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Future requirements for fossil power plants

M. Gaderer and H. Spliethoff

Institute of Energy Systems, Technische Universität München - München, Germany

Summary. — The fast increasing installation of technologies to convert renewable energy into power influences the operation of conventional power plants. New requirements on the technology, on the operation and on the economic have to be considered for already running and future power plants. Currently, first experiences with such a production and market situation are available. Technologies are discussed to store power and to reduce CO_2 emissions. New compensation models are necessary to enable economic operation of fossil power plants in base load. This article gives a short review about available technologies and future challenges.

1. – Energy market

Over the last 20 years, the worldwide primary energy demand has been increasing by 2% per year and in 2008 it ranged at approximately 514 Exajoule (142.000 TWh). Whereas in Europe the increase per annum amounts to 0.7%, the main consumers being countries in Asia, like China, with an average increase of energy demand of 7.6% per year over the same time. Different statistics and scenarios exist on how to cover the energy demand.

The scenario in fig. 1 is based on the actual energy mix and ends in 2030 with a demand of 80% based on coal, oil and natural gas, with only 14% being covered by renewables and 6% produced by nuclear energy (see fig. 1).

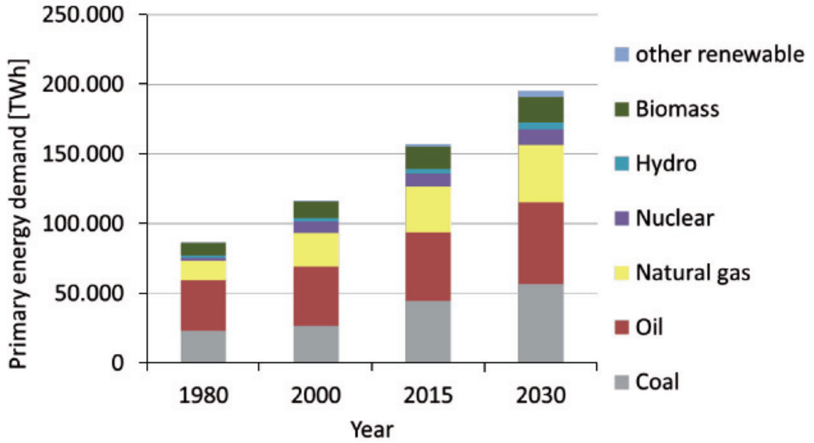

Fig. 1. – Worldwide primary energy demand [1].

Apparently, fossil energy carriers will still play a very important role in the future. For some areas,coal is of importance due to the local availability. Actually, China covers 66% of the demand with coal, USA 24% and Europe 19%. Biomass is used for 6–10% of the primary energy demand, thus ranging between 30 and 70% of the realistic potential, which, obviously, differs considerably depending on the individual countries.

In 2030, renewables will contribute 22% to power production, 67% will be covered by fossils and 10% by nuclear power, this distribution being comparable to the actual situation (see fig. 2).

The application of renewables differs considerably depending on the local situation.

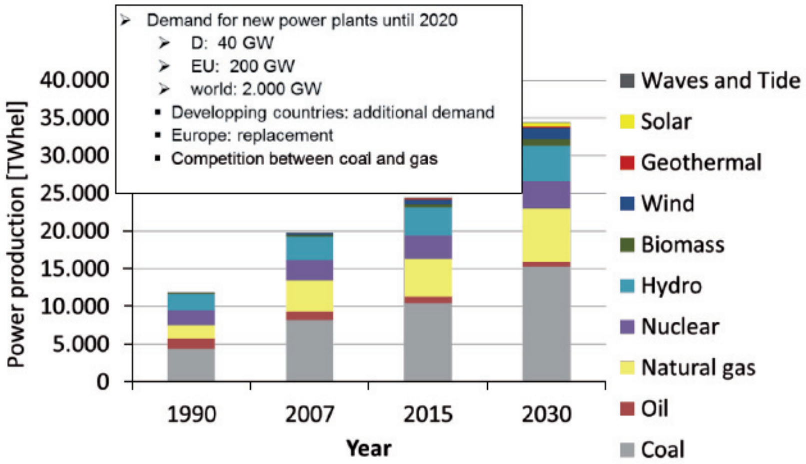

Fig. 2. – Worldwide power production [1].

