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Sustainable power generation from fossil fuels: aiming for near-zero emissions from coal after 2020

Impact Assessment

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GLOSSARY

Coal	The term as applied in this Impact Assessment refers to solid fossil fuels and includes both hard coal and sub-bituminous coals such as lignite and brown coal, as well as oil shale or peat.
Fossil Fuels	This expression covers energy resources originating from organic matter of great age such as fauna and flora that have been buried naturally and subsequently transformed and preserved permanently. Essentially, fossil fuels comprise solid fossil fuels such as peat, coal and oil shale (see above) as well as petroleum and natural gas.
CO2 Capture and Storage (CCS) Technologies	The idea of CCS rests on the notion of capturing the CO2 either before or after the fuel combustion and injecting it into geological formations in the ground where it could be stored for almost indefinite period of time. It is not strictly linked only to the use of coal in power generation; CCS is also relevant for other CO2-emitting processes, including gas-fired power stations as well as industrial processes in other sectors (refining, cement production, steel production, etc.). Synergies with other business sectors exist, stemming from the fact that depleted or active oil and gas fields could be used as appropriate geological formations for CO2 storage.
Clean Coal Technologies	A range of technologies that improve the efficiency of coal conversion and combustion and reduce the environmental impact of the coal process life cycle. Traditionally these extend from coal extraction and preparation, to advanced combustion technologies.
Sustainable Fossil Fuels Technologies; Sustainable Coal Technologies	This expression refers to the vision of an integrated technological solution leading to (near-) zero emissions electricity generation through improved power plant efficiency combined with capture and storage of carbon dioxide generated in the conversion process. This would enable highly efficient power plants that emit to the atmosphere less than 10% of the carbon content of their solid fossil fuel as carbon dioxide. In the particular case of coal-based power generation, the term is transferred into "Sustainable Coal" technologies.

1. SECTION 1: PROCEDURAL ISSUES AND CONSULTATION OF INTERESTED PARTIES

1.1. Organisation and timing

This Impact Assessment was produced in the context of the preparation of the Commission Communication on Sustainable Power Generation from Fossil Fuels which is included in the Commission's agenda planning database as item 2006/TREN/026). It focuses on coal-based power generation as the main and most imminent challenge in this regard.

The preparation of the Impact Assessment started with some preliminary analyses and consultations in 2005 and was intensified in spring 2006 after the subject and purpose of the Commission Communication was further specified and confirmed in the process of the drafting of the Commission Green Paper "A European Strategy for Sustainable, Competitive and Secure Energy" adopted in March 2006. The analysis feeding into the Impact Assessment was performed internally by the Commission services, partly with use of external sources of information and expertise.

1.2. Consultation and expertise

An Inter-Service Group (ISG) was established in April 2006 by Directorate-General for Energy & Transport (DG TREN) with participation from Secretariat General and DGs RTD, COMP, ENTR, ENV, ECFIN and JRC. The ISG met in May, June, July, September, October and November 2006 for discussions of the scope, of interim analytical results and of draft texts for individual elements of this Impact Assessment report.

In addition to the internal Commission consultative process involving the above mentioned services, the Impact Assessment study drew on consultations with external experts and stakeholders who were consulted throughout the preparation of the work and provided invaluable expertise. The output of the European Technology Platform for Zero-Emission Fossil Fuel Power Plants, ZEP, an industry initiative supported by the Commission, provided, amongst others, a vital source of information and external expertise.

The main platform for the consultation of stakeholders was in the Commission's Fossil Fuels "Berlin" Forum. The Forum itself is an annual event which was first convened in October 2005 and again in October 2006 in Berlin. The membership of the Forum is formed by over 100 representatives of European energy corporations, industry associations, energy-related national administrations of Member States and members of civil society (non-governmental organisations). The initial plans for a Commission Communication were discussed in broad terms during the Berlin Forum 2005 and the results of the Impact Assessment work were presented and discussed at the Berlin Forum 2006. Throughout the preparation of the Impact Assessment, the Coal Working Party of the Forum has been consulted on the progress (the Working Party met before the Berlin Forum 2006 in April, May, July and September 2006)[1].

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[1] Further details of this Forum can be obtained via its dedicated website : http://ec.europa.eu/energy/oil/berlin/index_en.htm.

The Commission also drew on the results of the work of the Working Group on Carbon Dioxide Capture and Storage established in the context of the Second European Climate Change Programme[2]. The Working Group was mandated to give advice to the Commission concerning the regulatory and incentive framework to enable the application of carbon dioxide capture and geological storage in the EU.

In addition to the structured dialogue within the Berlin Forum and its Working Groups and the ECCP II, the stakeholder community and external experts were consulted through several specialized ad-hoc consultative events and meetings organized on a bilateral basis between the Commission (DG TREN) and the individual stakeholders and stakeholder groups (multinational bodies, industry associations and major industry groups). These consultations provided unique access to up-to-date industrial expertise and know-how, including specialized studies conducted or commissioned by some of the consulted parties.

[2] The Working Groups brought together experts from Member States, various energy industries (coal, oil, gas, electricity), energy intensive industries, NGO's, research institutes and relevant Commission services. The Working Group had four meetings in the first half of 2006 under the Chairmanship of the Commission and delivered its final, unanimously approved, report on the 1st June 2006. More information on the Working Group and the report on CCS is available from http://forum.europa.eu.int/Public/irc/env/eccp_2/home.

2. SECTION 2: WHAT IS THE PROBLEM?

Coal is an important fuel for the generation of electricity but traditional technologies used for the generation of electricity from coal give rise to serious environmental concerns, such as emissions of NO_X, SO_2 and CO_2. It is clear that use of coal in the EU is hardly sustainable unless it begins a shift towards lower levels of CO_2 emissions and ultimately zero-emissions power plants. The development and deployment of technologies for zero-emission power generation from coal is thus a necessary condition, in the context of the Sustainable Development Strategy[3] and Climate Change policies[4], for coal to remain an important fuel in the energy mix of the EU and other parts of the world. An impact assessment is needed to identify and analyse policies that can enable continued use of coal to provide security of energy supply and diversification of energy resources in a CO_2-constrained world. It should identify which policies, actions and/or measures are needed so that the objectives that are set are met.

2.1. Background – Coal use in the EU and in the world

The European Union (EU) relies heavily on coal. Solid fossil fuels, i.e. predominantly coal, presently account for approximately 18% of all energy consumption, and around 30% of electricity production[5]. Coal is also an important feedstock for other coal conversion technologies (e.g. hydrogen production/poly-generation, coal-to-liquids and coal-to-chemicals processes, etc.) which could assume an increasing profile in the future at least in some parts of the world. Though this impact assessment refers primarily to coal-based power generation, its conclusions, both technological and economic are expected to (or could) be valid also for these other cases of industrial coal use.

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3 Communication from the Commission on the Review of the Sustainable Development Strategy, COM (2005)658 if 13 December 2005; Council Document 10917/06 of 26 June 2006, « Review of the EU Sustainable Development Strategy ».

4 Communication from the Commission « Winning the Battle against Global Climate Change », COM(2005)35 of 9th February 2005 and Green Paper “A European Strategy for Sustainable, Competitive and Secure Energy “, COM(2006)105 of 8th March 2006.

5 EEC(2003) European Energy and Transport – Trends to 203, European Commission, Brussels.

Total Coal and Energy Consumption in the EU Member States in Million tce[6]								
Countries	**Hard Coal**		**of which Hard Coal Import[7] (t = t)**		**Lignite[8]**		**Total Primary Energy Consumption**	
	2004	**2005**	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**
Germany	65.8	62.8	39.0	36.3	56.2	54.4	492	486
France	18.0	18.0	20.0	20.5			381	379
Italy	24.0	23.0	25.5	24.5			266	260
Netherlands	13.0	12.5	14.0	13.0			138	140
Belgium	8.0	8.0	10.0	10.0			96	94
Luxembourg	1.0	0.2	0.2	0.2			7	7
Great Britain	55.0	58.0	36.1	43.8			329	335
Ireland	2.0	2.2	2.3	2.5	0.5		21	22
Denmark	6.0	4.5	7.1	5.2			27	26
Greece	0.5	0.5	0.8	0.7	22.0	21.0	47	48
Spain	28.6	29.0	24.0	24.7	2.5	2.0	210	211
Portugal	5.5	5.5	5.5	5.3			36	35
Finland	5.5	3.5	7.7	4.5	2.0		41	42
Austria	4.5	4.7	3.8	4.1	0.5		47	46
Sweden	3.5	3.0	3.0	2.7			70	72
EU-15	**240.9**	**235.4**	**199.0**	**198.0**	**83.7**	**77.4**	**2207**	**2203**
Poland	67.0	66.0	2.0	2.0	18.5	18.7	133	134
Czech Republic	9.5	9.5	1.0	1.0	20.0	20.1	64	66
Hungary	1.5	1.5	0.6	0.5	3.6	3.0	34	37
Slovakia	5.0	4.0	7.0	5.6	1.0		26	26
Slovenia	0.5	0.5	0.5	0.5	1.4	1.4	7	8
Latvia	0.2	0.2	0.2	0.2			8	8
Lithuania	0.3	0.0	0.5	0.5			13	14
Estonia	0.5	3.0	0.5	0.5			10	10
Cyprus							7	7
Malta							7	7
Bulgaria[9]	4.2	4.0	1.0	n/a	23.7	23.0	27	28
Romania[10]	6.6	6.5	2.9	n/a	31.6	31.0	59	60
Total	**336.2**	**330.6**	**215.2**	**208.8**	**183.5**	**174.6**	**2602**	**2608**

Table 1: Energy consumption in the European Union in Million t_{ce}
Source: German Coal Importers' Association, VIK and Euracoal

Reserves of coal are more evenly distributed across the world than those of other traditional fuels. Coal can be procured from a number of countries practically from all continents through a vibrant and liquid global market. Reserves of hard coal are equivalent to close to 255 years of production at present rates; those of lignite should last for around 130 years of present production. This compares favourably to estimated reserves of oil and gas which are expected to last for 40 and 65 years[11]

6 Tonnes coal equivalent.
7 Million (without coke)
8 Incl. peat
9 2005 values estimated.
10 2005 values estimated.
11 BP Statistical Review of World Energy, June 2006.

respectively (at current rate of production). Coal can thus be regarded as a comparatively secure and abundant fossil fuel; as such, its inclusion in the energy mix offers clear benefits in terms of security of energy supply.

By drawing on a variety of primary energy sources, the EU maintains a diverse energy mix that moderates the impact of supply difficulties in any given fuel on overall energy supply and prices, and on the economy and society at large. Coal currently contributes significantly to this security through fuel diversity as much of the coal used in the EU is derived either internally or in an international market supplied from a number of geographically, politically and economically differentiated countries, such as Australia, Colombia, Indonesia, Russia and South Africa. This provides the international coal market with global reach and liquidity as well as unparalleled competitive structure and stability.

