1. EUSUSTEL WP3 Report
Gas & oil fired technologies

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1.1. Introduction

In recent years, gas-fired technologies became very popular for the electricity production. Resources are abundantly available and the environmental impacts are rather small, compared with the other fossil-based power plants on coal and oil. Recently, gas has suffered (somewhat) from stiff price increases; but the de-facto CO_2 tax on fuels via the Emission Trading Scheme and the expected post-Kyoto GHG reductions tend to favour gas over coal. These are some reasons why a lot of countries focus on gas-fired technologies for future electricity production, besides the use of renewables and taking into account the nuclear phase-out in some countries. Natural gas, as used in the existing power plants, is a mixture of mainly methane, ethane, propane and nitrogen.

Oil-fired power plants are not that common any more, and for the most part, electricity producers no longer invest in oil-fired capacity. The available oil reserves are mainly used for transport and the petrochemical industry. Peak units running on jet fuel do exists, but more and more, they are replaced by more efficient and environment friendly gas turbines. This is why oil-fired technologies are not further discussed in this chapter. The main reason why oil would be used for electricity generation (even taken into account price fluctuations of oil/gas/coal which will to some extent be offset by CO_2 taxes) would be for security of supply reasons: oil is a locally storable fuel, which is not the case for gas. But even in this case, oil would be used as jet fuel or kerosene in gas turbines, to be discussed next.

The basis of a gas-fired plant is a gas turbine. This turbine can be used in a simple configuration (SCGT) or in a combined cycle (CCGT), as discussed below. The term *'gas turbine'* does not automatically imply the use natural gas as fuel. It only means that a *'gas'* – whatever its origin – passes through a thermodynamic gas cycle.

1.2. General issues on gas & oil technologies

Before going into detail on the existing gas technologies in section 1.3, some general issues concerning costs, modularity, flexibility, environmental aspects, etc. are discussed.

1.2.1. Peculiarities

1.2.1.1. Cost aspects

With its short construction time of 2 to 3 years and its low overnight construction costs, the threshold to build a combined cycle gas-fired plant is rather small. According to a 2005 study on the costs of generating electricity [2], the overnight construction cost for a combined cycle gas plant is 400 to 800 €/kWe (1, 2). This is small, compared to a coal-fired plant and a nuclear plant, with costs of 1000 to 1500 €/kWe and 1000 to 2000 €/kWe respectively. The fuel cost is the major cost in gas-based plants. Of all costs, fuel costs are responsible for a share of approximately 80%, compared with the 20% share for investments, operation and maintenance (O&M). This is in contrast to nuclear power plants, for which the fuel costs are only responsible for approximately 1/10 to 1/5 of the total costs. Coal-based plants are somewhere in between. To summarise on the costs aspects, one can say that the low investment costs are in favour of the gas-fired plants, but there is a very strong dependency of the gas prices[3].

1.2.1.2. Modularity and flexibility

The more combined cycles are used, the more they have to operate in cycling mode, besides operating in base load. Simple cycle gas turbines serve both in cycling and peak operation.

The partial load behaviour of a combined cycle and its associate gas turbine, is presented in Figure 1. The plotted efficiency is relative to its 100% load case. The partial load efficiency is good, but it drops quickly below about 50% partial load. Besides the rapidly decreasing efficiency at 50% partial load, the increasing NO_x-emissions are another drawback, as will be explained further (section 1.2.2). It is important to keep the gas turbine exhaust temperature as constant as possible, when working at partial load, to leave the Rankine cycle as undisturbed as possible.

Gas turbines like e.g. the LM6000 of GE [5] (or similar turbines from Alstom [4], Siemens [6], Rolls Royce [7]...), can operate in base load, cycling and peak load. Very often, those kinds of turbines find their origin in aeroderivative turbines. As a rule of thumb, those turbines have a power output of 40 MW_{th}, 40 MW_e and an electric efficiency of 40 to 42% (versus 38% for a large gas turbine – 200 to 300 MW_e –, optimised for a combined cycle). As gas is very difficult to store in large volumes, it is technically perfectly possible to make use of jet fuel in case of an extreme temperature drop or gas price shock[4].

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[1] Used exchange rate: 1 USD = 1 EUR

[2] When Liquefied Natural Gas is used, costs amounts to more than 800 €/kWe

[3] Gas prices are as volatile as oil prices.