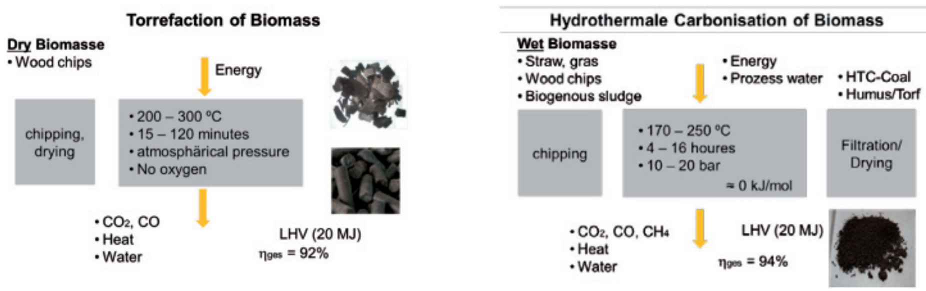

Fig. 3. – Torrefaction and hydrothermal carbonization as pretreatment technology for biomass.

Biomass

Countries in Northern Europe, Canada and Russia dispose of a high potential of biomass resources mainly based on wooden biomass whereas the major potential for countries in Europe, Asia and South America lies in agricultural biomass, which, however, causes competition with areas required for agriculture-based food. Furthermore, environmental problems originate from the change of natural areas to agricultural areas as well as the requirement of water and fertilizer for cultivation.

Although biomass is a form of stored solar energy, it is a limited resource. Compared to other renewables, it is used more flexibly for conversion into heat, power or synthetic fuels. The cost of biomass is a main economic factor and, due its extensive use,it has strongly increased in Europe since 2008, a fact that will finally limit its potential. Consequently, only cheap biogenic residuals like very wet biomass, sewage sludge or agriculture residuals as well biomass from countries like Canada or Sweden are of interest in Europe for industrial applications and for power production by co-firing of biomass in coal power stations. For this purpose, the biomass can be "upgraded" by carbonization of the biomass (fig. 3).

Torrefaction and hydrothermal carbonization are two processes, which are presently being developed to increase the volumetric energy density (fig. 4) for transport and to reduce the energy demand to mill the biomass into fine particles (size of $< 1\,\mathrm{mm}$) like coal for combustion in a dust burner.

	Wood chips	Wood-pellets	HTC/Torr. Biomass	HTC/Torr. Pellets
Water content ($\%_f$)	35	10	5	5
LHV (MJ/kg_{tr})	17,7	17,7	20,4	20,4
Bulk density (kg/m^3)	475	650	230	750
Energy density (GJ/m^3)	5	10,1	4,7	15
Ash content (%)	3	1	5	5

Fig. 4. – Comparison of the properties of different biomass [2].

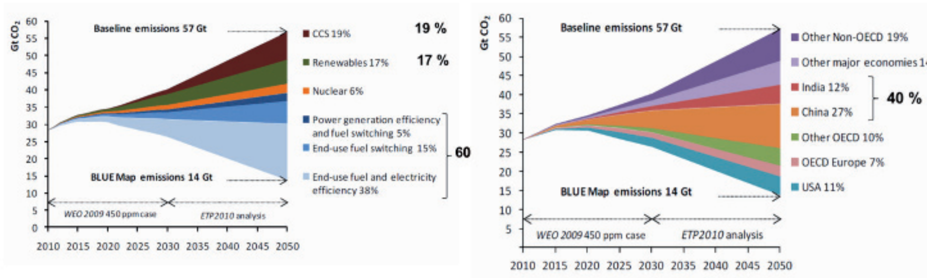

Fig. 5. – Left: scenario to reduce CO_2 emissions worldwide. Right: amount in relation to countries [3].