The important role for coal in primary energy use, and specifically in electricity generation, is not specific to Europe and can be observed in many of the world's highest energy-using regions.

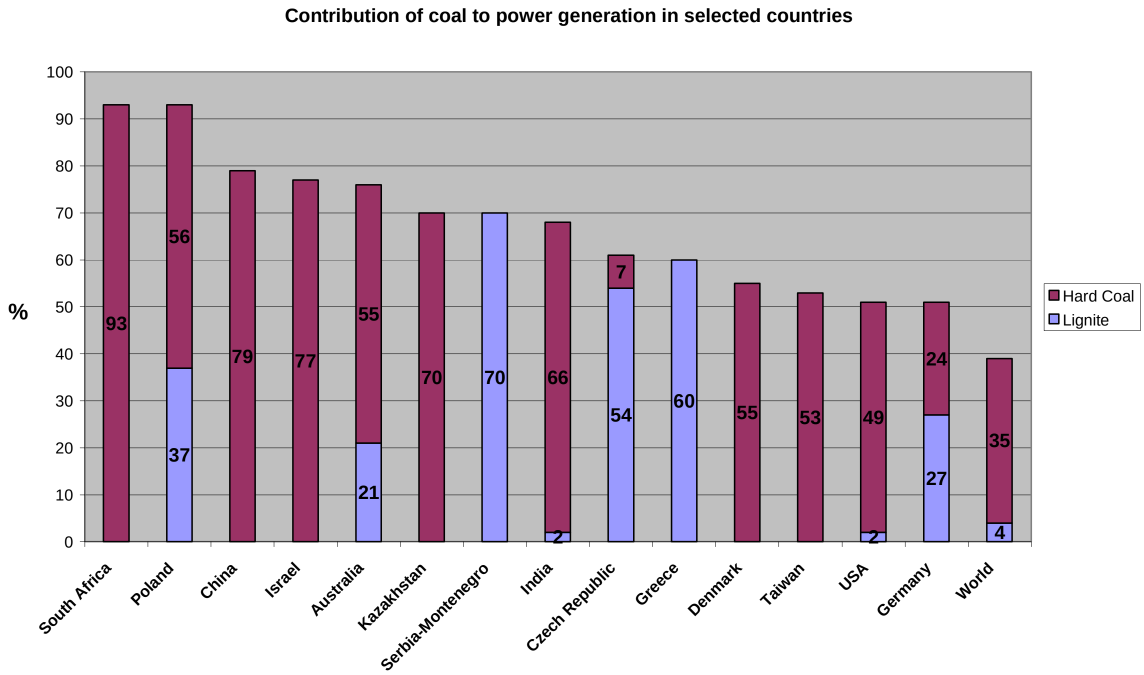

Fig. 1: Contribution of coal to power generation in selected counties, 2003
Source: IEA

2.2. Impact of coal combustion on the environment

2.2.1. Coal-based power generation and air pollution

Coal's demonstrable contribution to energy security and energy price stability notwithstanding, the reliance of the EU on coal for much of its energy supplies is problematic with regard to its environmental impact. This is a challenge of ever-increasing importance despite the undisputed recent improvements achieved in comparison to the practices of the past. Indeed, the utilisation of coal in the EU has become progressively cleaner in recent years. Coal combustion has been traditionally associated with emissions of sulphur oxides, nitrogen oxides, metals and particulates in far higher proportions than emissions from oil or natural gas. However, application of pollution-prevention technologies such as flue gas treatment has substantially reduced the release of these pollutants into the atmosphere in the EU and, thus, local as well as regional impacts (such as acid rain).

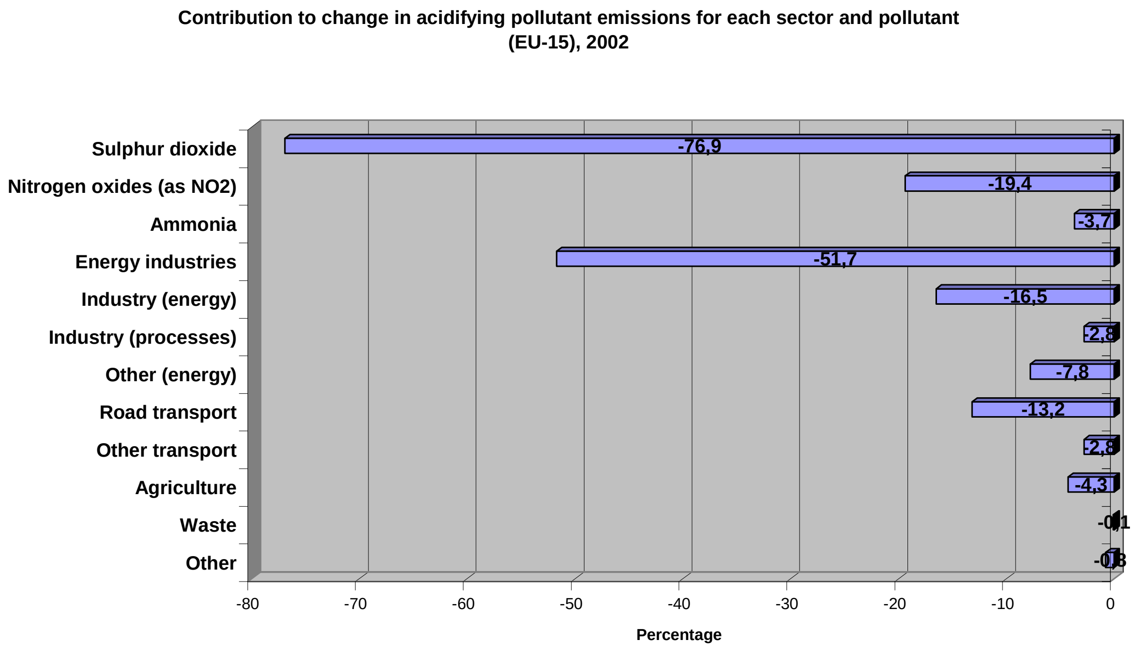

Fig. 2: Contribution to total change in acidifying pollutant emissions for each sector and pollutant (EU-15), 2002
Source: Eurostat/www.eea.eu.int

Acceptable air pollution levels have been achieved via effective EU-wide policies[12] that have placed requirements on large combustion plants to implement the necessary measures. These measures have enabled the continuation of coal-fired power generation throughout the EU. This has been of specific importance, both environmentally and economically, in several new member states of the enlarged EU where coal is currently the dominant energy source.

2.2.2. *Coal-based power generation and climate change*

The positive trends in reduction of traditional pollutants are counterbalanced by coal's high carbon content and thus the high levels of carbon dioxide that result from its combustion. Coal based power generation is responsible for a significant part of

12 Council Directive 96/61/EC on integrated pollution preveniton and control (« IPPC Directive »); Council Directive 96/62/EC on ambient air quality assessment and management ("Air Quality Framework Directive"); Council Directive 1999/30/EC relating to limit values for sulphur dioxide, nitrogen dioxide and dioxides of nitrogen, particulate matter and lead in ambient air ("First Daughter Directive"); Directive 2000/69/EC of the European Parliament and of the Council relating to limit values for benzene and carbon monoxide in ambient air ("Second Daughter Directive"); Commission proposal for a Directive 2005/447/EC (final) of the European Parliament and of the Council on ambient air quality and cleaner air for Europe.

the EU's and global greenhouse gas emissions. In the EU-27, around 950 million tonnes of CO2 were emitted from coal-fired power generation in 2005[13]. This represents 70% of Europe's total CO2 emissions from power generation and 24% of EU CO2 emissions across all sectors. The global figures are even more striking: ca 7 billion tonnes of CO2 currently emitted from coal-fired power generation on annual basis, representing 76% of emissions from power generation and 30% of total global emissions of CO2[14].

CO2 has a dominant position amongst all greenhouse gases (GHG). According to figures from 2000, 74% of world-wide GHG emissions were made up of CO2. While some other GHG have higher specific global warming potential (GWP), their representation in overall GHG emissions is much smaller (methane-16%, NOx-9% and others-1%)[15]. CO2 is thus the most significant anthropogenic cause of global climate change. Addressing the challenge of global climate change is a primary objective for European Union policies and is currently pursued under the requirements of the Kyoto protocol[16]. This establishes the requirement of substantial medium- and longer-term reductions of overall CO2 emissions. Satisfying such requirements cannot be done without acting on all the sources of CO2 emission, including coal-based energy production which is a dominant source of CO2, both in Europe and worldwide.

The EU's agreed objective to limit global temperature increase to a maximum of 2°C above pre-industrial levels[17] implies global greenhouse gas reductions of 15 to 50% in 2050 with respect to 1990, and 60 to 80% reductions for developed countries[18]. As illustrated in the graph below, it is clear that large scale coal based generation with current technology and associated CO2 emissions is not compatible with this scenario.

13 TREN calculations.

14 IEA GHG, 2002 : Building the cost curves for CO_2 storage, Part 1: Sources of CO_2.PH4/9, July, 48pp.

15 www.methanetomarket.org.

16 CO2 reduction through clean coal technologies is also prioritised by Commission in the European Climate Change Programme (htpp://ec.europa.eu/environment/climat/eccp.htm).

17 Conclusions of the Spring European Council 2005 (http://ec.europa.eu/environment/climat/pdf/spring_2005.pdf).

18 Conclusions of the Spring European Council 2006.

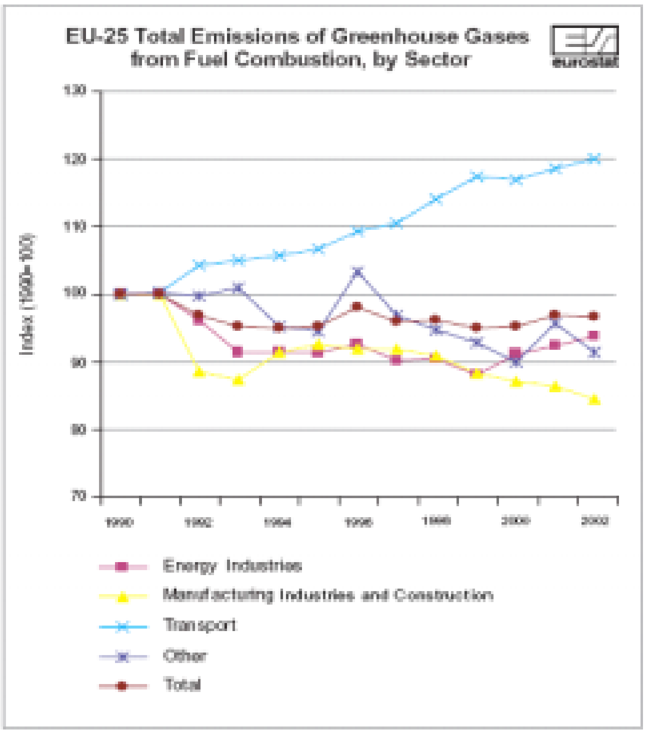

Fig. 3: EU-25 total emissions of greenhouse gases from fuel combustion, by sector

Source: Eurostat

The EU and the Member States have implemented a range of policy instruments to reduce GHG emissions. Policy instruments such as the European Union Emissions Trading Scheme (ETS) provide an incentive for investment in CO2 reductions in power generation. The European Commission is currently reviewing the EU ETS to adapt or modify its design features and to further improve its operation after 2012. This is necessary to give further and longer-term market signals to stimulate necessary investments in capital-intensive clean coal and CO2 capture and storage (CCS) technologies.