[4] Storage capacity of jet fuel is limited as well, so the use is only possible for a period of some weeks.

As mentioned in the introduction, oil-fired turbojet units can be used for peaking as well, but their efficiency is much lower than the ones of modern gas turbines.

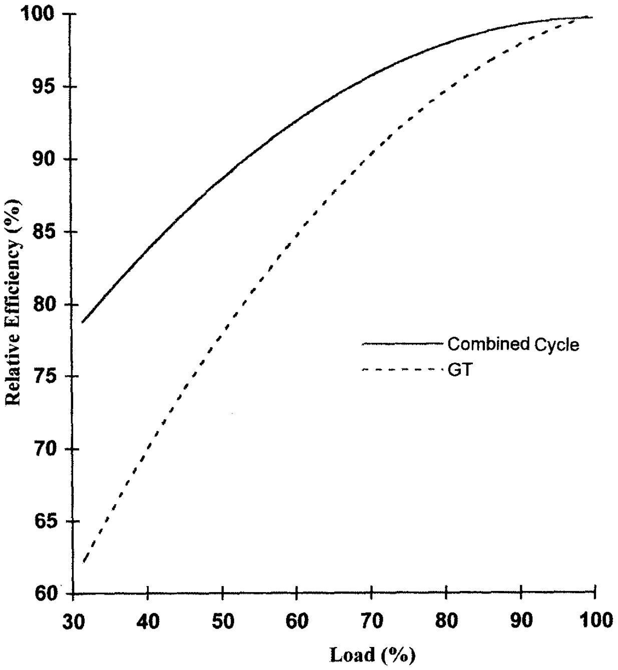

Figure 1 Partial load efficiency of gas turbine and combined cycle (Source: [8], p.211)

Simple cycle gas turbines are very flexible in use. They have a very short start-up time of 15 to 30 minutes, and they have quick load-change capabilities.

Combined cycles, on the other hand, are less flexible. This is because they consist of two cycles: the gas cycle – which is flexible as mentioned above – and the steam cycle – which is less flexible. The steam cycle operates under higher pressure, and all structures (steam turbine and boiler) have ticker walls. The thermal-stress limits of the material have to be respected, which results in slower start-up times. At operation temperature, the CCGT has a load change capability of approximately 5% fluctuation of the rated power per minute. This can be done by the regulation of the fuel and air injection. It is important to avoid temperature shocks. In the rate of several to 8 hours of non-operation, a hot start can be done in 40 to 50 minutes and after 60 hours, a warm start takes up to 2 hours [8]. To reach full power after complete cooling down, it takes 10 to 16 hours [3].

A possibility to increase the flexibility is to use a bypass stack/damper. By this, the start-up time of the CCGT can be reduced to that of the simple gas turbine, because the gas turbine exhaust gases 'bypass' the steam cycle in the start-up phase. Drawbacks of this system are the high costs (both investment and maintenance), the resulting efficiency and power output drop and the lower reliability of the overall system.

As will be discussed in section 1.3.2, in modern CCGT-plants, sometimes 2 gas turbines are combined with 1 steam turbine. This increases the flexibility of the plant. There are several operation strategies possible, but in general, the different strategies aim to maximise the overall CCGT-efficiency at a certain demand [MW_e], taking into account the technical and discharge restrictions. In the operation strategy, the air mass flow and the TIT[5] are important parameters. They are regulated by the inlet guide vanes of the compressor and the fuel injection of the burner [3], respectively.

1.2.2. Environmental aspects

In general, the combination of the high efficiency of gas-fired plants (especially CCGT plants) and the fact that natural gas is a rather environmentally friendly fuel, gas-fired plants produce little exhaust emissions and a low amount of waste heat.

During the combustion of natural gas, there are no sulphur oxides (SO_x) formed, as natural gas does not contain sulphur, or only in a very low concentration.

Compared to the other fossil fuels (oil and coal), a CCGT unit produces only a small amount of CO_2: 350 to 400 gram CO_2/kWh, compared to 650 to 750 gram CO_2/kWh and 700 – 1000 gram CO_2/kWh for oil and coal respectively.

