Briefing Paper: The Potential of Gas and Carbon Capture and Storage in Meeting the EU's 2050 Energy Goals

Introduction

In order to fulfil the EU's goal of achieving an 80-95% reduction in GHG emissions, as stated in the EU Energy Roadmap 2050[1], the power sector will need to be 95-100% decarbonised. The energy mix scenarios proposed by the European Commission in the 2050 Roadmap consider the possibilities of a continual increase in electricity consumption, a significant increase in the renewables share, uncertainties around the future of nuclear energy, as well as a greater role for clean fossil fuel technologies. ETN believes that the inclusion of clean fossil fuel technologies in the 2050 scenarios is essential to ensure a stable and flexible supply of electricity in order to meet future demand. This will require significant innovation and investment to enable the decarbonisation of fossil fuels through carbon capture and storage (CCS) technologies, while simultaneously improving supply-side efficiency.

There are uncertainties associated with the various scenarios, especially in relation to the share of intermittent renewable energy sources (RES) and the assumption of complete application of CCS for fossil fuels. One such uncertainty is whether the share of RES in the energy mix will rise as fast as currently anticipated, despite considerable subsidies given to RES development. Another consideration is whether there will be sufficient flexible power supply to balance the increased share of intermittent RES to ensure a stable grid[2]. A third uncertainty is whether the implementation and commercialisation of CCS technology will advance fast enough, considering the persistence of investment risks and technological challenges. These challenges must be overcome in order to meet the EU's emission reduction goals, and to avoid shortages in electricity production in the future.

In recent years, natural gas fired power generation has gained a more prominent position on the global and the European political agenda, partly due to its lower emissions compared to coal, additional global supplies (Liquefied Natural Gas, new pipelines and unconventional gas explorations), as well as due to uncertainties around the future of nuclear generation. Gas is no longer being mentioned only as a bridging fuel towards a zero-carbon energy scenario, but is once again being considered as an important player in the future power generation mix, with the capacity to act as a reliable back-up to RES. The key questions now are whether a secure and comprehensive gas infrastructure can be built in the coming years, and whether gas will attract enough political attention and support to enable it to act as a leveraging fuel for speeding up the realisation of the climate goals.

The increase in world gas reserves, the wide geographical distribution of the sources, planned and newly commissioned CO_2 storage facilities, and changing market conditions, will all facilitate a greater future role for gas. An energy policy that takes into account a balanced mix of energy sources, including a significant share of gas, could accelerate the realisation of the EU's climate objectives, and allow greater time for the necessary development in technology and infrastructure in cost-effective CCS and RES.

In this briefing paper, ETN considers a future technology pathway which could help meet the requirements of a fully decarbonised power sector by 2050. It compares the overall efficiency and CO_2 emission levels of natural gas- and coal-fired power generation both with and without CCS technology applied. The paper concludes that there are a number of advantages to flexible gas fired combined cycle gas turbine (CCGT) power stations with CCS (gas with CCS) when compared with coal fired super critical power plants with CCS (coal with CCS).

---

[1] Roadmap for moving to a competitive low-carbon economy in 2050, EC COM (2011) 112 final, 8 March 2011 (http://ec.europa.eu/clima/policies/roadmap/index_en.htm)

[2] For more insight into the technological impact of increasing the share of variable RES in the grid please see ETN position paper: The effect of increasing the share of renewable energy in the grid, European Turbine Network, Brussels, April 2011: http://www.etn-gasturbine.eu/page22905858.aspx

EC Roadmap to 2050 – Decarbonising the EU economy

In its "Roadmap to a competitive low-carbon economy in 2050," the European Commission (EC) published the latest figures on achieved emissions reductions in relation to energy consumption, population and GDP growth over the last 20 years (Figure 1).

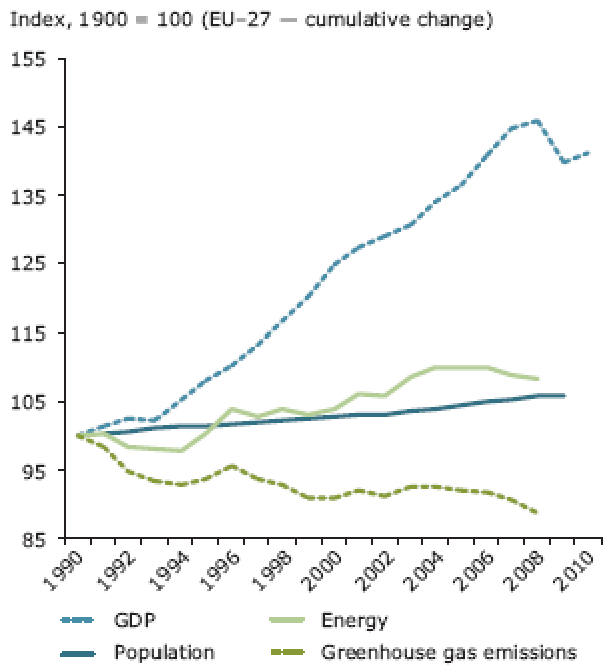


Figure 1: Current status of Europe's GHG emission reduction[3]

EU GHG emissions have been reduced by 16% over the last 20 years, while energy consumption and GDP grew over the same period. This leads to the conclusion that the EU is on track towards achieving a 20% emission reduction compared to 1990 levels by 2020. However, a continuation of current policies would only lead to a 40% GHG emissions reduction by 2050. This is far below the target of 80-95% set by the EU Member States in March 2011.

Moreover, current projections show that the EU is not on track to realise its objectives regarding the 2020 non-binding energy efficiency target (Figure 2) and suggest that more must be done to achieve the 20% energy efficiency improvement.