Enabling these technologies to mature to a level that makes them attractive to operators of coal-based power plants also requires investigation of other possible changes in the policy framework. Addressing greenhouse gas emissions in this way is the largest remaining challenge facing the continued use of coal in the European energy mix – both in the present mix and especially the post-2012 mix. It is clear that the imperative of ever-decreasing CO2 emissions will remain equally (if not more) valid also after 2012, regardless of the actual developments in the post-Kyoto regime.

2.3. “Sustainable” technologies can enable continued future use of coal

2.3.1. Sustainable Coal as part of the solution for growing energy demand

Reliable energy provision is a key component of economic growth. Scenarios indicate that in particular electricity demand in the EU 27 may continue its steady growth in coming years in tandem with economic performance unless all ambitious efficiency improvements materialize. Electricity demand may rise by 2030 by 50% in the EU 27 compared to 2000[19]. While increased use of energy efficiency measures and greater penetration of renewable energy sources are expected to contribute to meeting the increased demand, even ambitious scenarios foresee that most electricity will still be supplied by the traditional thermal power plants, both fossil fuel and nuclear. Realistic estimates place this in the neighbourhood of 3.7 GWh/year. Such supply needs call for the existence of installed capacity totalling around 800 GW in 2030. This figure includes both existing capacity (or its replacements due to aging of existing installations) and also a considerable proportion of new additional capacity.

At present the EU enjoys the benefits of a diverse energy mix which in electricity production includes natural gas, coal, renewable energy sources, and nuclear energy. The variety of energy sources contributes to supply reliability. Maintaining this variety is crucial for sustaining the benefits of such diversification. With commercialization of current and impending state-of-the-art technologies involving great efficiency improvements and with the implementation of carbon dioxide capture and storage (CCS) technologies that are currently being demonstrated, or will be demonstrated in the meantime, zero emissions coal-based electricity production could be introduced in the EU for commercial applications by 2020[20]. This would allow coal a place in the future fuel mix satisfying electricity demand through a diverse and secure range of low-carbon technologies. Sustainable Coal would then be included amongst low-/zero-emission options, besides renewables, nuclear or natural gas with CCS.

2.3.2. *Replacing retiring coal-fired generating capacity*

In addition to the benefits to be derived from inclusion of coal amongst the options for covering future electricity demand, the availability of sustainable coal technologies can help solve the issue of aging existing coal-fired installed capacity. Approximately 75 % of the coal-fired power plants in the EU 27 and accession and candidate countries are over 25 years old, and over 45 % are over 30 years old[21]. As they usually have an assumed nominal life of about 40 years and because of continued tightening of environmental standards, several hundred units, equal to about 100GWe, are facing replacement or life extension through retrofits in the next 10 to 15 years[22]. Replacement of these plants with coal-fired generating capacity to maintain a diverse energy mix will only be publicly acceptable, compatible with the EU's climate change objectives, and may only be economically viable if specific CO2 emissions are reduced drastically.

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[19] EC(2006)° European Energy and Transport – Trends to 2030, update 2005, European Commission, Brussels.

[20] Assuming the results of the current industry efforts, both as regards the activities of the Zero-emission fossil fuel Power Plant Technology Platform and the announced pilot and demonstration projects of European leading companies, are completed within estimated timeframes and perform satisfactorily for at least several years.

[21] Grammelis P., Kakaras E., Koukouzas N. (2004) The perspectives of Energy production from coal-fired power plants in an enlarged EU, *Int. J. Energy Res* (28), 799-815

[22] Of the current 183GW of solid fuel power plants in the EU, it is expected that 70GW will be replaced between 2006 and 2015, and 40WG between 2015 and 2025 (The future role of coal, Part I, Prognos AG, 21006).

2.4. What is the current state of play in Sustainable Coal?

2.4.1. Technological Development

Several technological routes have been developed to date and are being tested. These further improve power plant efficiencies leading in turn to reduced emissions. Moreover, technologies that make carbon dioxide capture and storage feasible have been applied, but mainly in other sectors.

A detailed overview of available sustainable coal technologies and their possible future developments, both in the EU and outside, including the projects supported by the EU, is provided in Annex 1 of this document.

CO2 Capture and Storage. The individual components of carbon dioxide separation and capture, transport, and long-term storage are all well-developed. The technologies for separating the carbon dioxide from other gases are well-known to the oil, gas and chemicals industries. The transport of carbon dioxide and its injection into geological formations has been developed for specific applications[23]. Current knowledge on CO2 storage and the possibility of identifying adequate location and design of storage sites imply that risks of leaks are predicted to be fully controllable although there is at present only limited real-life and lasting experience with long term geological storage of CO2[24]. Experience with up-scaling these technologies to sizes relevant for industrial coal-based power generation leading to the needed cost reductions is also lacking. This concerns primarily the question of the extraction of CO2 from the combustion process and needs to be addressed through the implementation of large-scale demonstration projects and associated research projects. All technologies will have to be given equal weighting in such demonstration and further R&D projects in order to maximise commercial opportunities.

Clean Coal Technologies for improved efficiency of the conversion cycle. Emissions reductions can be partly achieved by the employment of coal technologies that improve on conventional steam-cycle power plants. With current best available technique (BAT), energy conversion efficiency of coal-fired power plants is around 46% for hard coal plants and 43% for lignite plants. Improved combustion technologies include ultra-supercritical (USC), pressurised fluidised bed (PFB) and oxygen-rich combustion which are expected to improve efficiency above 50%, possibly up to 60%[25]. For each of these, further effort is required to increase their scale, reduce costs and develop new materials. Crucially, CCS can only be applied post-combustion in such plants, and methods for adding this final step to the power plant without an undue efficiency penalty still need to be demonstrated.

New approaches – integrated technological solutions. Technologies that take an integrated approach to zero-emissions coal firing are able to provide greater life-

23 E.g. gas is commonly performed for Enhanced Oil Recovery in areas such as Texas, which boasts 1100 miles of CO_2 pipelines.

24 One of the longest monitored CO_2 storage sites is the Sleipner field's Utsira formation in the North Sea where CO_2 storage activities have been ongoing for more than 10 years without any record of problems or safety issues.

25 COORETEC Report, 2004.

cycle efficiency from fuel-handling to CO_2 storage. Integrated gasification combined cycle (IGCC) plants offer a new approach that adopts chemical processes not traditionally associated with power generation. The challenge for IGCC is to combine the coal gasification and CO_2 separation technologies that have already been or will be developed separately on a smaller scale.

The above are the main technologies that will allow near zero emissions power generation from coal ("Sustainable Coal") to become a reality. These technologies are not currently at the same stage of development, but they all have the potential to mature to commercial viability through further research, demonstration and deployment. They are also not all designed to fulfil the same purpose. Some address incremental efficiency improvements or end-of-pipe remedies, whilst others take a more revolutionary approach to solving the problem of carbon dioxide emissions through integrated solutions.

Commercial viability of Sustainable Coal technologies will need to be demonstrated through a number of industrial-scale demonstration projects which will run on the basis of technological solutions incorporating high-efficiency advanced Clean Coal conversion cycles with pre-combustion or post-combustion CO_2 capture and subsequent geological storage. To provide meaningful results, these projects will have to run for around five years in order to accumulate adequate track record. The size of each demonstration project may vary but the requirement of their industrial-like scale dictates that their installed capacities should be in the range of 250-500 MWe. It is currently estimated that ten to twelve such projects could be built in Europe in the coming years and be operational by 2015. This would allow assessing the commercial viability of the Sustainable Coal concept by 2020. The cost of each such installation using current PC technologies (at BAT level) with post-combustion CCS (assuming CO_2 storage in a distance no more than 350 km from the generation site) is estimated at around €1.7m/MWe. In case of IGCC technologies with pre-combustion CCS, the cost could be around €1.5m/MWe[26]. These costs are expected to gradually decrease as the technology matures, especially in case of IGCC and USC-type PC.

Several such projects are ongoing or have been announced in 2006 in Europe by large industrial players. These intend to test and demonstrate the available technologies in combinations allowing zero emission power generation. These projects are mostly in the development phase, but provide a valuable indication of the positive outlook given to these technologies by industrial organisations. Moreover, a European Technology Platform on Zero Emission Fossil Fuel Power Generation (ZEP) was launched in December 2005 and has been actively working since then[27]. This Technology Platform has delivered in 2006 a vision paper for zero emission power generation in Europe as well as a Strategic Deployment Document (SDD) and a Strategic Research Agenda (SRA) identifying the innovative technologies to be developed in the areas of clean coal and CO_2 capture and storage

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26 See the « Carbon Dioxide Capture and Storage », Report prepared by the Intergovernmental Panel on Climate Change (IPCC), 2005

27 A complete overview of the activities of the Platform is available from the following site : http://ec.europa.eu/research/energy/pdf/zero_emission_ffpp_en.pdf

technologies[28]. One of ZEP's key recommendations is the construction of 10-12 industrial-scale power plants with CCS for demonstration by 2015. The output of this Technology Platform constitutes a valuable contribution to defining the overall work programme of the 7th Framework Programme for research, technological development and demonstration activities (FP7) in these areas.

2.4.2. *Barriers to Implementation of Sustainable Coal*

At present barriers exist that make investment in technologies for zero-emission coal-based power generation rather difficult. These barriers can lead power plant developers to opt for fuels other than coal when deciding on replacing or adding generating capacity in the circumstances of increasing needs for reducing CO2 emissions. Such fuel choices have the potential to affect the energy mix over a time period long after the commercial viability of zero emissions coal-fired power generation is expected to have been proven. This could occur through implementation of a specific infrastructure, such as an extensive network of gas pipelines or liquefied natural gas (LNG) terminals. Future fuel choices would be influenced by the existence of an infrastructure that would reduce lead times and capital costs. Without steady investment in coal transport infrastructure and planning for CO2 transport, short-term attempts to introduce zero-emissions technologies may be frustrated, despite favourable life-cycle economics. Removing or lowering these barriers with well-designed policy measures will be crucial to enabling widespread and rapid penetration of integrated zero-emissions coal-fired power plants.