The major environmental issue with natural gas is the formation of nitrogen oxides (i.e. NO and NO_2), because of the presence of nitrogen in the sucked-in air. NO_x is at the base of the formation of nitric acid (H_2NO_3), which is one of the main components of acid rain.

Nitrogen is formed at the very high temperatures, which occur in the flame of the combustor. This flame temperature is mainly dependent on the fuel to air ratio, the air temperature in the combustion chamber, the combustion pressure and the duration of the combustion. It is the highest in the case of stoechiometric combustion[6]. To have a stable combustion, combustors used to have a fuel to air ratio of 1, but nowadays, the fuel to air ratio has become less than 1 (± 0.8) to reduce the flame temperature, and as a consequence the NO_x-emissions. Modern combustors operate in several regimes, in order to reduce the flame temperatures. At approximately 50% partial load, the combustor mode switches from the diffusion mode into the so-called "pre-mix" regime (at more than 50% partial load). In the latter regime, NO_x-emissions can drop to 9 to 25 ppm (at 15% O_2). Other solutions, like the injection of steam or water in the burner or the "dry combustion", result in NO_x-emissions of 40 ppm and 25 ppm respectively. The drawbacks of the injection of water/steam is the large amount of demineralised water needed and the overall efficiency drop, which is not compensated for by the increased power output. The "dry combustion[7]" tackles those drawbacks, and gets its good emission results from the combination of the diluting of the fuel, the large amount of combustion air and the short residence time in the hot combustion zone.

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[5] TIT = Turbine Inlet Temperature.

[6] Stoechiometric combustion occurs when the fuel to air ratio equals 1.

[7] The combustor is designed to limit the formation of pollutants in the burning zone by utilising "lean-premixed" combustion technology. More info can be found on [5].

If there are more stringent NO_x-regulations, reduction systems in the HRSG[8], can result in NO_x-emissions below 5 ppm, but with an extra cost, efficiency drop (minus ± 0.3%-points) and extra maintenance.

Table 1 shows the amount of heat that needs to be dissipated into the environment for different 1000 MW_e plants.

Power plant **Heat sink**	Gas turbine	Combined cycle	Steam turbine	Nuclear
air/stack	1500-2000 MW	130-180 MW	70-100 MW	0 MW
water	0 MW	550-700 MW	1100-1400 MW	1800-2200 MW

Table 1 Comparison of the heat to be dissipated for different types of 1000 MW station (Source:[8] , p. 229)

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[8] HRSG = Heat Recovery Steam Generator (see Section 1.3.2).

1.3. Description of gas & oil technologies

1.3.1. Gas turbines: simple cycle

The gas turbine exists in its simplest form, in the simple, open cycle, based on a thermodynamic Brrayton cycle. In this cycle, the exhaust gases – at a temperature of approximately 600°C – are emitted in the atmosphere; the residual heat is lost. Currently, the available power range is from 100 to 300 MW (e.g. [4] and [5]). The basic working principle and main components are presented in Figure 2 and explained in the section 1.3.1.1 below.

Comparable to the open cycle, there is the closed cycle, in which heat is supplied and subtracted through a heat exchanger. Nowadays, those kind of closed-loop gas cycles are of no importance for electricity production and will not be discussed any further.

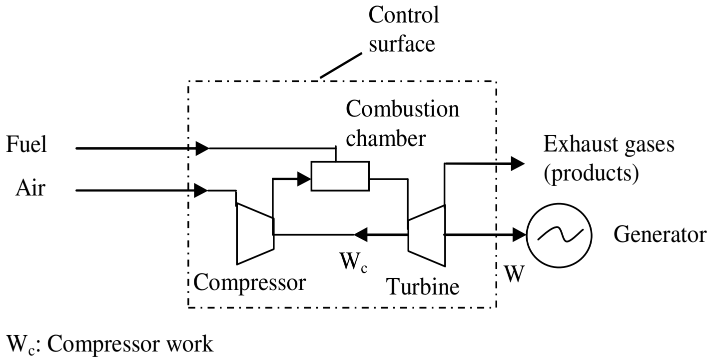

Figure 2 Working principle Simple Open Gas Cycle (Source [1])

1.3.1.1. Principle

The working principle of the Simple Cycle Gas Turbine (SCGT) is rather simple. Air, at atmospheric conditions goes through a compressor. As a result, its temperature and pressure increase[9]. In the next phase, it enters the combustion chamber, where combustion occurs after the injection of natural gas (or some other fuel). In practice, the combustion chamber can consist of 1 or 2 chambers, connected in parallel. The combustion reaction is almost isobar (there is a pressure drop of approximately 4%), and the exhaust gasses exit the combustion chamber at a temperature of approximately 1500°C. In the next phase, the hot gasses enter the turbine at 1200 to 1450°C[10] and are expanded, before being emitted into the atmosphere.