Solar, wind and hydro

Compared to biomass, wind and solar energy are free of charge, but the availability cannot be controlled and the storage of energy, *e.g.* hydro pump storages,is limited. However, the technology could be standardized(on shore wind and photovoltaic-PV) and manufactured in serial production which would allow the installation of a high number of units worldwide within a short period of time with limited risk, thus considerably reducing the production costs (see photovoltaic). This is a major advantage of solar and wind technology compared to others like biomass power plants or solar thermal power plants. Wind and solar power plants (actually mainly photovoltaic) will therefore be the major technology for new power plants based on renewables.

However,the market for renewables is difficult and still strongly influenced by public subsidies. Technologies requiring high investment costs like solar thermal power and off-shore wind are difficult to realize.

Hydropower is still being used; however, the implementation of new plants is extremely time-consuming and cost-intensive. Of special interests are hydro pump storages to store excess power, produced with solar and wind energy.

Reduction of fossil energy demand and CO_2 emissions

A switch of energy carriers and the reduction of consumption will be indispensable for achieving the major objective of reduction and change of the energy demand.

Figure 5 presents a scenario which should allow to reach a stable concentration of 450 ppm CO_2 in the atmosphere (450 ppm case) by 2030 and to reduce the overall energy-related CO_2 emissions (28 Gigatonnes CO_2 in 2010) until 2050 by 50% (14 Gigatonnes CO_2). The main technical factors to reach this goal are increased efficiency (in total 60%), renewables (17%) and carbon capture and storage (19%). The right side of fig. 5 shows that the most important countries where CO_2 saving should be performed are China, India and USA. However, both the increase of efficiency and the reduction of emissions is a huge challenge. Actually it is unclear how the goals might be achieved.

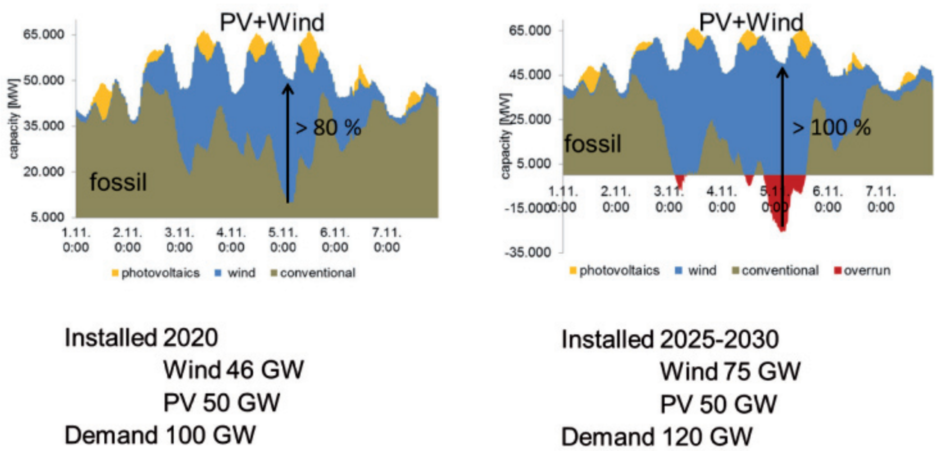

Fig. 6. – power production with fossil(base load), wind and PV. Left:case, if 80% of power demand is covered by wind and PV. Right: case, if wind and PV covers > 100% of power demand. Databases [5].

Energy costs

The production costs of power based on renewables range from 5 to 37 €-cents/kWh$_{\mathrm{el}}$ [4] which is higher than the costs for fossil-based power. Nevertheless, the cost of electricity for end-users ranges between 17 and 25 €-cents/kWh$_{\mathrm{el}}$. Depending on boundary conditions, the cost of power produced with water, biomass, wind and photovoltaic might range at this level. Although we do not want to deepen this aspect at the moment, it should be mentioned that the self-production of power based on renewables might turn out to be attractive for private and industrial consumers and might lead to reduction of power costs even without receiving any governmental aid.