Public perception/acceptance of CO2 capture and storage. Although the positions of EU institutions as well as interested parties from public and private sectors currently recognize coal not only as a fuel with a "glorious past"[29] but also as an important player in European energy, reservations concerning coal's future in the EU energy mix persist in many quarters. The benefits offered by coal and the realistic expectations of availability in the relatively near future of zero-emission power generation from coal have yet to be conveyed to the European public. Wider public acceptance of the measures associated with advanced clean coal and CCS technologies is needed. Public debate will need to focus on the environmental and energy supply benefits considering in particular the feasibility of managing risks associated with transport and geological storage of CO2. Moreover, as with other potential sources of low-CO2 electricity, increased investment and operating costs may lead to concerns about possible higher electricity prices.

It is important to consider the seriousness of public acceptability of CCS: so far less than 10% of European population has heard of CCS; of those, only 13% feel positive about it right away – this increases to 55% following an explanation of the concept[30]. Wider public acceptance of the measures associated with advanced Clean Coal and CCS technologies is thus needed. Public debate will need to focus on the environmental and energy supply benefits and the feasibility of managing risks associated with transport and geological storage of CO_2.

[28] SRA and SDD can be found :http://www.zero-emissionplatform.eu/website/library/index.htlm.

[29] As expressed in the Commission Green Paper towards a European Strategy on security of energy supply COM(2000)769.

[30] Source : ZET Technology Platform

Cost. Sustainable coal technologies currently present high capital costs to investors in new power generation capacity. These technologies only provide significant efficiency gains in large scale applications. Hence, the costs are prohibitive for smaller plants. For example, 300 MW of capacity costs around €300 million without the additional expenditures for CO2 capture[31]. In addition, coal-fired power generation traditionally has a long investment cycle as plants operate for 40 years or even longer. The new generations of power plants are being, and will continue to be, commissioned for equally long time periods. The decision to invest in coal therefore requires investors' confidence in long-term persistence of conditions allowing for sufficient payback times. This becomes important especially when coal-based power generation is compared to the lower capital costs of natural gas CCGT plant. Besides capital costs, operating costs also present a barrier to uptake of the technology when comparing "capture ready" versions of power plant designs with existing coal technologies. Investors who wish to take advantage of the stable supply of coal fuel and the strong technology base in the EU, must also consider the profitability of investing in cleaner generating technologies. The risks and high costs of opting for best available high-efficiency processes that reduce CO2 emissions compared to traditional coal technologies present an obstacle to the advancement of sustainable coal technologies. Whilst existing technologies appear to make it possible to capture 80-90% of the CO2 produced in coal power plant flues, the impact of using such technologies could lead under present conditions to significant increases in the cost of electricity generation and in electricity prices. This indicates that both technological improvements that reduce capital and operating costs and so shorten payback times, and long-term stability of the market framework (for instance the ETS), are vital conditions for the success of sustainable coal.

Regulatory framework. European-level legislation and initiatives have been effective in achieving incremental improvements in emission levels from coal. However, the present regulatory environment does not provide sufficient incentives to invest in radical CO2-reducing technologies. Current environmental legislation has been drawn up prior to the existence of the CCS technology and may be creating unintentional and unwarranted barriers. The example of the Water Framework Directive[32] can be quoted as a case in point – its current text effectively disables storage of CO2 in saline aquifers although these geological structures have little relation to underground water conditions. Planning regimes, regimes for disposal of gaseous waste and for geological surveys may need clarification to remove the obstacles to CCS. These issues are currently the subject of a European Commission study as a part of the European Climate Change Programme.

CO2 value chain. The absence of a value chain for the end-product carbon dioxide is a barrier to the rapid uptake of Sustainable Coal. The ETS could provide the conditions to introduce such a value chain, but it currently excludes CO2 avoided through capture and storage from its permit trading system. A regulatory environment providing guarantees of long-term existence of a CO2 value chain would enhance security of investment and encourage rapid development and

31 « Pre-engineering studies for a new IGCC plant based on Puertollano ELCOGAS plant experience », CARNOT Contract N°4.1004/D/02-002/2002.

32 Directive 2000/60/EC of the European Parliament and of the Council of 23rd October 2000, establishing a framework for Community action in the field of water policy.

deployment of sustainable coal technologies. Refining the regulatory environment also includes satisfying the environmental requirements concerning carbon dioxide storage.

CO2 infrastructure. Another issue to be resolved in the context of a European energy policy is that of coordinating the build-up of carbon dioxide infrastructure (pipelines etc.) to ensure optimal network connections and transportation of the captured CO2 to suitable storage sites.

Demonstrated commercial feasibility. A sufficient record of operational experience of the variety of sustainable coal technology options leading to zero emissions power plants is currently not available. An acceptable proof of the operational suitability of the technological solutions is necessary to provide confidence in their reliable performance and commercial viability. Competition in the liberalised European energy market will require that embarking upon high-risk or high-investment projects such as those that would be necessary for the demonstration of new methods on a commercial scale needs to be considered very carefully. Existing or announced projects for the demonstration of zero-emissions power generation indicate that some activities are underway in European industry and Member States but these may need further support at EU level to reach the necessary scale and to make progress quickly enough.

2.5. Benefits of technologies for sustainable use of coal: beyond environmental concerns and security of supply

In addition to the benefits for climate change and security of energy supply, overcoming the identified barriers through policy measures and enabling a wide deployment of zero-emissions coal-fired power plants would offer additional benefits by providing opportunities for technology transfer and contributing to the Lisbon strategy goals of growth and jobs.

Europe has a large skills base in cutting edge coal technologies and has been at the forefront of CCS deployment. Technology development in the power-generation sector is often driven by small and medium-sized enterprises (SMEs) and not exclusively by a few large operators and investors. Both large energy corporations and SMEs working in the coal and electricity generation industries currently make strong contributions to local economies throughout Europe. The commercial arrival of technologies for zero-emission power generation from coal will reflect positively on these enterprises.

If the European energy sector retains the character of a competitive industry with a superior knowledge base along the whole coal value chain, including valuable new intellectual property, its businesses will be well placed to capitalize on the opportunities for export of these technologies to countries such as China, India and other major coal users. This will provide further business opportunities to European enterprises, contributing to improving competitiveness and securing employment.

3. SECTION 3: WHAT ARE THE OBJECTIVES?

In view of the challenges presented above, the goal of European policy in this area should be to facilitate the conditions for widespread deployment of economically-viable zero emissions coal-based power plants in the shortest possible time. This could ultimately lead to up to a 100%-penetration of such installations in coal-based power production if such absolute level of penetration turns out both necessary for combating climate change and commercially and technically feasible. Wide penetration of such technologies will not be in any case achieved without rapid and successful demonstration of the commercial viability of the technologies. In the intervening period the application of best available techniques (BAT) to all new stations built should constitute a bridging solution. This BAT should include provisions that allow easy subsequent addition of suitable CCS technologies once these are proven as commercially viable. Achieving the above stated overall goal requires the development of policy measures and/or actions that attempt, at EU level, to:

– Overcome the barriers identified above;

– Enable, in the earliest possible time horizon, the commercial deployment of the technologies outlined above and in the annex;

– Motivate operators in the power-generation business to view zero emissions technologies as the technologies of choice in coal-based power generation, once those are proven as commercially viable;

– Maximize competitiveness and sustainability of coal-based power generation in comparison with other types of low-carbon energy sources (nuclear, renewables, gas with CCS).

3.1. General objectives

In view of the overall logic outlined above, the following can be stated as general objectives of EU policy regarding Sustainable Coal Technologies:

(1) To enable continued and unhindered presence of coal in electricity generation in the EU energy mix as a factor of security of supply by making coal-based electricity generation an environmentally and economically sustainable option;

(2) To enable coal-based power generation to become a competitive low-/near-zero emission power generation technology, thus enabling it to make a contribution to the EU's Lisbon and sustainability goals, including the creation of new business opportunities both in the EU and abroad.

3.2. Defining technology/technologies to meet general objectives

While pursuing the above stated ambitions and general objectives, European policy in the area should avoid selecting a specific technological solution from amongst the existing or anticipated alternatives. Winner-picking should be resisted both at early stages of the development of Sustainable Coal as well as later on, regardless of whether certain technologies may appear at a given point to be more promising than others. However, setting specific targets and objectives requires consideration of the comparative advantages of the main technology types that exist. In general, the two different, but complementary, approaches to lowering CO_2 emissions from coal-based power generation are: the reduction of fuel costs and emissions through efficiency gains and the removal of CO_2 from the conversion process through its capture and storage. As the major policy aim is to facilitate the conditions for widespread deployment of promising technologies, and since the two technology types may require different policy approaches, it is judicious to assess whether one technology route can provide sufficient benefits alone, or if both require attention. Assessing these two technology routes separately and in combination for their potential contribution to security of supply, CO_2 emission reductions, and associated economic and social benefits allows the focusing of the policy objectives towards the most beneficial options.

Three routes have thus been tested:

(a) Seeking to achieve CO_2 emissions reductions through the implementation of energy efficiency measures in coal-fired power plants, without using CCS;

(b) Seeking to achieve the reduction of CO_2 emissions through the implementation of CCS measures in coal-fired power plants, without putting further emphasis on the improvement of energy efficiency in these power plants;

(c) Seeking to achieve the reduction of CO_2 emissions through combined implementation of energy efficiency measures and the use of CCS in coal-fired power plants.

Annex II details the analysis of the three routes. It can be concluded from the analysis that, in order to provide deep cuts in CO_2 emissions by 2050 whilst enabling coal to provide up to 30% (i.e. unhindered compared to today) of the EU's electricity over the period 2005-2050, both efficiency gains and CCS must be pursued at the same time.

Technology route A (focus on efficiency alone) can achieve significant reduction of specific CO_2 emissions. However it can only reduce total CO_2 emissions from coal generation in the initial period. In the longer term, total CO_2 emissions from coal generation increase due to increasing electricity demand. It can not achieve the near zero emission target.

Technology route B (focus on CCS only) can achieve the near zero emission target. However, as this would be done in a context of relatively low energy efficiency of power plants, it would require much larger quantities of coal for the same level of electricity production. This would compromise the competitiveness of coal-based power production or (in case of disproportionate growth of prices of competing fuels) would lead to an accelerated depletion of finite coal resources and, consequently, to further cost and security of supply constraints.

Technology route C offers definite advantages when compared to the more narrow technological approaches of routes A and B. It combines efficiency gains with the near-zero potential of CCS and thus leads to both environmental benefits and economic rewards. Consequently, the specific and operational objectives defined below have been set in alignment with the premise that no matter how they are technically specified (in terms of the conversion cycle, etc.) Sustainable Coal Technologies will rest upon both highly improved energy efficiency and the implementation of CCS in an integrated approach ("integrated technological solution").

