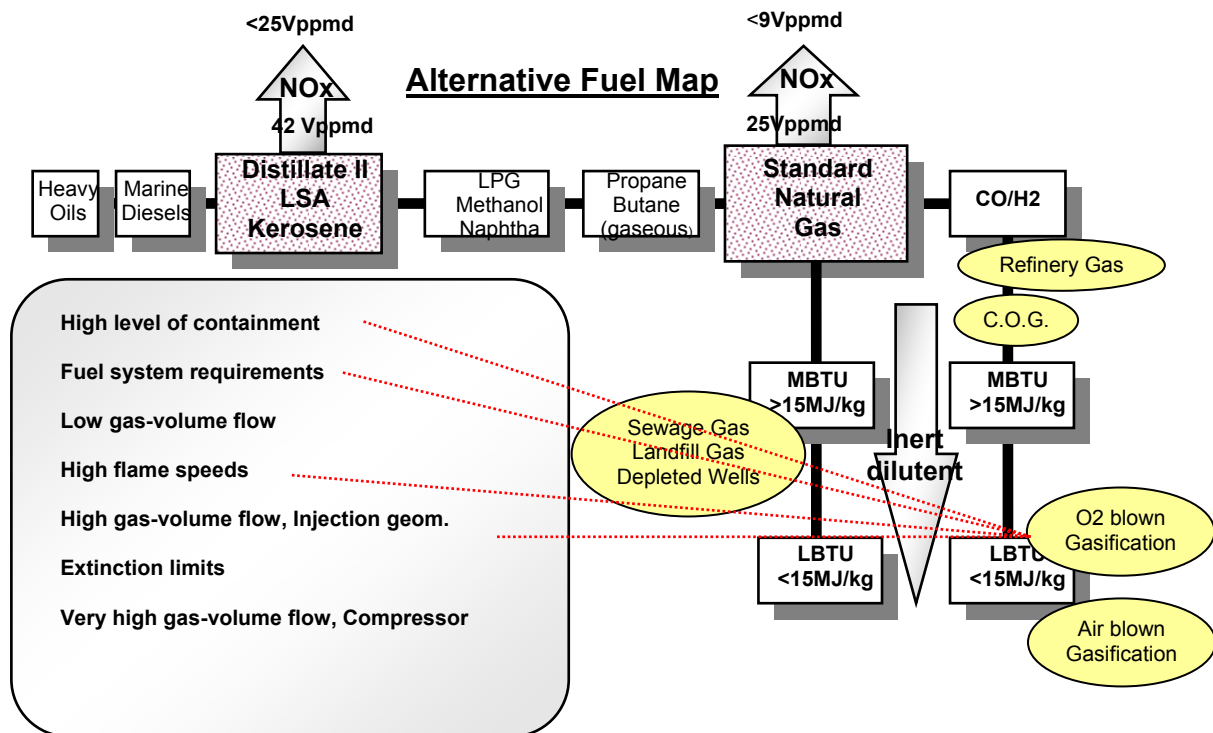


Figure 4 Family of fuels showing key characteristics

Volume flow is the easiest to understand: as the heating value of the fuel drops, larger flow areas are required to deliver and inject the fuel into the turbine and provide the same heating

value. In some extreme cases, such as fuels derived from air-blown gasification or blast-furnace gas, the compressor and turbine may need to be re-designed to cope with the difference in volume added after the compressor in the form of fuel. In the case of blast furnace gas, the volume of fuel injected into the combustor is actually higher than the volume of air exiting the compressor.

The extinction limit of the fuel determines the flammability range for combustion, meaning that only very rich fuel-air mixtures will stay alight (particularly of concern for lean-burn DLE systems). Given a high enough inert content, some fuels may become incombustible. One of the biggest challenges for DLE combustion systems comes with gases containing hydrogen. Figure 5 below shows the impact of hydrogen (and CO) on the burning velocity of gas mixtures.

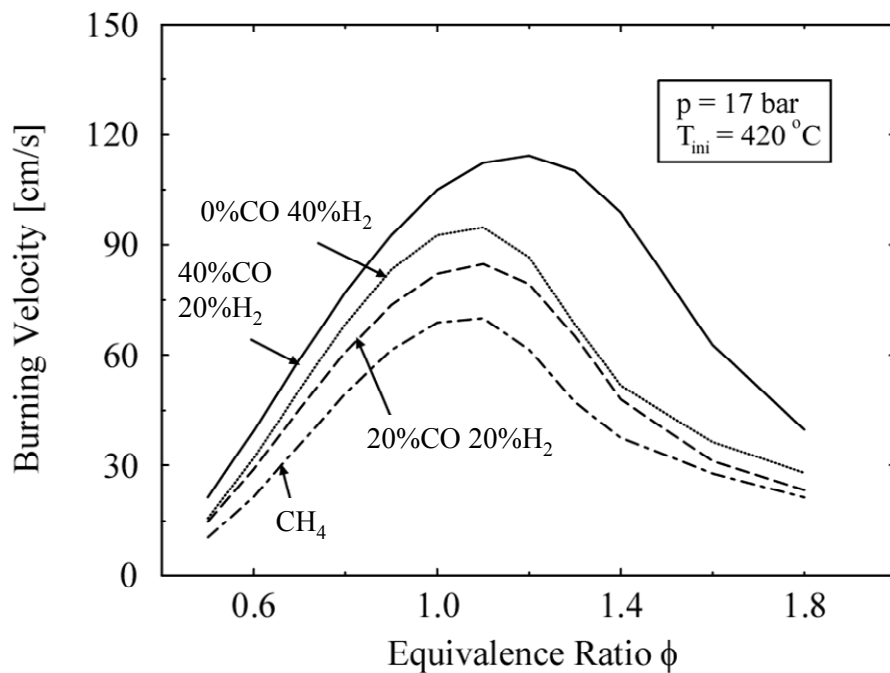


Figure 5. Burning velocity of various fuel mixtures compared to methane. Note the balance of composition is made up with inert gas, in this case Nitrogen.

As can be seen, relative to natural gas the flame speed increases dramatically with the addition of hydrogen, a situation which is further aggravated through the addition of carbon monoxide. The top line in the chart is roughly where indirectly fired gasification fuels sit (the balance being inerts). As a stable combustion system relies on ignition of the fuel away from the fuel-injection geometry, addition of hydrogen leads in some cases to the flame establishing itself in an abnormal position too close to the fuel injector or combustor walls.

This is known as flashback and can lead to significant damage to the gas turbine within seconds of occurring.

As a consequence, systems operating today on high-hydrogen fuels, such as refinery gas, are based on diffusion-based combustion systems and any NO_x-control relies on the injection of a diluent such as water, steam or inert gas (some gasification processes adopt this) to reduce NO_x to required levels.

The key challenge, that gas-turbine manufacturers face, for future operation on alternative fuels is developing a dry low-NO_x combustion system capable of operation on high-hydrogen fuels.

In addition, the high level of contaminants associated with some of the gases illustrated in figure 4 needs to be reduced to levels suitable for long-term operation in gas turbines. The additional fuel treatment to remove components such as ammonia and tars from syngases produced by gasification and hydrogen sulfide and siloxanes from digester and landfill gases, add to the overall plant complexity and cost.

4.0 Summary

Cogeneration plants fuelled using waste gases provide an economic and environmentally friendly way of helping to satisfy the heat and power needs of industry or a community. The paper has explored the use of waste fuels in a gas turbine, explaining some of the main considerations necessary to ensure the cogeneration plant provides the required heat and power in a reliable, efficient manner.

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