Influence of renewables on conventional power production

Considering financial governmental aid and regulation for CO_2, renewables are as well of interest for power authorities. The increased power production by wind and solar energy influences the operation of conventional power plants which becomes obvious in Germany today. The peak demand in Germany amounts to 100 GW$_{\mathrm{el}}$. In 2011, the installed wind power ranged at 30 GW$_{\mathrm{el}}$ and the installed PV power 20 GW$_{\mathrm{el}}$.

By 2020, almost 100 MW of wind and solar power might be installed in Germany, rising to approximately 120 GW in 2025. However, synchrony effects will limit the available power. Figure 6 shows the influence on fossil power stations, if 80% (left) of the load and > 100% (right) of the load are covered by wind and PV.

As a consequence, fossil power stations will have to be operated in part load operation mode; the fast change of wind and solar power in the range of several (3–7) GW/hour and > 10 GW per day will have to be absorbed by fossil power stations based on coal, natural gas, nuclear or hydro pump storage or other storages. Evidently, the storage of renewable power will be an important factor in the future. As shown on the right-hand

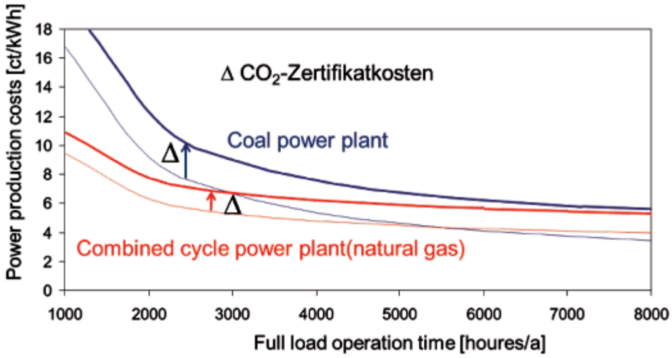

Fig. 7. – The increase of the costs of power production with a coal power plant and a gas fired combined cycle [6].

side of fig. 6, excess power will be available in the near future, which could be stored and used later on.

The first very important effect is that the full load operation time over the year of coal power stations and natural gas power plants (*e.g.* combined cycles) will decrease. Due to this fact and the additional costs for CO_2 certificates for the operation of fossil power units, the cost for base load power will increase from 4–8 cent to 8–11 cent (fig. 7).

However, most of the existing plants in Germany are older than 20 years and have already been amortized. Thus, investment costs are not an important cost factor for plants already in operation. However, within a period of 20 years, old plants in the range of 20–40 GW will have to be replaced in Germany, 200 GW in the European Union and 2000 GW worldwide (data in fig. 2). The realization of these plants will require some 5–15 years depending on the local regulations and necessary procedures to obtain the permissions for erection and operation.

As a result at the time being, at least in Germany, investments into new fossil power stations are not available, the reasons therefore being the decrease in profit ratio, unforeseeable risks in fuel costs and increasing renewable power sources.

This shows that the realization and operation of coal power stations and gas fired combined power stations is highly influenced by the implementation of renewable power technologies. Solutions to solve these problems are under discussion but not available now. New compensation models for power plants in base load operation mode are one possible solution to overcome the lack of investments. Nevertheless, the production costs of power will increase in the future.

2. – Energy technology

Among the key factors for the operation of power stations are the CO_2 emissions and the availability of storage capacities. The reduction of CO_2 can be achieved by using renewables (*e.g.* co-combustion of biomass) or by separation of CO_2 and its use or storage in unmineable coal beds, deep saline aquifers, depleted oil or gas reservoirs or in the cold deep sea.