3.3. Specific objectives for advancing the integrated technological solution

The general objectives stated above and the nature of the problem as described so far dictate that suitable policy decisions have to contribute to the following specific objectives:

– To assure that the use of coal in power generation does not compromise the EU’s ability to fulfil any post-2012 commitments regarding levels of CO2 emissions;

– To demonstrate zero-emissions energy generation from coal by 2020 as a commercially viable generation route that is competitive with alternative electricity generation methods;

– To enable rapid up-take of zero-emission technologies, once these become commercially viable, with the possible ultimate goal of 100% penetration of these technologies in coal-fired power generation in the EU should this be economically feasible and necessary for EU's policy goals with respect to climate change or energy;

– To sustain EU technological leadership in the coal-based segment of the power generation sector worldwide.

3.4. Operational objectives

The specific objectives can be translated into the following operational objectives for particular periods of time within the overall timeframe of the general objectives:

– To achieve, for the period until commercialisation of zero-emissions technologies, the application of the best-available techniques on all newly built coal power plants;

– To create conditions whereby as of 2010 all new built power plants are built as "capture ready", i.e. that their design features are fully compatible with CCS refurbishment;

– To demonstrate zero-emissions technologies for coal-fired power generation on a commercial scale by 2020. This objective and its timing dovetail with processes already under way in the EU and undertaken by the European industry with the support of the Commission (the Zero-Emission Fossil Fuel Power Plant Technology Platform, ZEP TP);

– To enable zero-emission technologies to become after 2020 the technologies of choice for coal-based power generation and to be economically competitive with power-generation technologies using other fuels. This should lead to the replacement of non-zero emissions operations in the coal-fired power generation sector, e.g. by 2050;

– To enable the EU to stay at the forefront of the development and deployment of Sustainable Coal Technologies worldwide. The EU should be the global leader in technology transfer projects in this area at any point during the technological transition to sustainable coal and especially afterwards.

3.5. Objectives summary interview

The following table summarizes the objectives in all three categories (general, specific and operational) as they are outlined in the preceding section. It also defines the indicators against which their achievements can be measured.

	Objective	**Indicator**
	General Objectives	
1.	Continued and unhindered presence of coal in electricity generation in the EU energy mix as a factor of security of supply	Share of coal in EU energy mix and electricity generation compared to current figures
2.	Coal-based power generation to become a competitive low-/near-zero emission power generation technology	Specific emissions (CO_2/kWh) and cost of electricity produced (€/kWh) for new coal-fired power plants
	Specific Objectives	
1.	Use of coal in power generation does not compromise the EU's ability to fulfil any post-2012 commitments regarding levels of CO_2 emissions	Atmospheric GHG emissions from coal-fired power plants in relation to EU's post-2012 commitments
2.	Demonstration of zero-emissions energy generation from coal by 2020 as a commercially viable generation route that is competitive with alternative electricity generation methods	Cost of electricity produced in zero-emission coal-based power plants compared to that from other power generation installations, incl. cost of CO_2 emissions
3.	Rapid up-take of zero-emission technologies, once these become commercially viable, with the ultimate goal of 100% penetration of these technologies in coal-fired power generation in the EU	Percentage of zero-emission power plants in all coal-fired power plants
4.	Sustain EU technological leadership in the coal-based segment of the power generation sector worldwide	Proportion of projects in third countries based on EU technology
	Operational Objectives	
1.	To achieve, for the period until commercialisation of zero-emissions technologies, the application of the best-available techniques on all newly built coal power plants	Percentage of newly built installations using high-efficiency BAT and/or CO_2 capture and storage

2.	Create conditions whereby as of 2010 all new power plants are built as "capture ready", i.e. that their design features are fully compatible with CCS refurbishment	Proportion of "capture-ready" plants in all new coal-fired power plants
3.	Demonstrate zero-emissions technologies for coal-fired power generation on a commercial scale by 2020	Number of projects with successful track record of 3-5 years; number of failed projects
4.	Enable zero-emission technologies to become after 2020 the technologies of choice for coal-based power generation and to be economically competitive with power-generation technologies using other fuels	Percentage of zero-emission power plants in all coal-fired power plants
5.	Enable the EU to stay at the forefront of the development and deployment of Sustainable Coal Technologies worldwide	Number of EU-originating projects for zero-emission power generation from coal worldwide, % thereof in all such projects worldwide; % of EU-originating projects in zero-emission power generation from coal in all such projects worldwide involving technology transfer to a third country

3.6. Compatibility with other EU policies and strategies

The policy objectives outlined above for Sustainable Coal are consistent with the European Commission's Green Paper of 2006 A European Strategy for Sustainable, Competitive and Secure Energy. The Green Paper stated that "coal and lignite, for example, presently account for around one-third of the EU's electricity production: climate change means that this is only sustainable if accompanied by commercialised carbon sequestration and clean coal technologies on an EU level." It went on to explain that "carbon capture and geological storage, in combination with clean fossil fuel technologies provides a third opportunity of near zero emission technology. It can be particularly important for countries which choose to continue the use of coal as a secure and abundant energy source."

Given the current EU energy landscape, this impact assessment assesses EU policy measures to promote zero-emissions power generation in the broader context of a liberalised electricity market, whilst retaining also the argument of the benefits of a diversification of energy sources. Proposed objectives and policies therefore need to be compatible with both energy market liberalisation and security of supply strategies in the EU.

This impact assessment takes account of other European initiatives in this area, such as the Hypogen initiative[33]and the Dynamis project[34] and investigates the likely

[33] HYPOGEN is a power plant concept, proposed by the European Commission as a part of the European Initiative for Growth, that envisages the co-production of electricity and hydrogen from fossil fuels on a large scale with the simultaneous capture and storage of carbon dioxide. The goal of the HYPOGEN project is to provide Europe with a realistic and economically viable route to the hydrogen economy.

impacts of action over and above their current scope. It also recognizes the work of the Zero-emission Fossil Fuel Power Plant Technology Platform (ZEP TP), which has recently adopted important documents on the future of zero-emission power generation from fossil fuels in Europe (a strategic research agenda and a deployment document were proposed by the ZEP Technology Platform in the autumn of 2006).

This impact assessment fully recognizes the contribution of the EU research policy for reaching the Sustainable Coal policy objectives. After the adoption of FP7, the Commission will be able to launch the related calls for proposals (first round in December 2006 or early 2007, further rounds to follow) and receive the first firm commitments from the industry. These proposals are expected after the adoption of the Communication related to this impact assessment.

This impact assessment takes into account the impact of Sustainable Coal policies on the meeting of the objectives of the Lisbon strategy for growth and jobs in Europe. Evaluation in the context of the EU sustainable development strategy is also important. This impact assessment therefore also takes account of the Commission's plans for forthcoming legislative initiatives intended to facilitate the authorising and implementing of CCS technologies and plans for post-2012 climate change policy, including the revision of the Emissions Trading Scheme. These initiatives will be taken with due considerations of the environmental risks and how they can be minimised without compromising investment.

[34] The FP6 DYNAMIS Integrated Project, started in March 2006, is Phase I of HYPOGEN, designed to investigate viable routes to large-scale cost effective hydrogen production from Coal and Natural Gas with integrated CO_2 management for subsequent development of a full-scale plant by industry by 2012. The plant intends to generate electricity of about 400 MW using hydrogen-fired turbines, while exporting hydrogen equivalent to 0-50 MW.

4. SECTION 4: WHAT ARE THE POLICY OPTIONS?

This Impact Assessment addresses the ability of the following three policy options to meet the objectives described in the preceding chapter. The associated impacts of each option on the development and penetration of Sustainable Coal Technologies, and the subsequent economic, social, political and environmental impacts of their introduction, are assessed in the next chapter.

Option 0: No policy change

Option 0 supposes that the existing legal and regulatory framework remains unchanged and that the current policy instruments and measures continue, in the same fields and with the same intensities. It can be considered a "no policy change" scenario.

Option 1: Removal of barriers to Sustainable Coal Technologies (through improvements of existing legislation and use of currently available instruments)

Option 1 aims to facilitate Sustainable Coal Technologies primarily through amendment of the existing legal and regulatory framework and strategic targeting of the available financial support schemes to technological development. It addresses the barriers identified earlier but does not further promote Sustainable Coal Technologies in the market through specifically targeted regulatory or financial incentives.

Option 2: Introduction of special incentives for the development and penetration of Sustainable Coal Technologies

Option 2 considers the introduction of stronger incentives, going beyond the existing policy instruments and measures and the regulatory changes envisaged under option 1. These incentives will require further evaluation as to their costs and benefits and expected impact and effectiveness. An in-depth impact assessment analysis of the policy tools and initiatives suggested for generating such incentives will need to be undertaken to assess each of them in their full complexity to determine the viability of each policy instrument.

The options are described below individually in greater detail.

4.1. Option 0: No policy change

Policy option 0 leaves unchanged the legal and regulatory framework applicable to clean coal and CO2 capture and storage projects, and supposes the continuation of the existing financial support measures as in the recent past, in the same fields and with the same intensities. The extent to which clean coal or CO2 capture and storage activities are or are not covered by existing regulations and current measures is explained hereafter.

Existing Legal and Regulatory Framework

Emissions Trading Scheme (ETS)

– Reduction of CO_2 emissions as a result of increased energy efficiency in coal fired power plant is counted in the ETS and is credited to the operator;

– CCS is not opted in to phase II of ETS and so CO_2 captured and subsequently stored underground in geological formations is not credited to the operator. CCS thus does not benefit from any financial stimulation through the ETS.

General Regulatory Framework

– Projects for improvement of the energy efficiency (in existing and in new plants) or for CO_2 capture, transport and storage are governed by existing regulations on industrial activities[35] (in general), on electricity production[36], on gas transport and by the applicable legislation on mining and on hydrocarbons exploration and production;

– There is no specific regulatory framework for CO_2 capture and storage;

– New and existing policy documents and legal measures may include provisions openly or effectively going against underground CO_2 storage;

– Environmental Impact Assessment Directives;

– Modifications to existing power plants for improving the energy efficiency, construction of new more efficient power plants and capture of CO_2 in power plants are within the scope of the Environmental Impact Assessment Directives;

– Transport and storage of CO_2 remain outside of the scope of Environmental Impact Assessment Directives[37];

– International Conventions on the Seas;

– In their present form, the International Conventions on the Seas (such as the OSPAR Convention) do not recognise CO_2 underground geological storage as a permissible off-shore activity [38].

Existing Non-Regulatory Framework

Financial support schemes for technological development remain as they are. Industry projects needing further technological development or demonstration go ahead without strategic support from the EU beyond the measures already decided.

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35 Council Directive 96/61/EC on integrated pollution prevention and control (“IPPC Directive”).

36 Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large comubustion plants (« LCP Directive »°. IPPC Reference Document on Best Available Techniques for Large Combustions Plants, adopted July 2006.

37 Council Directive 97/11/EC of 3rd March 1997 amending Directive 85/337/EEC of 27th June 1985 on the assessment of the effects certain public and private projects on the environment.