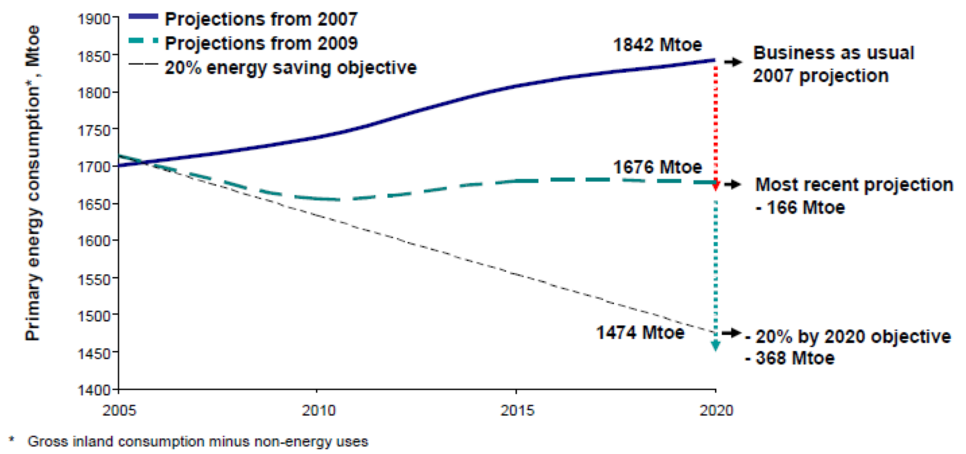


Figure 2: EU efficiency goal and projection to 2020[3]

The EU Member States have set their greenhouse gas abatement objective for Europe (similar to other developed countries) at 80-95% below 1990 levels by 2050. This was in line with the proposed reductions by the Intergovernmental Panel on Climate Change for developed countries as a group. Combined with the

[3] Roadmap 2050 presentation in some Member States, Peter Zapfel, DG Climate Action, 8 March 2011

expected contributions of the developing countries, this should lead to a global reduction of GHG emissions of 50% by 2050. Only in this way can global warming be restricted to 2^0C in the 21st century (Figure 3).

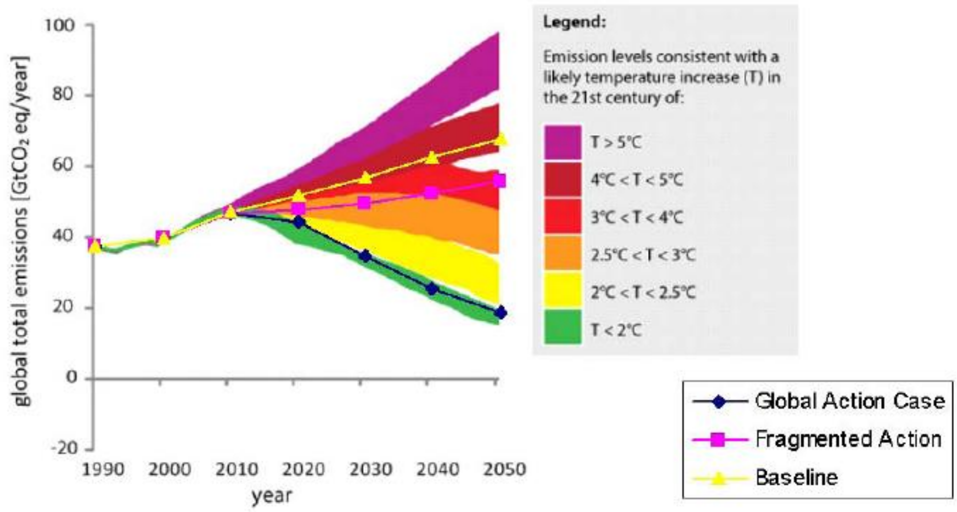


Figure 3: Global emissions pathway in the next 40 years will determine likely warming by the end of the century[4]

Figure 4 shows the EU's cost-effective pathway towards 80% domestic GHG emissions reduction by 2050. This scenario is based on currently available technology and, with behavioural change, only induced through prices. While all sectors contribute greatly to the overall target, the power sector is required to reduce emissions towards essentially a zero level (93 to 99% reduction). An intermediate milestone for the power sector is a GHG emission reduction of 60% by 2030.

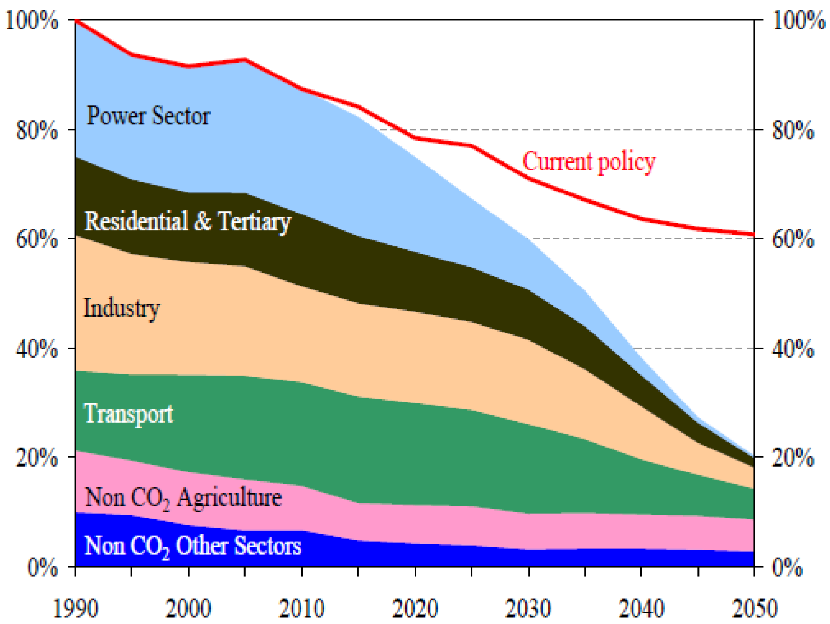


Figure 4: A cost effective pathway towards 2050; 80% domestic European GHG emission reduction is feasible[4]