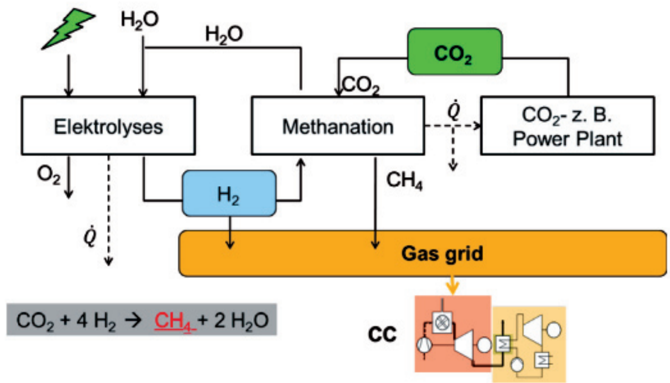

Fig. 8. – Methanation of CO_2 with hydrogen.

Storage technologies for power production

In Germany, the available storage capacity for power with pumped hydro storage (PHS, efficiency 78–85%) amounts to 7 GW for 7 hours. Norway, Sweden, Austria and Switzerland can provide 38–55 GW. However, the development potential for this type of storage is limited [7-9].

The storage demand in Germany could rise to 80 GW in the future, even though the potential for compressed air storages (CAES) is limited and the use of pure hydrogen is limited by missing infrastructure and high losses due to the diffusion of hydrogen. A possible solution might be the production of methane from CO_2 coming from a power station and hydrogen produced with renewable excess power. With it a substitute of natural gas is produced (SNG). The exothermal chemical reaction is known as Sabatier-Reaction and called "methanation".

The reaction takes place at approximately 300 °C with Ni-catalysts (fig. 8). Important research has to be performed for the electrolysis at full scale of several MW. The resulting product, CH_4, can lead to the natural gas grid and can be stored in natural gas storages, the infrastructure therefore being available. Germany alone disposes of 200 TWh of natural gas storage capacity. Methane can be used for power production with high efficient combined cycles (efficiency 60%). The overall efficiency from power (renewable) to power from methane will amount to 23–39%, even without making use of the waste heat (exothermal reaction). If the waste heat is also used, the efficiency can rise to 32–69%. However, the process will be economically acceptable only by making use of waste heat and a very high overall efficiency. Otherwise, the cost of power will range from 30–55 €-cent/kWh_{el} [10-13].

CO_2 sequestration

Figure 9 shows a schematic diagram of the main CO_2 capture processes. All of them require steps for separation of CO_2, H_2O or H_2 from the flue gas or synthesis gas.

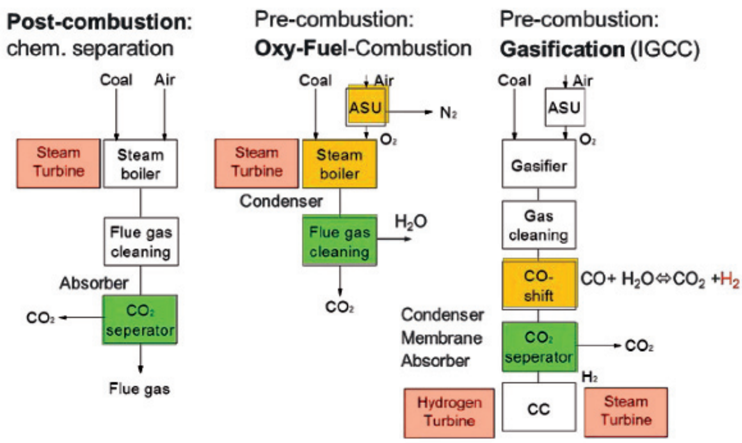

Fig. 9. – CO_2 sequestration technologies [14].

Separation can be accomplished either by means of physical or chemical solvents, high-temperature membranes, solid sorbents or by cryogenic separation. The type of specific capture technology chosen depends on the process conditions for operation.

Typically, post-combustion technology uses chemical solvents (*e.g.* amine scrubbers)for the absorption to remove the carbon dioxide from the flue gas. The combustion takes place with atmospheric air.