38 Although most recently, an important international document, the London Protocol, was amended in this respect and permits as of 2007 CO_2 storage in sub-seabeds (First meeting of the contracting parties to the London Protocol, 31st Octo-3rd Nov 2006).

Financial support from the EU would be limited to the kind of support available under the current EU RTD programmes. It is assumed that the EU financial means available for future activities in both areas would be of the same order than those available so far (through the FP6 and the RFCS):

– For CO2 capture and storage: as in FP6 (in total, around 70 million €);

– For R&D on coal mining, coal preparation and coal conversion and combustion: from the Research Fund for Coal and Steel (RFCS, with around 16 million €/y).

Existing national financial support schemes continue to be available and deliver expected results[39]. Industry projects needing further technological development or demonstration may benefit from national aid schemes already established in some Member States in the areas of clean coal and CO2 capture and storage.

4.2. Option 1: Removal of barriers to Sustainable Coal Technologies

The aim of this policy option is the facilitation of Sustainable Coal Technologies through adaptation of the existing regulatory framework to achieve a removal of the major non-economic barriers. Together with appropriate amendments to the existing regulatory regime, this option puts a very strong emphasis on the further development and demonstration of clean coal and CO2 capture and storage technologies through increasing support to technological development. In this option, further penetration of Sustainable Coal Technologies after they have been demonstrated as commercially viable depends exclusively on the prevailing economic context.

Addressing legal and regulatory barriers

Policy option 1 includes the use of regulatory instruments to remove the current regulatory barriers to the deployment of CCS to ensure that CCS activities are included in the EU ETS and to ensure the environmental integrity of long-term storage of CO2. The following conventions, legislation, regulations and procedures have been provisionally identified. Subject to detailed impact assessment, including a subsidiarity check (checking whether the measure is best taken at EU level), the Commission makes these necessary changes part of its work programme as of 2007:

– For the Environmental Impact Assessment Directives, ensure that projects for CO2 capture, transport and storage are subject to evaluation of their environmental impacts, that the outcome of these evaluations are made known to the public, and that consultation of the public is integrated in the authorisation procedures of the projects;

[39] For example, in Germany the COORETEC R&D concept (**COO REduction TECh**nologies) for sustainable fossil electricity generation by means of highly efficient, low emission coal and gas fired power plants, is implemented and co-financed (with approx. €12 million/yr) by the federal government. In France, the UK and Spain schemes for clean coal and CCS demonstration have been in place. See Annex 1 for a more complete overview.

– The IPPC Directive and requirements concerning the permitting regime, including the possibility to stimulate a trend whereby new coal-fired power plants are built capture-ready after 2010;

– Possibilities for Member States to request the Commission for an opt-in for CCS activities for phase II of the Emissions Trading Scheme (ETS) to enable the monitoring of geologically stored CO2 and thus the acceptance of CO2 captured and avoided through storage as CO2 not emitted;

– The inclusion of CCS activities in the EU ETS in the context of the review of the Directive, including consideration of how stronger incentives for low carbon long term investments can be given;

– Adoption of an EU-wide specific regulatory framework for CCS that clarifies issues of quality, safety, security and liability, with a view to introducing a CO2 value chain;

– CO2 storage and the water Framework directive;

– CO2 transport and storage and the waste framework Directive, including considerations regarding the purity of CO2 streams;

– Amendment of the conventions of the seas to allow CO2 storage in underground geological formations below the seas.

Addressing barriers of costs and lack of demonstration

Through financial support and coordination, deployed effectively through FP7 and other Community resources, Policy option 1 addresses the needs for research, development and demonstration (R&D). This has the double aim of bringing the technologies to maturity and reducing costs. The EU would support financially and coordinate the initiatives of the industry in defined priority fields, with possible involvement of Member States. Clean coal and CCS are prioritised in the existing Community research programmes. Specific projects arising from the industry would be supported by the EU through the co-financing mechanism (a share of the eligible cost of the projects) or through loans. Best practices and results from the interventions of the financial instruments established at EU and national levels would be exchanged through a mechanism constructed at Community level.

Financial Instruments

– Various possibilities of financial assistance exist in the form of Structural Funds and the Cohesion Funds in eligible regions/countries where coal production and/or coal use constitutes an important economic sector. These instruments would allow the implementation of projects in the eligible regions/countries using technologies developed in the most advanced Member States and the stimulation of a more even penetration of Sustainable Coal between interested Member States. Community loans (from the European Investment Bank, EIB, or the European Bank for Reconstruction and Development, EBRD) can also play a decisive role for financing innovative projects in some countries.

State aid

– Member States can support research and development in the areas of clean coal and CO_2 capture and storage, making use of state aid provisions for research and technological development.

Community support to R&D

The 7th Framework Programme for research (FP7) would propose a significant increase of funding to the areas of CCS and coal use in power generation. The Commission has in fact already proposed to support both clean coal and CCS technologies under the energy section of the current draft of FP7. The FP7 proposal is under discussion with the European Parliament and the Council. Furthermore, the Research Fund for Coal and Steel (RFCS). Past experience has shown that the RFCS has the potential to support clean coal conversion technologies with a stable annual budget of around €16 million per year.

Under this policy option, the EU would seek clear concentration of the FP7 and RFCS funding available for coal-related R&D in topics and activities focusing on the development and demonstration of technological solutions and components necessary for Sustainable Coal.

1. in the area of clean coal:

– Demonstration of the technical and economic viability of commercial-scale plants using results of earlier research programmes (with the aim of reaching an energy efficiency of 50 %);

– The launch of new research and development (R&D) activities needed for developing the next generation of even more energy efficient power plants (going well above 50 % for energy efficiency, given that the technical limits are around 65 % for pulverised coal ultra high temperature steam cycle and around 60 % for IGCC);

– Additional topics for related research include: energy efficiency improvement in coal power plants; cleaner combustion; operational and fuel flexibility.

2. in the area of CO2 Capture and Storage:

– Technological improvement and cost reduction in the post-combustion phase (separation of carbon dioxide from flue gases), pre-combustion phase (decarbonisation of the fuel) or through oxy combustion (combustion with pure oxygen or a mixture of oxygen and carbon dioxide);

– Demonstration and monitoring of the long term storage of CO2 in underground geological formations such as: oil and gas fields (for enhanced production), depleted oil and gas fields, saline aquifers and deep coal seams (for enhanced methane recovery).

Addressing barriers of public perception and acceptance

Policy option 1 addresses the provision of factual and engaging information to the public on all issues related to safety, integrity and monitoring of CO2 storage. The launch of an information campaign could be envisaged, probably in cooperation with Member States, using existing Community instruments and funding for information dissemination.

4.3. Option 2: Introduction of incentives for the development and penetration of Sustainable Coal Technologies

Policy option 2 includes measures outlined in option 1 and, in addition, considers the introduction of incentives going beyond the existing policy instruments and measures. Any measures considered under policy option 2 would be *in addition to* the instruments and measures proposed under option 1 and would aim to address additional barriers, market failures and/or to give stronger incentives as the case may be.

The measures below do not constitute a single 'package' of policy instruments. They describe some of the numerous tools that could be considered if pro-active policies were considered necessary at various stages of the development, demonstration and deployment of Sustainable Coal. The list below does not have the ambition to be exhaustive nor does it represent measures for which the Commission would express preference; an omission of a possible measure to support CCS does not imply its conscious rejection. A further elaboration and an in-depth impact assessment of each option or set of measures would be in any case necessary before the given option/measure could be recommended for possible implementation.

Incentives through regulatory instruments

EU-wide regulatory framework providing for:

– Adoption of a requirement that all new coal-fired power plants be CCS equipped after 2020;

– Supporting development of CO2 infrastructure;

– Community-level identification of major CO2 storage sites (onshore, offshore), including those having a multi-country potential;

– Community-level identification of main necessary CO2 pipeline infrastructure (inland, cross-border, offshore), for the linking of CO2 sources to major storage sites.

– Enhanced version of the EU Emissions Trading Scheme;

This would address primarily the question of comprehensiveness and time horizon of incentives delivered by the system. An enhanced EU ETS would aim to:

– Establish generally more favourable framework for long term investment in low-emission technologies by introducing a concept of "relative perpetuity". Having a system with the time horizon at least matching but rather surpassing the usual investment cycle of the power industry is of particular importance for clean coal and CCS given that solid fuel power generation projects have typical lifetimes of 40 years and often operate for even longer periods;

– Inclusion of a more comprehensive set of industrial CO2 sources to cover all important CO2-generating sectors and to set for emerging emitting sectors a clear threshold beyond which these would also be included;

– Reduction of the role of administrative allocations of allowances for emissions (i.e. allocations of emission allowances through mechanisms which do not subject the emitters to the obligation to procure allowances through market-based mechanisms);

– Setting a benchmark for allowed CO2 emissions from energy production regardless of source.

Incentives in favour of Sustainable Coal-fired electricity

– Enable the provision of privileged access to the electricity pool for zero-emissions power, as it is now the case for electricity derived from renewable resources (in some Member States) or electricity from co-generation plants. (This would not discriminate between energy sources, but between their environmental impacts.);

– High buy-back prices of the ‘sustainable electricity’ produced or an obligation imposed on electricity suppliers to include a minimum share of ‘sustainable electricity’. (This would not discriminate between energy sources, but between their environmental impacts.);

– Timed Phase-Out: To ensure that coal-fired power generation is equipped with CO2 capture and storage, high-CO2 emitting installations (large power plants using coal or other fossil fuels) could be strategically phased-out by a given date (for instance by 2050). This might be achieved through an extension of the Large Combustion Plants (LCPD) or the Integrated Pollution Prevention and Control (IPPC) Directives to include CO2.

State aid

– National support measures for the development, commercialisation and market penetration of clean coal and CO2 capture and storage may involve state aid;

– In addition to support for research and development as described in option 1, Member States could focus more strongly national support for innovation in the areas of clean coal and CO2 capture and storage, making use in particular of state aid provisions for research, technological development and innovation;

– Member States could accelerate the commercial penetration of clean coal and CO2 capture and storage technologies and/or the establishment of the main CO2 pipeline infrastructure through national support making use of existing state aid rules. In this context, the Commission could assess, in particular in the context of the ongoing state aid reform, whether there is a need to broaden the possibilities for allowing aid to environmentally friendly energy sources.

Incentives through non-regulatory instruments

These include measures such as:

Voluntary schemes for specific investment

– The advantages of a voluntary scheme would include potential high participation rates from industrial actors who could accrue good publicity from their activities;

– A non-binding scheme would, however, be dependent on participants to determine its success, but its flexibility could facilitate competition between participants, leading to high investment rates.