As the enthalpy content of the combustion products, which enter the turbine, is larger than the energy content of the air entering the compressor, the turbine power output is larger than the needed compressor power. The turbine drives the compressor, and the residual part of the rotational energy is transformed in the generator into electricity. By making use of heat exchangers (e.g. a heat recovery heat exchanger for the flue gasses), this simplest form of SCGT can be optimised.

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[9] Pressure ratio of 15 to 30.

[10] This is often indicated as the 'TIT' = Turbine Inlet Temperature.

1.3.1.2. Performances

The efficiency of a modern gas turbine amounts to 40 to 42%. It is calculated as the proportion of the mechanical power on the shaft to the generator and the product of the fuel mass flow and the lower heating value (LHV)[11].

$$\eta = \frac{P_{shaft,to\,generator}\left[W\right]}{\dot{m}_{fuel}\left[kg/s\right] x\, LHV\left[J/kg\right]} \qquad (1)$$

The overall efficiency can be increased by the use of a higher compressor ratio. But as the TIT is proportionally related to the pressure ratio, it limits the efficiency increase, since the maximal TIT is dependent on the thermal material restrictions. The cooling of the turbine is a key issue for modern gas turbines. Cooling of the turbine blades is done by making use of compressed air from the compressor, which is sent through internal channels into the blades. By convective heat transfer, the turbine is cooled and the air escapes from the internal channels of the blades, through small holes. In a second phase, it covers the turbine blades with a small film of air. Up to 20% of the compressed air is used for cooling. This cooling is absolutely necessary for the turbine, but it reduces the overall efficiency: by the injection of air, the gas temperature decreases and simultaneously, the mixing of air and exhaust gasses reduces the pressure, both of which influence the turbine power output negatively. Future evolutions will be discussed below.

The current efficiencies of the compressor and the turbine are rather high, 91% and 89%, respectively.

1.3.2. Gas turbines: combined cycle

The Combined Cycle Gas Turbine (CCGT) is based on the SSGT as discussed above, but as the name suggests, it combines 2 thermodynamic cycles. The first one is the gas cycle, and the second one a steam cycle. The gasses, which exit the gas turbine, contain a lot of enthalpy, as they are at a temperature of 560 to 640°C. To recover a share of that energy, the flue gasses firstly pass through a heat exchanger, to form steam for the second cycle. Figure 3 presents the CCGT in its simplest form and is discussed in the next paragraph. Other configurations, which make use of reheaters, superheaters, etc., are perfectly possible and common in use.

In modern combined cycles, 1 or 2 gas turbines are combined with 1 steam turbine. Different configurations with *"single or multiple shafts[12]"* are possible. When the CCGT combines 1 gas and 1 steam turbine, the single shaft configuration is preferred, because of its slightly higher efficiency (less auxiliary services, fewer losses, etc.) and its lower investment- and O&M-costs (only one generator, more compact, etc.). As a drawback of the single-shaft train, the balancing of the shaft is more difficult and the individual components are more heavily constructed, which makes

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[11] The condensation heat cannot be brought into account, as the temperature of the flue gasses is about 600 °C.

[12] In a single shaft configuration, both the steam and the gas turbine are placed on the same shaft and drive, as a consequence, the same generator. In a multiple shaft configuration, the different turbines are placed on different shafts and drive different generators.

maintenance less practical. Mostly, when a large amount of steam needs to be tapped off, the double shaft configuration is preferred [3]. When 2 gas turbines are combined with 1 steam turbine, 3 generators are always used.