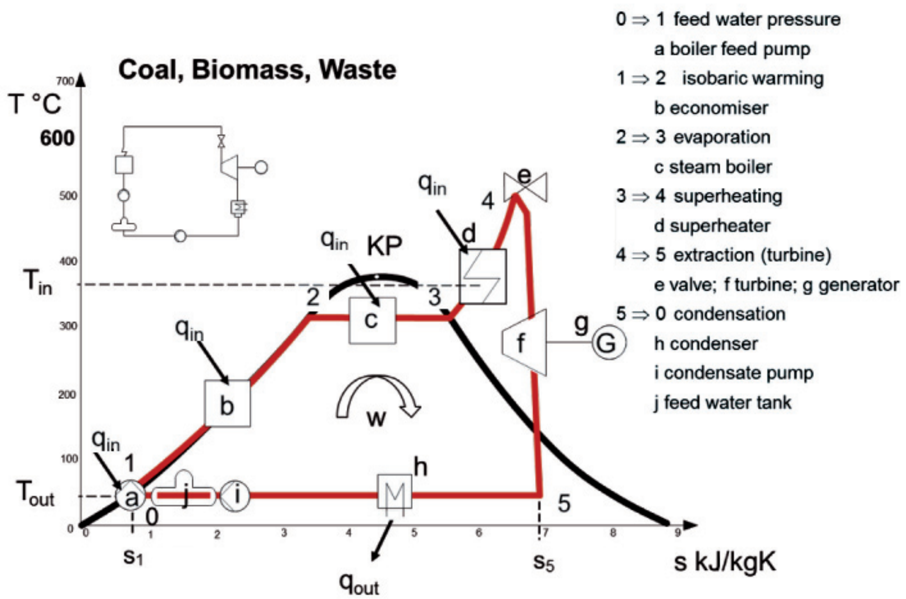

Fig. 10. – Principles of the Clausius-Rankine cycle.

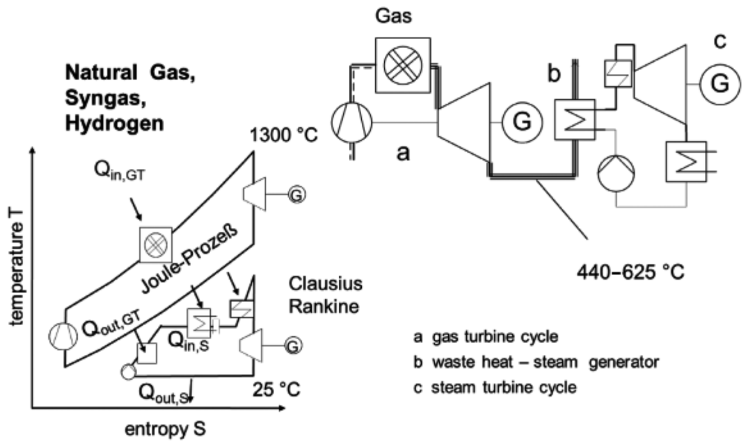

Fig. 11. – Principles of the combined cycle.

The pure oxygen required for pre-combustion is produced by means of an air separation unit (ASU), cryogenic distillation air separation being the standard technology. An alternative to the ASU would be pressure swing adsorption. Pre-combustion can be used for combustion (oxy-fuel-combustion) or for gasification (IGCC). If combustion is used, the flue gas contains mainly H_2O (as steam) and CO_2. The steam can be condensed and separated by cooling down the flue gas, CO_2 will remain.

In gasification processes, the pressurized synthesis gas mainly contains CO, H_2O, H_2 and CO_2. For the sequestration of CO_2 solid sorbents (*e.g.* CaO), physical liquid solvents (*e.g.* seloxol) or high-temperature membrane technologies —still being under development— could be used.

For post- and oxy-fuel-combustion cycles, a Clausius-Rankine-Cycle, *i.e.* a steam turbine cycle according to fig. 10, is used for energy conversion.

For gasification process, a combined cycle (CC) according to fig. 11 —using a combination of a Joule cycle (gas turbine) and a Clausius-Rankine cycle (steam turbine)— is integrated. Hydrogen-rich gas is available for the gas turbine which has to be taken into account for design of the gas turbine.