Joint Technology Initiative (JTI) and/or Joint Undertaking (JU)

– In the decision establishing a JTI or JU, the EU defines the kind of projects or technologies that will be promoted, announces the financial support it is ready to give and invites companies to join and bring in their contribution;

– Though a JTI or a JU, the Commission together with the industrial partners that will join can effectively take over a large scale demonstration and the initial deployment of the selected sustainable coal technology; 10-12 large-scale demonstration projects could be financed;

– The difference between the two mechanisms is that a JTI is more a cooperative approach while a JU implies the establishment of a company;

– The creation of such powerful tools by the Commission could be justified in areas of very high common interest but where initial commitments by the operators or the Member States are insufficient to achieve the expected results.

5. SECTION 5: WHAT ARE THE LIKELY ECONOMIC, SOCIAL, POLITICAL AND ENVIRONMENTAL IMPACTS? HOW DO THE OPTIONS COMPARE?

The impacts of each policy option have been assessed on the basis of their likely outcomes for coal-fired power generation, their implications for other sectors within the EU, and their ability to meet the objectives set. These likely outcomes of the policy options have been built upon a set of key assumptions. that have been used to formulate scenarios that describe the likely technological development and penetration of sustainable coal technologies between 2005 and 2050. The underlying storylines for each scenario have been quantified to allow for the comparison of the policy options. The complete quantitative analysis is set out in Annex III. Provided below are, on the basis of the quantitative analysis, the assessments of the likely impacts of each policy option.

It should be recognized that this analysis considers only actions currently under way in the EU at European and national levels and the other actions/further initiatives identified in this document. It does not take into account possible future actions of individual Member States undertaken on their own initiative. It would be, of course, desirable for future actions in support of the Sustainable Coal concept to take place in Europe in a coordinated manner, in order to exploit the synergies between EU policies in the area and possible national-level initiatives by Member States.

5.1. Coal-fired generation capacity

The TRENDS[40] baseline scenario is the basis for the illustrative analysis and the assumptions of the three policy options considered in this impact assessment.

For electricity generation, the TRENDS baseline scenario foresees a steady increase of electricity demand and hence of generation until 2030, with a lower increase in the later period. For the period between 2030 and 2050, TRENDS figures were extrapolated, using an estimated rate of increase similar to that used by TRENDS for the period until 2030.

Maintaining coal-fired generation capacity in the EU would require a rate of replacement or retrofitting of just above 4.5GW/year on average. However, without a clear indication that coal will be a politically acceptable fuel, and without specific efforts to remove technical and regulatory barriers to more sustainable technologies for coal use, this replacement is not expected to proceed at a rate that can ensure maintaining capacity at current levels. The TRENDS baseline scenario foresees a sharp decline in coal capacity due to this effect up to 2015, but predicts that capacity will be restored by 2025 and will increase up to 2030.

This impact assessment incorporates the TRENDS scenario in its analysis of the possible impact of identified policy options on coal-fired generation capacity in the following way:

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[40] European Energy and Transport : Trends to 2030 – update 2005, publication prepared by the Institute of Communication and Computer Systems of National University of Athens, for DG TREN, published 2006.

– Option 1 follows strictly the TRENDS baseline scenario (with extrapolation for 2030-2050);

– Option 0 is more pessimistic than the TRENDS baseline scenario;

– Option 2 is more optimistic than the TRENDS baseline scenario.

With 'No Policy Change' (Policy Option 0), the TRENDS baseline scenario seems to represent an unlikely optimistic path. If the industry does not receive clear signals through policy initiatives tackling current drawbacks of coal, a sizeable increase in long-term investments in coal from 2015 onwards is unlikely to materialize. In the period to 2015, 95% of retiring coal-fired capacity is definitively closed and replaced by non-coal capacity, as assumed by the TRENDS baseline scenario. In the period 2015-2050, the reduction of coal-fired capacity continues albeit with a declining rate. This appears consistent with other available estimates (JRC figures indicate that capacity will drop from the present 172 GW to 95 GW in 2015 and 38 GW in 2030). Some investments are still foreseen after 2015 but it is assumed that coal capacity continues to fall as a result of a lack of certainty among power producers that coal-based power generation could meet CO2 constraints and withstand competition mainly from natural gas, some nuclear replacement and the increasing economic feasibility of renewable energies. It can be therefore assumed that the evolution envisaged by the TRENDS baseline scenario for the period 2005-2015 is prolonged as far as 2050. However, the rate of decline in coal-generation capacity levels off in the second half of the period. In this second period, more retiring coal plants are replaced with more efficient new coal plants. The reduction of coal-fired capacity is practically levelled off by 2050, as it is assumed that there will probably be no other capacities available further to replace coal and that some local coal and lignite will in any case continue to be used for power generation (see Figure 4). This will bring the share of coal in electricity production to around 14-15%.

In policy option 1 (Removal of existing barriers but no pro-active measures) coal-fired power generation capacity in the EU follows that of the TRENDS baseline scenario[41]. The coal-fired capacity is reduced in the period until 2015, and then rebuilt at a higher level. After 2030, coal-fired capacity only increases in line with increasing electricity demand (see Figure 4). In the period until 2015, most of the retiring coal plants are closed and replaced by non-coal capacity. Only a few of those plants reaching the end of their lifetimes are retrofitted or replaced. In the period from 2015 to 2050, outdated and least efficient plants are retrofitted or replaced with new coal plants. Coal is generally seen as a viable fuel option for power generation as existing barriers to penetration of sustainable coal technologies are removed by revisions of applicable legislation. Additional capacity is thus built between 2015 and 2030 to compensate for earlier losses and to cope with increasing electricity demand but the choice between coal and other energy sources continues to depend on the development of a number of market-based drivers, such as the price of CO2 emission allowances, the difference between the investment intensity of modern coal power plants (with CCS) and that of other types of power plants (e.g. gas), and the

[41] This reflects the assumption that the removal of barriers to Sustainable Coal would enable coal-fired power generation to remain a possible technology option also in a carbon-constraint environment but would not guarantee that the technology is commercially viable.

relative price of gas and coal. It also depends on progress in the development of sustainable coal technologies which in Option 1 continues to be largely driven by industry initiatives. Accordingly, coal's contribution to the electricity mix in the EU follows that of the TRENDS baseline scenario. This foresees a reduction in the share of coal between 2005 and 2015, followed by a partial recovery until 2030. For the period 2030-2050, the (extrapolated) share of coal is assumed to be in the range around that of present levels, i.e. between 27.5% and 30%.

In policy option 2 ("Pro-Active"), coal-fired capacity is assumed to increase practically continuously, drawn upwards by the general trends assumed in the TRENDS baseline scenario but reinforced by policy initiatives which focus on the support of the development and penetration of technologies for zero-emission power generation from coal. The main difference in the impacts of policy options 1 and 2 is in the initial period until 2015. As a result of new and strong policy signals, the industry is assumed to trust that coal will be politically acceptable and commercially viable for an extended period of time and therefore acts systematically to replace all retiring coal-fired plants again by new, 'state-of-the-art' coal plants, while additional coal-fired capacity may also be constructed to cope with increasing electricity demand. The proportion of coal-fired additional capacity in overall additional capacity is roughly equal to the overall proportion of coal-fired capacity in total capacity. After the period until 2015 (in which, in view of the above, no pronounced trough is seen as was the case in Option 1), such a development effectively means that coal's contribution to the electricity mix in the EU is maintained at the 2005 level of 29% until 2030. In the period 2030-2050, the share of coal is assumed to increase slightly and be in the range of 30% to 35% as pro-active policies make Sustainable Coal Technologies attractive to investors and coal may even gain some ground over other low-CO2 sources.

The assumed development paths for all three policy options are summarized below:

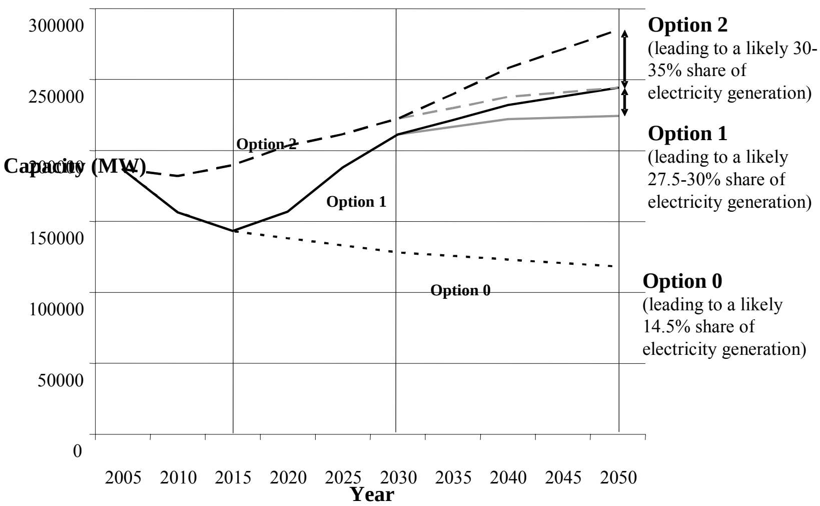

Figure 4. Anticipated effects on Capacity of Coal-Fired Power Plants in the EU under the three options

With the above overall considerations about coal-fired power generation capacity in mind, the effects of individual policy options in other analyzed directions are outlined in later sections of this chapter for each option in detail.

5.2. Environmental impact, Air Pollution

The deployment of Sustainable Coal technologies will require storage of vast amounts of CO_2 both in Europe and especially world-wide. In Europe alone, retaining coal in the energy mix at current levels and with 30% penetration of Sustainable Coal by 2030 will lead to 300-400 million tonnes of CO_2 stored annually; 100% penetration of Sustainable Coal by 2050 will lead to annual injection of some 900 million tonnes of CO_2 under ground. Available information shows that there is enough storage capacity in Europe to enable the sequestration of such amounts for several decades (see Annex 1 for further details).

The main new impact of carbon dioxide capture and storage relates to the potential release of CO_2 from the storage site which can have both local and global impacts. However, the IPCC Special Report has estimated that the fraction of CO_2 retained in appropriately selected and managed geological reservoirs is very likely (i.e. with probability of 90-99%) to exceed 99% over 100 years and is likely (i.e. with probability of 66-90%) to exceed 99% over 1000 years.

Penetration of Sustainable Coal technologies is likely to reinforce the positive impact of recent improvements in coal-fired power generation through the application of clean coal technologies. These have led to date to significant reductions of most critical air pollution agents, notably sulphur dioxide (SO2) and nitrogen oxides (NOx). These pollutants are major contributors to ocean acidification, eutrophication, ground level ozone as well as particular matter. Particulate matter is a major health hazard, as indicated in the Thematic Strategy on Air Pollution[42]. At this stage no information is available on the impact on emissions of particulate matter and thus, it is likely that the impacts on air quality have been underestimated to some extent.

The deployment of CCS in power generation is likely to have both positive and negative impacts on air pollution, in particular on the emissions of SO2 and NOx. Table 2 shows the possible impacts per GWh electricity produced, taking into account the efficiency losses associated with the use of CO2 capture.