M_A: Mass flow air
M_F: Mass flow fuel
M_{ST}: Mass flow steam
M_G: Mass flow gas
Fg: Flue gas
CC: Combustion chamber
HRSG: Heat Recovery Steam Generator
P: Pump
T_{ST}: Steam Turbine
T_G: Gas Turbine
C: Compressor
CON: Condensor
Q_L: Heat transfer
W: Work
Gen: Generator

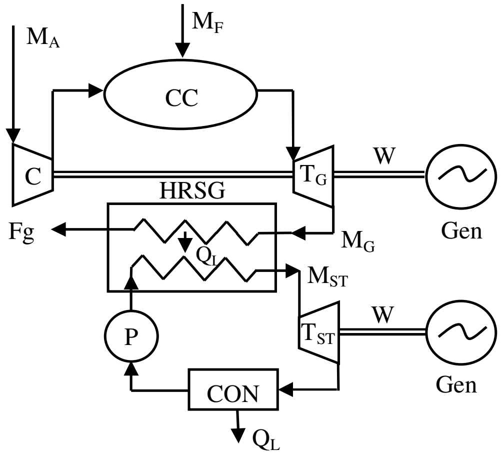

Figure 3 Working principle Combined Cycle Gas Turbine (Source [1])

1.3.2.1. Principle

As can be seen on Figure 3, the CCGT combines two cycles which are connected to each other in the Heat Recovery Steam Generator (HRSG). At the “high” temperature level, a gas turbine operates as discussed in section 1.3.1. At the “low” temperature level, one can find the classic closed Rankine cycle. A pump brings the water to a higher pressure level, after which the water evaporates in the HRSG. In the next phase, steam undergoes expansion over the steam turbine, before it passes through the condensator on its way to the pump.

In Figure 3, the HRSG is presented as a simple heat exchanger, but in reality, it contains several components. An economiser brings the feed water to the saturation temperature; in the evaporator, steam is formed; and in the superheater, steam can be superheated. Another evolution is the use of several pressure levels in the HRSG (up to 3 levels: low (LP), medium (MP) and high (HP) pressure). This has the advantage that the steam can reach higher superheated temperatures at higher pressures. Another possibility is the use of a ‘reheat cycle’. In this cycle, steam returns to the HRSG after the expansion of the HP to the MP level, and mixes with the steam, leaving the MP superheater. All types of combinations of the abovementioned configurations are possible.

1.3.2.2. Performances

Before starting the discussion on efficiencies and performances, it is important to realise that a maximised gas turbine efficiency does not automatically result in a maximised combined cycle efficiency. This is mainly because of the relation between the pressure ratios used in the gas cycle and the flue gas exhaust temperature at the inlet of the HRSG. An optimised gas turbine, with a high pressure ratio has an efficiency of about 42%. But when this turbine is used in a combined cycle, the overall CCGT efficiency is lower, than when a gas turbine is used with a lower pressure ratio and as a consequence a lower efficiency (± 38%). This is because a higher exhaust temperature is reached.

A way to uncouple the high pressure ratio and the low exhaust temperatures, is the use of sequential combustion. After a partial expansion over the gas turbine, the gasses are reheated in a second combustion chamber (e.g. by Alstom [4]). This sequential combustion has a positive effect on the NO_x-emissions as well.

The overall CCGT efficiency can roughly be estimated by the following reasoning. Approximately 60% of the energy content of the fuel is available in the exhaust gasses in a gas turbine with an overall efficiency of 40%. As the efficiency of the steam cycle is about 38%, in the end ± 37% of the energy content of the injected fuel is lost and ± 63% is transformed in useful energy (i.e. electricity)[13]. In reality, commercial installations have an efficiency from ± 54% to 60%. Recently, the H System^{TM} of GE is the first CCGT to reach an overall thermal efficiency of 60% [5]. This plant makes use of advanced technologies as discussed below. Table 2 gives a performance overview of different types of CCGT concepts.

		Single-pressure	Dual-pressure	Triple-pressure	Triple-pressure reheat	Dual-pressure reheat	Single-pressure/supplementary firing
Gas Turbine Fuel Input (LHV)	MW	473	473	473	473	473	473
Duct Burner Fuel Input (LHV)	MW	0	0	0	0	0	51
Total Fuel Input (LHV)	MW	473	473	473	473	473	524
Gas Turbine Output	MW	178	178	178	178	178	178
Steam Turbine Output	MW	94.8	99.0	99.7	102.5	104.9	125.5
Gross Output	MW	272.8	277	277.7	280.5	282.9	303.5
Gross Efficiency (LHV)	%	57.7	58.6	58.7	59.3	59.8	57.9
Auxiliary Consumption	MW	4.1	4.5	4.5	4.6	5.2	5.0
Net Output	MW	268.7	272.5	273.2	275.9	277.7	298.5
Net Efficiency (LHV)	%	56.8	57.6	57.8	58.3	58.7	57.0
Net Heat Rate (LHV)	kJ/kWh	6337	6249	6233	6172	6132	6320