[4] Roadmap 2050 presentation in some Member States, Peter Zapfel, DG Climate Action, 8 March 2011

Emission reduction scenarios for the power sector

Based on the European Council's 80 – 95% GHG emissions abatement objective for Europe by 2050 the European Climate Foundation initiated a study to "establish a fact base behind this initiative and derive the implications for European industry, particularly in the electricity sector". The result is the "Roadmap 2050: a practical guide to a prosperous, low-carbon Europe".[5]

The study examined three different pathways that differ in the shares of three constituents: fossil fuel with CCS, nuclear energy and a mix of renewable technologies. In addition a fourth scenario was assessed with 100% electricity from renewables and a baseline/reference scenario: 'business as usual'.

The supply mixes in the three power scenarios cover a respective share of renewable energy of 40%, 60% and 80%, a share of nuclear energy between 10% and 30% and a share of fossil fuel with CCS between 10% and 30%. In each of the pathways, CCS must be applied in order to achieve the required reductions. The baseline scenario has a mix of 34% renewables, 49% fossil fuel without CCS and 17% nuclear generation. The evolution of production shares in the various pathways is shown in Figure 5.

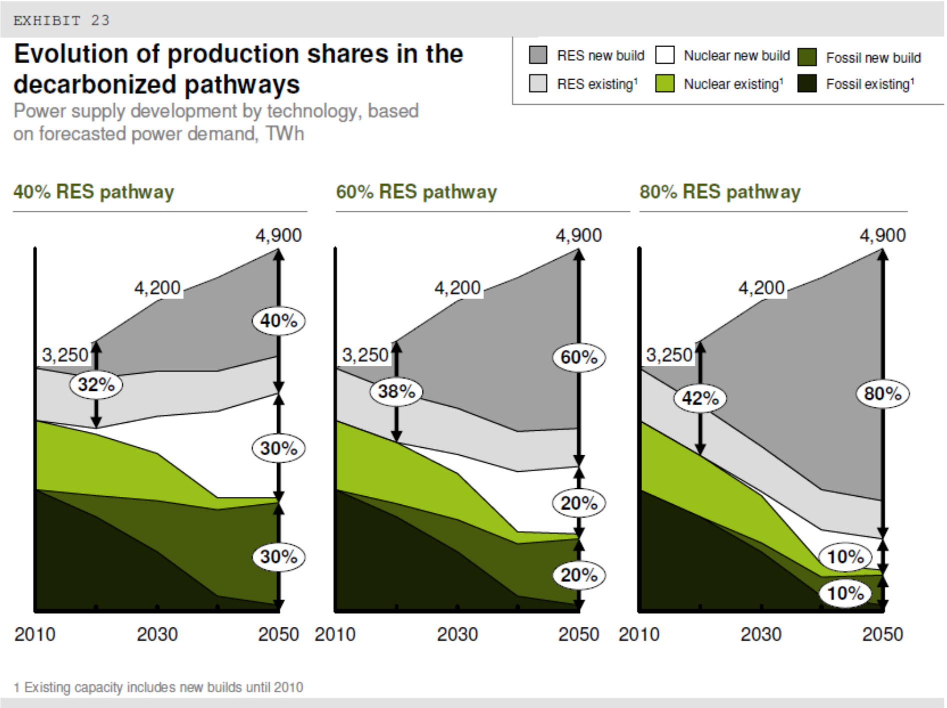


Figure 5: Evolution of production shares in the decarbonised pathways, based on forecast power demand[5]

Some basic assumptions for the three scenarios were made:

- The nuclear share in power production is equal to the fossil fuel with CCS share.
- There is an even split between gas and coal in fossil fuel power production.

The results of the study show various pathways and their implications and interdependencies, but also some basic boundary conditions to be met. Major observations are:

- Nearly 100% decarbonisation of the power sector is required in order to attain the EU goals of 80% reduction of GHG emissions by 2050 over the total economy;
- CCS is required in each pathway, both for coal and gas, in order to achieve the abatement objective;
- The CO_2 reduction potential of the total power sector is assumed to be approximately 95%. This value is limited only by the CCS abatement efficiency of fossil power plants (typically 90% capture) and by the resulting CO_2 emissions from flexible, open cycle gas turbine plants (OCGT), necessary to provide back-up capacity to maintain system security.

[5] Roadmap 2050: a practical guide to a prosperous low-carbon Europe, European Climate Foundation, April 2010

The study does not address in detail choices between the use of nuclear versus fossil fuel with CCS, or between coal and gas for reasons of simplicity, to remain neutral in technology selection and to increase the robustness of the results. Nevertheless, these aspects are important for the power industry and suppliers, and may well affect future policies, investment decisions and required R&D.

Especially with regard to the ultimate goal - reduction of emissions in the relatively short time period ahead - the relative shares of gas and coal in the fossil fuel mix are important. In the past, decisions on the application of gas or coal for power generation were very much related to national or regional policies, the availability of nearby resources, price, security of power supply, or available technology. Currently the following aspects should also be taken into account:

- Primary energy balance and the effect of CCS efficiency on overall emissions;
- CO_2-storage requirements and storage capacity;
- Required back-up capacity in the power sector and its impact on overall emissions;
- Urgency: transition to a low-carbon power sector has to start immediately.