Figure 12 shows the process of a modern Integrated Gasification with Combined Cycle (IGCC). Pulverized coal is gasified in an entrained flow gasifier in a scale of several 100 MW fuel. IGCCs achieve the highest efficiency if solid fuels are used with the electrical efficiency being in the range of 52% without CO_2 sequestration. If a CO_2 sequestration is included, the electrical efficiency will be reduced to 42%.

The different technologies permit capturing 80–95% of the carbon dioxide produced in coal-fired power plants. Higher capture efficiencies are possible, however, they require considerably larger separation devices which are more energy-intensive and cost-intensive. Capture and compression would require approximately 10–40% more energy than an equivalent plant without capture, depending on the type of system.

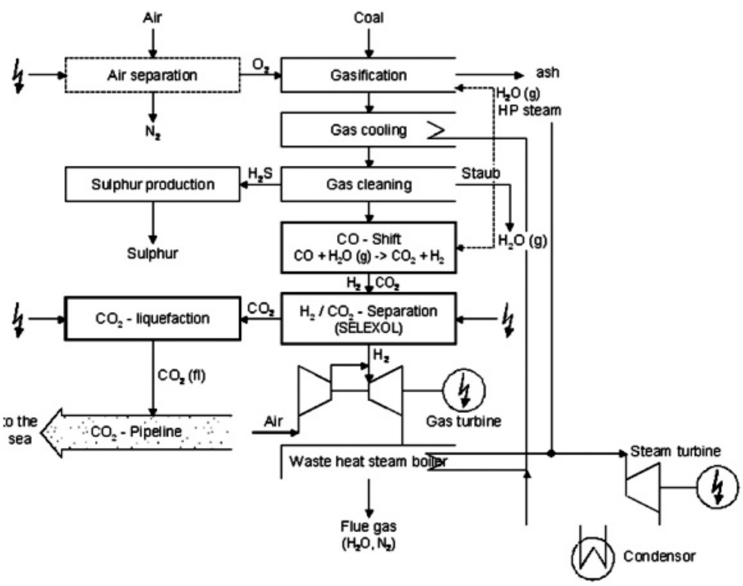

Fig. 12. – Integrated-Gasification Combined-Cycle (IGCC) power plant with CO_2 separation (pre-combustion) [14].

Figure 13 shows the effect of CO_2 sequestration for lignite. The efficiency decreases by 20%, the specific investment costs will increase by 50% and thus the production costs for power will increase as well.

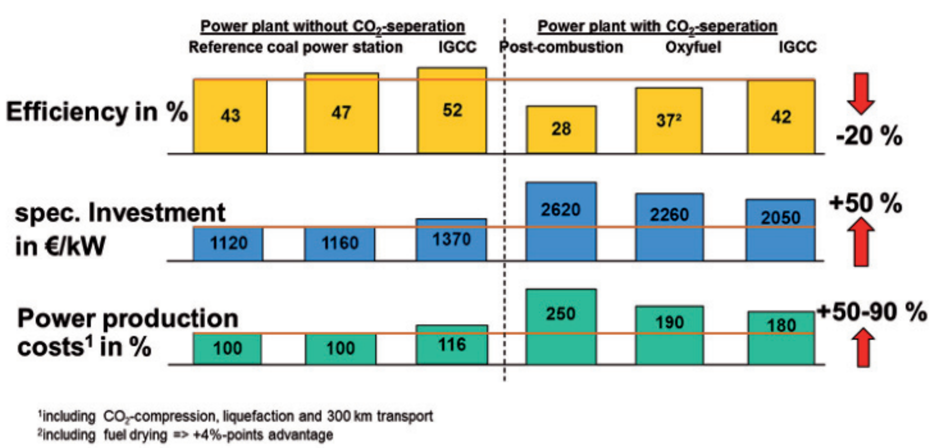

Fig. 13. – Effects of CO_2 sequestration if brown coal (lignite) is used [14].

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