Table 2 Performance comparison for different cycle concepts (Natural gas fuel with low sulphur content) (Source: [8], p. 103)

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[13] $\eta_{CC} = \eta_{GT} + \eta_{ST}(1 - \eta_{GT})$; e.g.: 0.63 = 0.4 + 0.38(1 - 0.4)

1.3.3. Other gas & oil technologies

1.3.3.1. Aeroderivative gas turbines

Aeroderivative gas turbines find their origin in the aviation sector. They used to have superior efficiencies, thanks to the advanced cooling techniques used and the focus on the high specific power output, due to the obligate weight reductions in the aviation industry. Available power output is below 50 MW. Nowadays, a lot of the used techniques are implemented in gas turbines, designed for electricity production (e.g. LM6000 of GE [5]).

1.3.3.2. STIG-cycle

In a Steam Injected Gas turbine cycle, as the name suggest, steam is injected into the burner of the gas cycle. As discussed in section 1.2.2 on environmental issues, this has a positive effect on the NO_x-emissions. Another consequence is the higher power output of the gas turbine, with an increased efficiency compared to a SCGT. When compared to a CCGT, the efficiency of a STIG-unit is lower. This type of plant is perfectly fitted to be used as a peak unit, in areas where water is plentiful, since a lot of make-up water is required, as all generated steam is lost in the atmosphere. Maximum 2 to 4% (of the air mass flow) steam can be injected. Otherwise, major modifications have to be made to the gas turbines. This limits the commercial viability, as gas turbines are highly standardised.

1.3.3.3. Turbo-STIG

Another STIG-configuration, which makes less excessive use of water, is the turbo-STIG. In this cycle – which mostly makes use of an aeroderivative gas turbine – a steam turbine is placed on the same shaft as the gas turbine. The HRSG produces steam for the steam turbine, where it expands to a pressure level, suitable for entering the HRSG to reheat the steam before injection in the gas turbine. By the introduction of the steam turbine, a higher power output and a higher thermal efficiency can be reached. But as the use of water remains quiet high and the efficiency remains lower than that of a CCGT, all types of STIG-plants are not such a great success. Anyway, these types of units are well fitted to drive smaller cogeneration plants.

1.3.3.4. Cogeneration

In a CCGT plant, both heat and power are produced. This makes it a valuable option for cogeneration. More details on cogeneration and the use of CCGT, can be found in the chapter on *‘Combined heat & power’*.

1.3.4. Future gas & oil technologies

1.3.4.1. Cooling systems

As discussed in section 1.3.1, the cooling of the turbine is a very hot topic in the gas turbine sector. In recent years, cooling techniques have evolved rapidly, which makes further improvements more difficult to be achieved. Besides the reduction of used air mass flow – which is delivered by the compressor – for the internal cooling of the turbine blades and an improvemed convection and film cooling, closed-circuit cooling is developed. In this option, the abovementioned temperature and pressure drop, because of the mixing process, is avoided, as no air is 'tapped off' the compressor. An external coolant is used in a closed circuit. This option is interesting for a CCGT, where steam can be used as a coolant and by this, the removed heat can be used effectively. In a simple cycle gas turbine, internal cooling is not very common.

1.3.4.2. Co-combustion, multi-fuel and repowering

To decrease the dependency on natural gas somewhat, and in the framework of more environmental friendly electricity production, bio fuels could be used for combustion in the gas turbine. It is possible to add 5 to 10% bio fuel in gas turbines, without having to implement major changes to the existing gas turbines [3]. In any case, R&D is needed on the subject of multi-fuel burners and it is necessary to have a broader supply of highly qualitative bio-fuels. With the co-combustion of bio-fuels, public-service obligations can be fulfilled, in some countries allowing the gathering of Green Certificates for the produced "green electricity".