The above listed aspects will be addressed in the section below.

Gas and Coal for power generation – the primary energy balance

The current 'standard' state of the art technologies for the application of gas and coal for power generation are[6]:

1. Combined Cycle Gas Turbine (CCGT) power plants
2. Super Critical (SC) coal power plants

In both cases, post-combustion CCS can be added to the systems. The implications of the application of CCS for CCGT plants and SC coal plants are best understood by comparing the different energy flows for an equivalent energy output:

A. Gas fired CCGT power plant

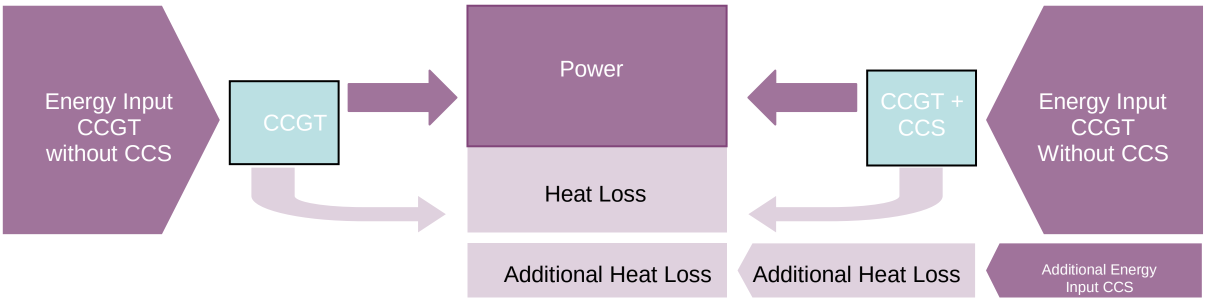


Figure 6: Energy flows in gas fired CCGT power plant with and without CCS

In the current state-of-the-art CCGT plant (without CCS) about 58% of the primary energy is transformed into electricity. The remaining 42% is heat loss, which can still partially be used for industrial or district heating purposes, where appropriate. When CCS is applied, and considering the same net power output, about 17% additional primary energy is required to run the CCS system.

The energy flows in both systems (CCGT with and without CCS) are indicated in Figure 6.

[6] Pre-Combustion CCS with IGCC is a possible alternative, but has not been analysed in this report in detail as currently the majority of projects are either SC coal or gas CCGT.

Coal fired Super Critical power plant

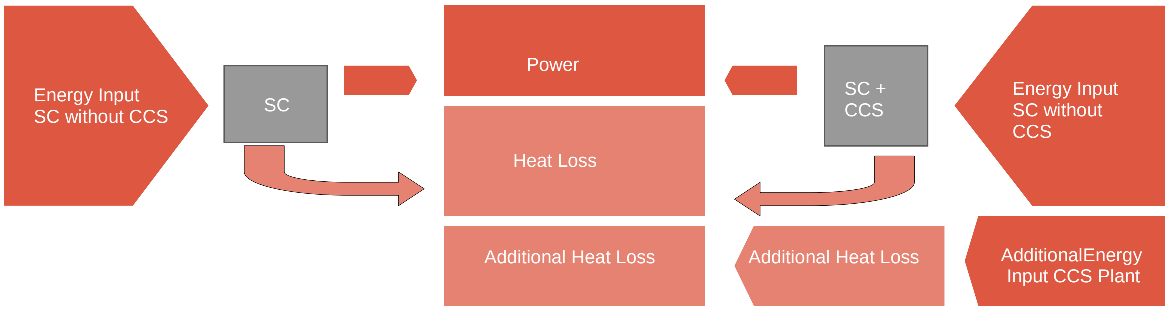
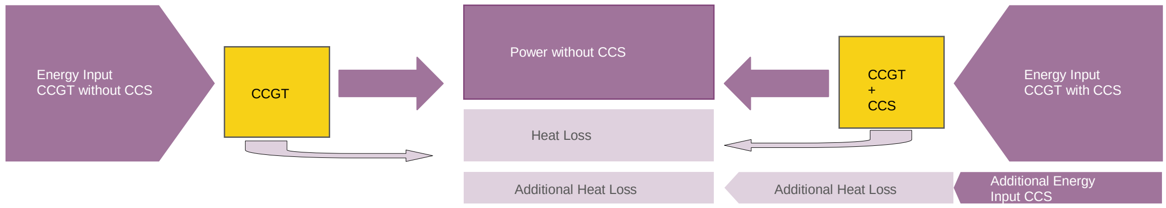


Figure 7: Energy flows in SC coal power plant with and without CCS

In Figure 7 a similar energy flow chart represents the supercritical (SC) coal plant, both with and without CCS. In this case, a state-of-the-art SC coal plant electrical efficiency of 42% is assumed; 58% of the primary energy is transferred to waste heat. When CCS is applied, and again taking into account the same net power output, about 23% additional primary energy is needed.

Figure 8 compares the CCGT gas fired power plant and the SC coal plant, both with and without CCS.