Another "multi-fuel option" is the installation of a gas-fired CCGT-unit into, e.g. a coal-fired plant. The coal-based plant remains to deliver the main power output, but the CCGT-part can both produce extra steam and help in raising the temperature of the feed water.

"Repowering" is the conversion of existing steam power plants into combined cycle plants. This can be done when the steam turbines are still in a good condition, but when the boiler needs to be replaced. After some time, one can/must change to gas as the power plant's fuel.

1.3.4.3. Components

An overall remark has to be made on the flexibility towards partial load behaviour. As mentioned before, this becomes more and more important as more CCGT's come into cycling operation.

Material research, e.g. the possible use of ceramic top layers to increase the TIT, is going on. If a higher TIT can be realised, a higher useful enthalpy range is available, so a higher efficiency and power output can be obtained, with a decreasing specific power plant cost. Another important research topic is the increase of the exhaust gas temperatures. This is beneficially for the steam cycle.

Gas compressors have to handle higher mass flow of air and have to reach higher pressure ratios. As the current efficiencies of both the compressor and the turbine are rather high, one cannot expect many more future improvements on those components.

If the steam turbine inlet temperature and pressure can be increased up to supercritical circumstances, it could be possible to achieve steam cycle efficiencies of about 45%. This should make it possible to ameliorate the overall CCGT efficiency with 2%-pts.

1.3.4.4. Overview

Current CCGT-plants have efficiencies from about 54 to 60%. In a VGB-article on technologies for gas turbines of future generations [11], estimations are made on the possible improvements. The share of the different contributions on the material side, the steam turbine side and the gas turbine side are presented in Figure 4. The used reference power plant has an efficiency of 57.4%, and phase 3 is expected to be realised somewhere around 2025.

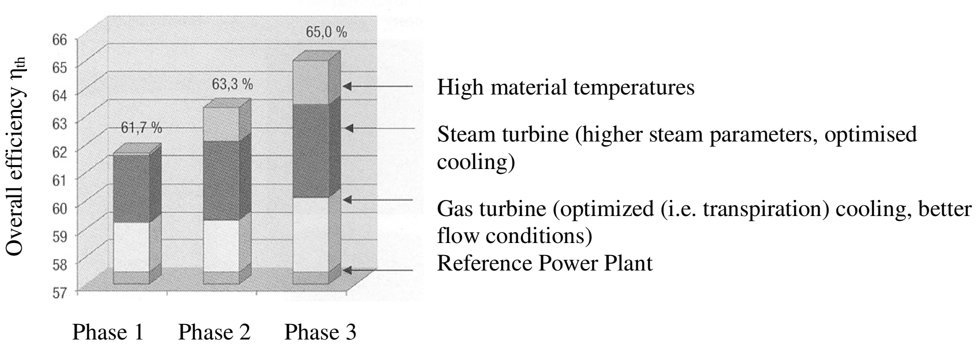

Figure 4 Contribution of different technologies to the increase of the overall efficiency of Combined Cycle power plants. (From [11], p. 70)

Table 3 gives a more detailed overview of the projected evolutions of some important CCGT parameters towards 2025. Some projections seem rather optimistic. E.g. the "Need for coolant (gas turbine)" [14] parameter is estimated to reach 10%, but other specialists [3] think 15% is a much more realistic figure.

	Reference Power Plant	Phase 1	Phase 2	Phase 3
Overall thermal efficiency [%]	57.4	61.7	63.3	65.0
Combustion chamber outlet temperature [°C]	1500	1500	1520	1520
Need for coolant (gas turbine) [%]	21.46	11.7	12.4	9.9
TIT [°C]	1172	1432	1439	1473
Maximum material parameters (gas turbine) [°C]	850	900	950	990
Maximum material parameters (steam turbine) [°C]	560	580	595	650
Need for coolant (steam turbine) [%]	-	2.2	1.0	0.3

Table 3 Overview of the development of the different process parameter in the different phases of the research project. (Source [11], p. 70)

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[14] The need for coolant is expressed as the ratio of the mass flow air in the compressor.

1.4. Present gas & oil power plant market

Figure 5 (the left-hand side) presents the currently available gas resources in Europe and the surrounding countries. One can see that there are quite a lot of gas suppliers all over this region.

The gas market is as volatile as the oil market. Prices fluctuate very often and in general the gas prices follow the same (long term increasing) trend as the oil prices.