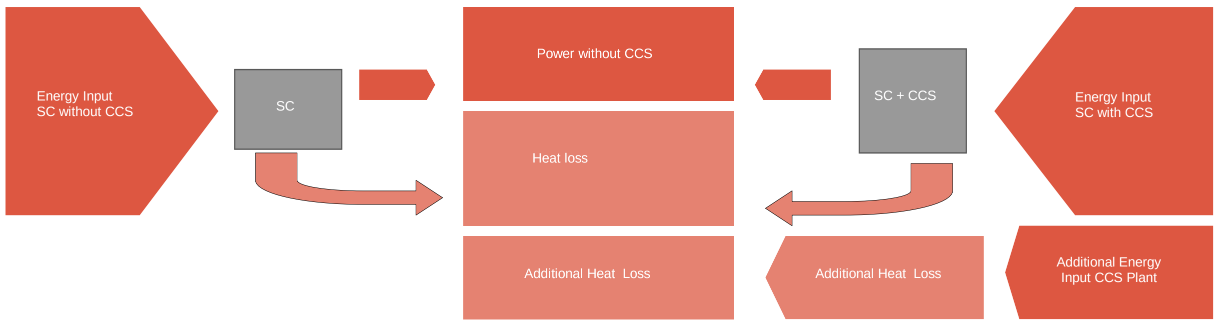


Figure 8: Comparison of CCGT gas fired plant and SC coal plant, both with and without CCS

As shown in Figure 8, CCS for CCGT only uses about half the amount of additional primary energy required for the CCS process as compared to CCS for SC coal. There are two reasons for this:

1. In gas fired generation, CCS requires a relatively small amount of additional primary energy as a percentage of the total energy input (17% versus 23%);
2. SC coal power plant has a lower efficiency (42% versus 58% for CCGT) and so the additional energy needed for CCS, in absolute terms, is also much higher for SC coal.

In conclusion, the advantages of gas fired CCGT with CCS over SC coal with CCS from an energy consumption perspective are significant.

The CO_2 emissions balance

When comparing CO_2 emissions for the same net power output, SC coal plant emits 2.7 times more CO_2 than CCGT plant (see Figures 9 and 10).

A. Gas fired CCGT power plant

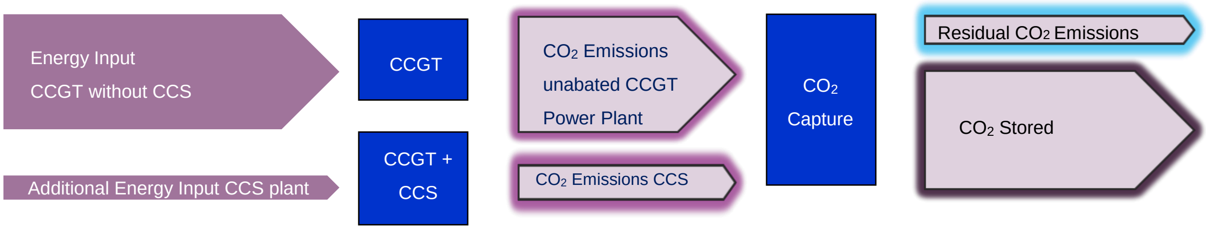


Figure 9: The CO_2 balance in a gas fired CCGT power plant with and without CCS

B. Coal fired Super Critical power plant

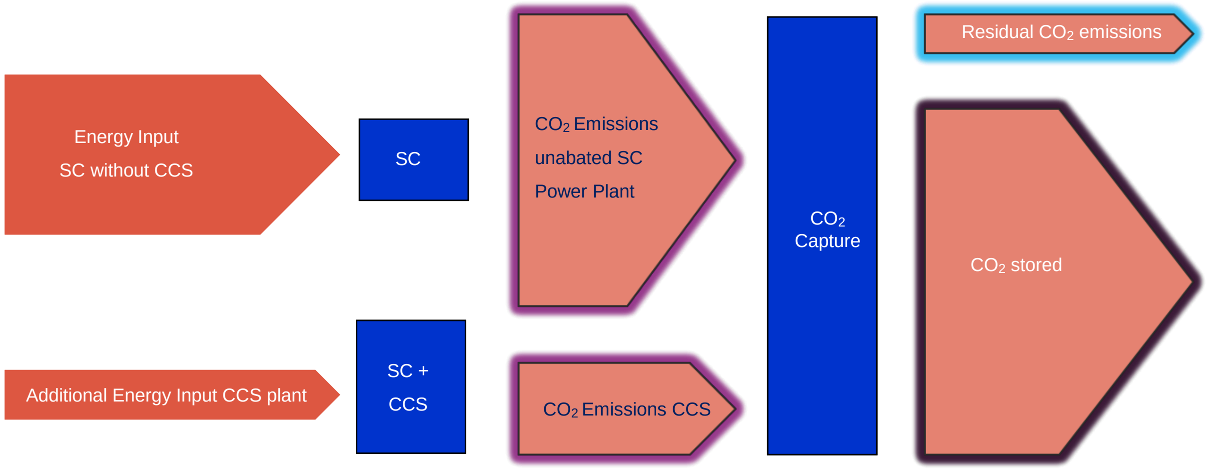


Figure 10: The CO_2 balance in a SC coal fired power plant with and without CCS

It is, therefore, necessary to capture and store 2.7 times more CO_2 for SC coal with CCS than for CCGT with CCS. However, one should consider that the specific energy consumption when capturing CO_2 for a gas-fired CCGT with CCS plant is slightly higher than for SC coal with CCS, due to the lower partial CO_2 pressure in the exhaust. The final outcome is that the total amount of primary energy required for capture in an SC coal with CCS plant is 1.87 (instead of 2.7) times higher than in a CCGT with CCS facility.

Assuming a CO_2 capture rate of 90% when applied, the absolute quantity of CO_2 still being emitted by an SC with CCS plant will still be 2.7 times higher than the residual emissions from a CCGT with CCS plant. Therefore, the percentage of decarbonisation of the power sector could even further increase by a shift towards gas.

Storage of captured CO_2

Storage of CO_2 will be an important consideration in the selection of the future energy mix. The much higher volume of CO_2 captured in an SC coal plant, where CCS is applied, compared with a CCGT plant with CCS, needs to be stored. The global CO_2 storage capacity is currently uncertain and it is unclear if there will be sufficient storage space (which is considered politically and socially acceptable) for the CO_2 captured. Therefore, the limited space available for CO_2 storage should be used sparingly, and it would thus be more economical to use it for gas CCGT with CCS applications and industrial processes, than for the much higher volumes of CO_2 derived from coal power production.

The need for back-up capacity

The back-up system is extremely important to prevent instability of the grid and to balance the system, in order to avoid major power failures and black-outs[7]. The CO_2 emissions from the back-up system would have to be taken into account, and could amount to 1-6% of total power sector emissions before abatement, and for 7-15% of pre-abatement emissions under the 100% renewables scenario. These emissions can be avoided by burning green fuels, for example biogas or hydrogen. Currently, gas turbines are able to burn biogas, and efforts are underway to develop gas turbines which would be able to burn pure hydrogen[8]. The application of gas turbine technology, with the additional use of green fuels, is an important driver to reduce power sector emissions further.

The need for additional back-up capacity is very much dependent on the ability of current fossil fuel (and nuclear) power systems to compensate for the intermittency of renewable energy sources. Nuclear and coal power can follow electricity demand to some extent and modern coal plants are improving in their ability of load following. However, they are not flexible enough to accommodate large and fast-occurring fluctuations. Energy storage could reduce the required back-up capacity, as could major grid improvement, cross-border interconnections and full exploitation of smart grid options. Nevertheless, current energy storage technologies and expected capacities are unlikely to be able to compensate for the large variations in intermittent electricity production.

Gas turbine power plants provide the best means to balance power production. However the addition of a CCS system, being a chemical process with current technology, requires uninterrupted operation. Hence CCS processes should be developed which can operate in cyclic mode.

Availability of gas

In the past the limited availability of natural gas has tended to shift the supply mix for power production more towards coal and nuclear. Some decades ago the world gas reserves were still considered to be far below 100 years. During the last decennia and especially the last years, major gas reserves have been found and exploited. Diversification of sources of supply, a more balanced geographical distribution and more access routes have been realised. LNG, produced in a variety of world regions, has become more important, and the construction of LNG terminals and storage sites at many strategic locations will have a definitive impact on security of supply. Unconventional gas has also emerged, leading to a drastically different world market for gas. For instance, the US, previously a major importer of LNG, has almost completely shifted towards their own inland supply of conventional and unconventional gas making the LNG supply available for the world market (Figure 11).

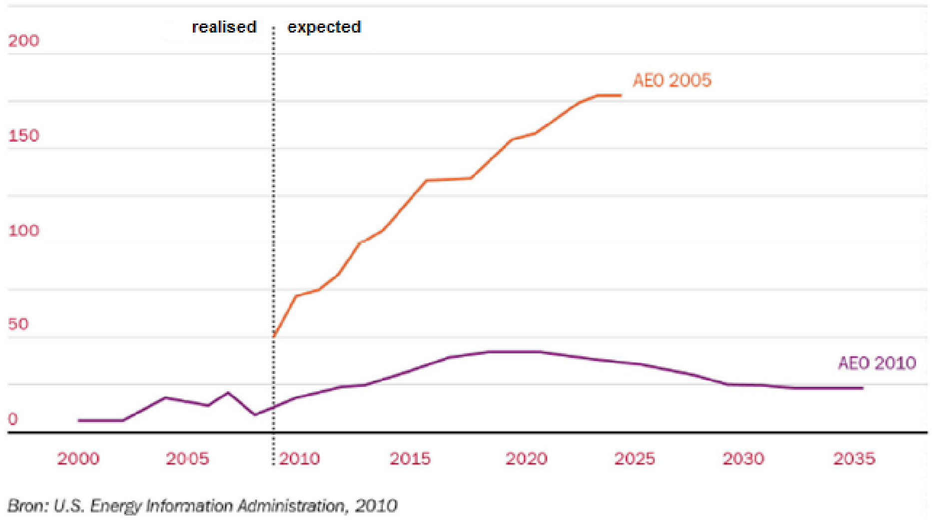


Figure 11: Net LNG import to the US in billion m^3 (Annual Energy Outlook projections made in 2005 and 2010)[9]

The IEA World Energy Outlook 2010[10] estimated the world's recoverable conventional and unconventional gas reserves to be 800 tcm, which is equivalent to 250 years of current production.

[7] For more insight into the technological impact of increasing the share of variable RES in the grid please see ETN position paper: The effect of increasing the share of renewable energy in the grid, European Turbine Network, Brussels, April 2011: http://www.etn-gasturbine.eu/page22905858.aspx

[8] ETN, H2-IGCC project: www.h2-igcc.eu

[9] Energieraad (Energy Council of the Netherlands); Advice to the Minister of Economic Affairs, 8 February 2011

[10] IEA, World Energy Outlook 2010

The disruption of primary source supply has been a major issue for policy makers and the power industry in selecting the energy mix, but the recent developments with respect to gas availability and security of supply are very much in favour of moving towards a greater share of natural gas in the supply mix, especially if the environmental impacts are taken into account. The risk of a serious disruption in gas supply has recently also been analysed; it was concluded that Europe is resilient to severe disruptions of gas supply, see Figure 12.