Over the last 30 years, the electricity production in the OECD countries annually increased by 2.8% [12]. The demand for electricity is not expected to decrease in the future and in combination with the planned nuclear phase-out in some European countries, the fossil-fired electricity production option is chosen for base load and cycling[15]. Some years ago, the “dash for gas” was going on in several European countries, but as in last years, the gas prices increased, coal-fired plants were the first option for electricity base load production (besides the existing nuclear and other “must-run” units). The gas-fired units operate more and more as cycling units.

In 2005, in the EU-25, slightly more than 50% of the electricity production is fossil-based: i.e. 1650 TWh out of 3043 TWh (from [13]). Approximately 54% of this 1650 TWh is produced by coal-fired units. Gas- and oil-fired units have a share of 38% and 8% respectively. These numbers illustrate the discussion from above: the importance of fossil-fired power plants and the relation between gas and coal.

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[15] While not forgetting the increasing interest in renewable sources.

1.5. Future Development

On the right-hand side of Figure 5, the estimated natural gas presence in the EU (+ surrounding countries) in 2025 is presented. It can be seen clearly that gas will have to be imported from outside the EU-borders. This puts a big challenge concerning the security of supply on the gas market.

Table 4 gives a projection of the long term evolution of the gas-fired share in electricity production in the EU-25.

2010	21%
2020	28%
2030	34%

Table 4 Share of natural gas in electricity production in EU-25 (Source [10], p. 29).

This concern of security of supply, combined with the already high (and still increasing) gas prices and the more stringent environmental regulations, urge the 'gas turbine market' to react. More efficient gas-fired power plants are envisaged and other options which make use of the gas turbine technology are under development. One example of this is the Integrated Gasification Combined Cycle (IGCC). In the IGCC, coal (or other heavy fuels) is converted into syngas, which is used as the primary fuel for the gas turbine. This can become an environmental friendly option in combination with CO_2-sequestration, prior to the combustion process. More details on this cycle can be found in the chapter on *'Coal fired technologies'*.

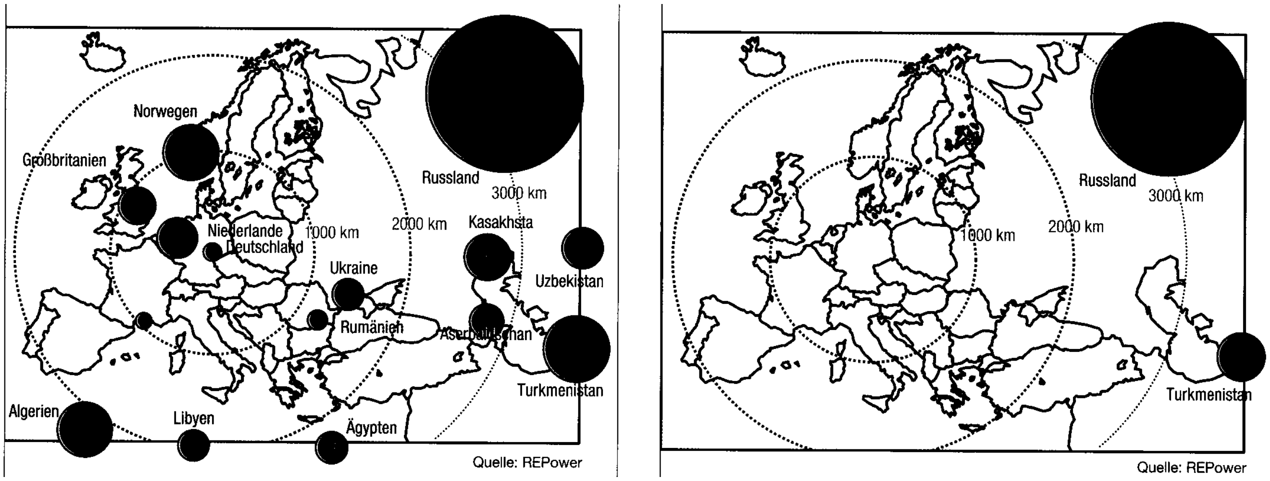

Figure 5 Presence of natural gas: situation in 1999 (left) and 2025 (right) (Source [10] , p.31)

1.6. References

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