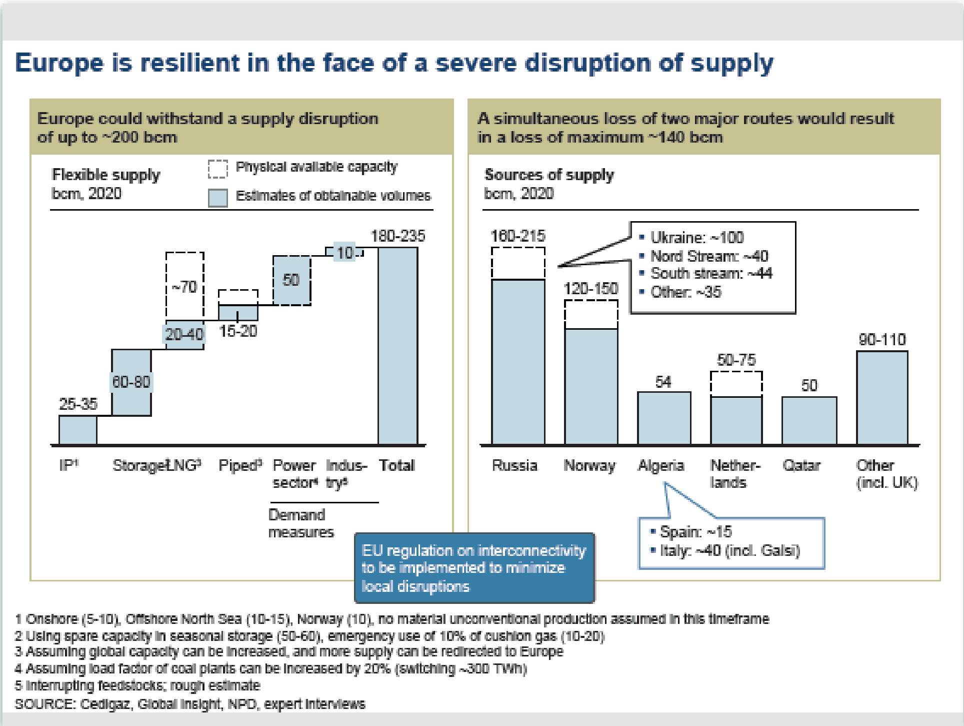


Figure 12: Resilience of Europe towards a severe disruption of gas supply[11]

For instance, the Netherlands Energy Council concluded in a recent report[12] that the structural increase in world gas reserves, the geographic distribution of the sources (therefore security of supply) and the changing market conditions leading to a buyers' market, will allow gas to play a more active role in the transition to a more sustainable energy mix. In addition, the Council strongly recommends the use of less CO_2 emitting gas over coal in the power sector, as it eases the urgency of large-scale implementation of not yet mature CCS technology.

Cost of electricity with CCS

The economics of a gas fired CCGT + CCS power plant versus a SC coal + CCS plant is of course a major driver for investment decision between gas and coal. Costs of electricity (CoE) derived from either gas or coal and the cost for CO_2 avoided are important parameters. A comprehensive overview on this issue has recently been published[13]. This article shows a Cost of Electricity analyses on gas + CCS and coal + CCS; in addition also a comparison is made with nuclear and sustainable technologies. The authors indicate that the relative increase in CoE because of CCS is lower on gas than on coal, because gas plant emissions are only half of coal plant emissions, resulting is smaller CCS equipment, lower Capex and a lower energy penalty. The outcome is that, although gas prices in Europe are much higher than coal prices, for new power plants ordered in the coming 5 years the CoE for gas + CCS is 79 €/MWh compared to 92 €/MWh for coal + CCS (Figure 13[13]).
The CoE comparison of gas + CCS with offshore wind and solar is also in favour of gas + CCS (Note: coal + CCS has also lower CoE compared to these two sustainable sources).

---

[11] EGAF Presentation, How Europe can meet its CO_2 abatement targets at the lowest costs, February 2011
[12] Energieraad (Energy Council of the Netherlands); Advice to the Minister of Economic Affairs, 8 February 2011
[13] Cost of electricity of coal and gas power plants equipped with CCS; J-F Léandri, A. Skea, C. Bohtz, G. Heinz, Power-Gen Europe, Cologne, June 2012

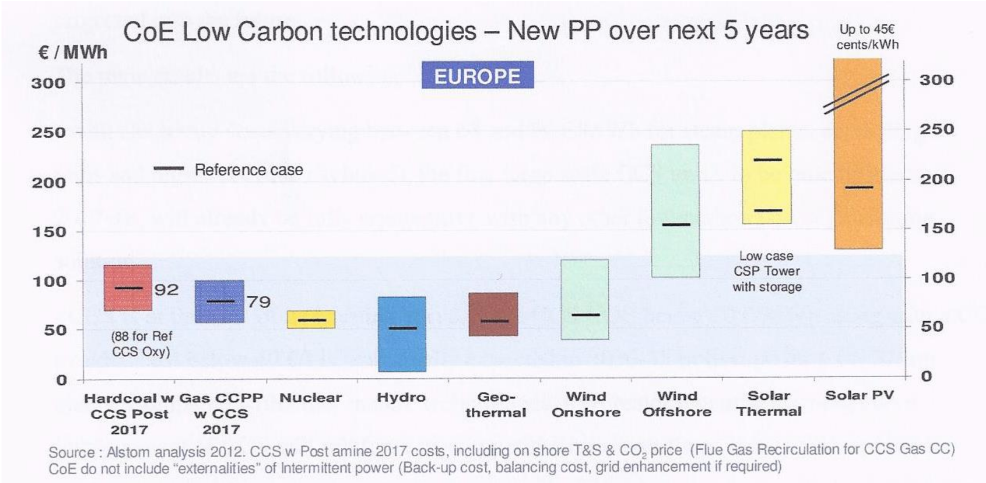


Figure 13: CoE of low carbon technologies - Europe 2012 – 2017[13]

When looking at costs for CO_2 avoided in Europe the analysis indicates an expected level of 35 €/t on coal and 53 €/t on gas in 2032. Based on the CO_2 emission ratio between coal and gas plants (both including CCS) of 2.7 this is also clearly in favour for gas + CCS plants. Of course there is a strong dependency on fuel prices in all of the above calculations. However based on the current situation of high gas prices in Europe, low gas prices in the US and new and voluminous supplies of gas on the world market it is not directly foreseen that the relative unattractiveness of gas in Europe will worsen, rather the contrary.

In a recent report from the International Energy Agency[14] similar data on LCOE and Cost of CO_2 avoided where published. LCOE (levelised cost of electricity) of coal + CCS (post combustion) and natural gas + CCS were (based on a €/$ ratio of 1.3) respectively 82.3 €/MWh and 78.4 €/MWh. Cost of CO_2 avoided amounts to 44.6 €/t on coal and 61.5 €/t on gas, reflecting the same ranking in favour of gas as in the aforementioned report.

The urgency for action

The implementation of new low-carbon technologies is of utmost importance, and their implementation should begin as soon as possible. As the development of cost-effective RES and nuclear power requires considerable effort and time (accompanied by considerable political and societal constraints, especially in relation to nuclear), ETN envisages that significant steps can be made in the short to medium-term by replacing old power capacity (very often coal) with modern, high efficiency gas fired CCGT. This makes the realisation of the ambitious objectives for CO_2 abatement much more realistic.

A comprehensive article in Power Engineering[15] stated that 1 Gton less CO_2 per year (about 10% of world power sector CO_2 emissions) could be emitted if the older coal-fired power plants were to be brought up to an efficiency level of 35.5%, which is an (easily) achievable target. If old coal plants were to be replaced by modern, high-efficiency CCGT plants, a much greater and faster emission reduction could be realised, allowing more time for the development of cost- and energy-effective CCS technology.
Initially, gas fired generation can be undertaken unabated, because even in the short-term it will have considerable CO_2-reduction advantages over coal. From 2030 onwards, CCGT should be retrofitted and built with CCS, as an alternative to coal with CCS for base load and mid-merit plants.

The proposed way forward

The paper clearly highlights the benefit of moving towards the application of gas in any future energy mix for power generation, in parallel with improved efficiency, an increased level of renewables and energy storage. Efficient gas fired combined cycle power generation in combination with CCS will lead to a near zero emissions power sector. Thus, with its low CO_2 burden, gas has the ability to address Europe's climate goals sooner, more economical and in a way that provides the necessary boundary conditions for ensuring a high level of renewable capacity, due to its ability to balance intermittent renewable power generation. It should be noted, however, that the application of a carbon capture system behind a CCGT plant requires the

14 Energy Technology Perspectives 2012, Pathways to a Clean Energy System, IEA, presentation by S. Heinen at the International Gas Turbine Conference, The future of gas turbine technology, Brussels, October 2012

15 S. Stallard, P. DiPietro, "An Opportunity to Improve Coal-fired Generation Efficiency"; Power Engineering, November 2009, pp 122-125

development and demonstration of cost- and energy effective CCS technology. This is a major objective for future R&D work and should be supported in the new European framework programmes, the HORIZON 2020.

In addition, power generation could be made essentially carbon-free, even when open cycle gas turbines (without CCS) are used for the required back-up capacity for intermittent renewable energy production. In this case, gas turbine technology allows the use of zero carbon or CO_2-neutral fuels (biomass, biogas, hydrogen) and hence no CO_2 emissions.

A complete shift from coal to gas in the short to medium term is difficult to realise. Highly efficient IGCC (integrated coal gasification combined cycle) with integrated CCS technology might be an alternative to SC coal with CCS. This could also lead to the efficient burning of biomass and, as a consequence, reduce CO_2 emission levels. In IGCC with CCS, hydrogen-rich syngas is burned in gas turbines, which can contribute to the realisation of a hydrogen economy in the longer term, where hydrogen can be directly applied and used as an intermediate storage fuel, produced by the intermittent oversupply of sustainable energy (power to gas, based on solar and wind).

Conclusions

1. This technical briefing paper clearly highlights that an almost fully decarbonised power sector is only achievable with a shift from coal to gas in power generation, in conjunction with the application of highly efficient CCGT technology, including CCS.

2. Power generation from gas with CCS has the following advantages over coal with CCS:
   - For the same net electrical output 31% less primary energy is needed;
   - The amount of CO_2 emissions is 2.7 times lower for gas, making storage easier achievable;
   - The absolute amount of residual CO_2 emissions (after CCS) is 2.7 times lower for gas.

3. The limited CO_2 storage capacity can be more sparingly used for industrial processes and gas with CCS power generation than for the higher volumes of CO_2 captured in coal power generation.

4. The back-up capacity required for high volumes of intermittent RES production can more easily be provided by flexible gas fired CCGT power stations than by coal and nuclear.

5. Cost- and energy efficient CCS technologies in combination with CCGT operating in a highly dynamic electricity network should be developed and demonstrated on short to medium term. The new European framework programmes (Horizon 2020) should incorporate these developments.

***

ETN a.i.s.b.l • Chaussée de Charleroi 146-148/20 • 1060 Brussels • Belgium
Tel: +32 (0)2 646 15 77 • info@etn-gasturbine.eu • www.etn-gasturbine.eu