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42 Commission Communication on a Thematic Strategy on Air Pollution COM(2005) 446 of 21st September 2005.

Table 2. Impacts CCS on air pollution[43]

Emissions	Natural Gas Combined Cycle (NGCC)			Pulverized Coal (PC)			Integrated Gasification Combined Cycle (IGCC)	
	NGGC	NGCC+ CCS	Change (%)	PC	PC+CCS	Change (%)	With CCS	Change (%) versus PC
CO2 t/GWh	367	62	-83%	762	145	-81%	97	-87%
SO2 kg/GWh	0	0	0%	308	12	-96%	17	-94%
NOx kg/GWh	262	275	5%	594	707	19%	110	-81%

Source Rubin et al (2005), Tzimas et al (2006),RAINS (2006)

Table 2 shows that with Natural Gas Combined Cycle and Pulverized Coal, NOx emissions would increase slightly (5% to 20%) with carbon dioxide capture, while still meeting the limits values stipulated in the Large Combustion Plant Directive. For pulverized coal with CCS, SO2 emissions would be reduced considerably (92%) even when compared to current coal fired power plants using modern flue gas desulphurization. Advanced technologies such as IGCC with CCS would reduce both NOx and SO2 emissions by 81% and 94% respectively.

Table 3 uses these results to estimate the environmental benefits (such as reduced mortality and morbidity) due to the changes in NOx and SO2 emissions for a typical 500 MWe coal fired plant operating in base load (6000 hours per year). The benefit estimates are based on EU average benefits per tonne of emission, reduced. These benefits depend on the location of the plant. The estimates are based on the Thematic Strategy for Air Pollution[44].

43 Rubin, E., A. Rao and C. Chen (2005) Comparative assessments of fossil fuel plants with CO2 capture and storage, Proceedings of the 7th International Conference on Green house Gas Technologies, Vancouver, Canada, 3-9 September 2004. Vol 1. E. Rubin, D; Keith and C. Gilboy (eds.) Elsevier.
Tzimas, E., A. Mercier, C. Cormos and S. Petevis (2006) Trade-offs in emissions of acid gas pollutants and of carbon dioxide in fossil fuel fired plants with carbon capture, European Commission, DGJRC, Institute for Energy, Petten, the Netherlands.
Emission factors for pulverized coal with CCS are based on the emission factor for new, coal fired power plants in Germany assuming FGD and DeNox (SCR) from the RAINS database (www..iiasa.ac.at/web-apps/apd/RainsWeb/)
Special Report on Carbon Dioxide Capture and Sotrage, Special Report of the Intergovernmental Panel on Climate Change B. Metz, O. Davidson, H. de Coninnck, M. Loos and L. Meyer (Eds.) (2006).http://www.ipcc.ch/pub/reports.htm. I.e. chapter 3 (Capture of CO2.

44 AEAT (2005) Damages per tonne emission PM2.5, NH3, SO2, NOx and VOCs EU 25 Member States, available at http://ec.europa.eu/environment/air/cafe/activities/pdf/cafe_cba_externalities.pdf.

Table 3. Example: Estimated benefits of air pollution changes for 500 MW coal fired plants in the EU[45]

			Emissions			
		Pulverized Coal	Pulverized Coal with CCS		Integrated Gasification Combined Cycle (IGCC) with CCS	
CO2	Mt/yr	2.29	0.43	0.43	0.29	0.29
NOx	kt/yr	1.78	2.12	2.12	0.33	0.33
SO2	kt/yr	0.92	0.04	0.04	0.9205	0.9205
			Estimated benefits €/ tonne avoided per year			
			Low	High	Low	High
NOx	€/t NOX reduced		4400	12000	4400	12000
SO2	€/t SO2 reduced		5600	16000	5600	16000
			Estimated benefits € million/per year compared to pulverized coal			
NOx	Mln €/yr		-1.5	-4.1	6.4	17.4
SO2	Mln €/yr		5.0	14.2	0.0	0.0
Total	Mln €/yr		3.5	10.1	6.4	17.4
Carbon capture costs (€30/t CO2 for PC and €20/t CO2 for IGCC[46])	Mln €/yr		55.5	55.5	41.9	41.9
Share of air pollution co-benefits vs. capture costs			6%	18%	27%	75%

Note: "Low" corresponds to the low range of values used in health benefits due to reduced air pollution and "High" corresponds to the high range. See details in AEAT (2005).for benefits and Rubin et.al.(2005) and IPPC (2006) for carbon capture costs including enhanced oil recovery premium.

The illustrative calculation in Table 3 implies that 6% to 18% of the additional costs of carbon capture using pulverized coal could be recouped by benefits due to improved air quality. Furthermore, if coal based IGCC were combined with CCS the improved air quality would result into health benefits that are 1/4 to 3/4 of the total CCS costs. If a high value was used for human health, air pollution related co-benefits alone could be as high as ¾ of the additional costs of CCS. It should be noted that if CCS coal plants were located in Central Europe the benefits would be much higher (a factor 4, due to higher population densities). Thus, for the IGCC plant located in central Europe, the air pollution related health benefits could be as high as half or even 50 % higher than the costs of applying CCS. In sum, net the air pollution benefits of CCS can be significant and are likely to be a major factor when

45 Tzimas, E, & Peteves SD : The impact of carbon sequestration on the production cost of electricity and hydrogen from coal and natural-gas technologies in Europe in the medium term, Energy 30 (2005) 2672-2689

46 Assuming revenues of €10/tCO_2 from use of CO_2 in enhanced oil recovery.

the sustainable coal policy is designed. These net positive impacts on air pollution are associated with policy option 1 and option 2.

5.3. Cost of electricity produced and the choice between coal- and gas-fired technologies

Sustainable Coal technologies, especially the deployment of CCS in power generation, will increase the costs of power production from coal. This is certain to be the case when current technologies are considered. However, given the expected development of new technologies already in the pipeline or likely to materialize soon, significant cost increases in a sustained manner may not necessarily be the case.

The special report of the UN Intergovernmental Panel on Climate Change (IPCC)[47] indicates a wide range of cost estimates for CO2 capture from power generation, ranging from US$15 to $75 (i.e. €12 to €60) per tonne of CO2. The costs of transportation and injection of CO2 equally vary from just over €1 per tonne of CO2 for both transportation and injection in total to €13. According to some estimates[48], these figures, if reflected in the economics of power generation on the basis of **current** technologies, translate into an estimated additional cost of coal generated electricity with CCS between 33 % and 57%, in comparison with electricity generated from coal without CCS. The increased cost due to CCS deployment depend on the combustion and capture technologies used Lower cost increases (possibly by as little as 33%) apply to IGGC technologies (implying pre-combustion capture of CO2), higher cost increases (up to 57%) to more traditional pulverized coal technologies which require post-combustion capture of CO2. Other estimates[49] come to similar conclusions, putting the cost of CCS at €c 2.5/kWh (i.e. on top of the current cost of €c 5-6/kWh from coal without CCS).

At the current stage of technology development CCS costs thus may seem prohibitively high for commercial use of these technologies in power generation on a large scale. However, as the estimated cost increases have been established from models run for new power plants based on **current** technology, they do not include the technology improvements anticipated in the coming years. Gains in the conversion efficiency of future plants and reductions in future CO2 capture costs are highly probable and are certain to reduce considerably CCS costs as well as overall cost of electricity produced using Sustainable Coal technologies. The exact reductions will depend on the fuel price. Available models and studies looking at the long end of coal-based power generation with CCS thus allow for estimates of increases in the costs of power generation in the range of 10% or even on a par with the current levels by **2020 or soon afterwards**. The ZEP Technology Platform indicates commercial deployment by 2020.

Some research projects currently under way aim to demonstrate in the near future technologies able to produce electricity from coal-fired power station with CCS at

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47 Reference for IPCC Special Report, see also Report of Working Group on Carbon Capture and Geological Storage of ECCPII.

48 E.g. evaluation done in 2006 under ECCP II.

49 E.g. the IEA Greenhouse Gas R&D Programme 2001 study « Putting Carbon back into Ground ».

costs only moderately higher compared to current technologies without CCS[50]. The US-based FutureGen project expects to demonstrate early in the next decade an economically viable power generation from coal (using the IGCC technology) with 90% reduction of CO2 emissions (through CCS), with costs of electricity produced only 10% higher compared to current levels. Albeit having almost the same technological objective within a comparable timeframe, the EU-led Hypogen initiative is less ambitious in this respect. Energy forecast models run by the Commission in cooperation with the National Technical University of Athens using the PRIMES model show costs of electricity as low as €c 6/kWh (i.e. around current levels) for some realistically possible combinations of underlying variables; see Table 4 further below for details.

Furthermore, there may also be side-benefits from the use of CCS in power generation for example through the use of captured streams of CO2 for enhanced oil recovery. This can further reduce the net costs of particular power generation operations based on Sustainable Coal.

At the same time, it is clear that the relative price of gas and coal will also play a role in determining the costs of electricity produced from coal. Even more crucially, the relative price of gas and coal will determine the extent to which future investments in power generation capacity are likely to favour coal over gas, or vice versa. There is also clearly an interplay between the price of coal and gas, which influences the profitability of carbon capture and storage.

The following table illustrates the impact of relative coal/gas price on the choice of power generation technologies under a given level of carbon constraint. It follows the results of a modelling exercise undertaken with the use of standard Commission modelling tools[51]. It is important to note that the relative price of gas and coal (expressed as a ratio of prices for a unit of energy to be obtained from gas and coal respectively) was in 2004-5 below 3 while it is in late 2006 close to 3.7. It is difficult to predict the future path this ratio will take. It is equally difficult to predict the future carbon value expressed in the cost of CO2 allowances. Clearly, the extent of the overall requirement to reduce CO2 emissions plays a role as well as different targets for cuts in CO2 emissions may lead to different choices between gas and coal. For illustrative purposes two carbon values have been used to simulate two different degrees of carbon restriction: € 27/tCO2 and € 40/tCO2 simulating less or more ambitious climate policies.

50 See for example pp.12 and 14-15 of the 2004 World Coal Institute Publication « Clean Coal-Building a Future through Technology ».

51 Using the PRIMES model as employed for the European Commission by the National Technical University of Athens.

Table 4. Sensitivity of Carbon Dioxide Capture and Storage to the prices of gas and coal as well as CO2

		Technology choice			Wholesale price (€/MWh)		
Gas/ Coal	CO2 Value	2010	2020	2030	2010	2020	2030
3.7	40	Coal PF	**Coal PF - CCS post**	**Coal IGCC - CCS pre**	72	66	61
3.2	40	GTCC	**Coal PF - CCS post**	**Coal IGCC - CCS pre**	70	66	61
2.8	40	GTCC	GTCC	**Coal IGCC - CCS pre**	64	64	61
3.7	27	Coal PF	Coal PF	Coal PF	62	60	59
3.2	27	Coal PF	Coal PF	Coal PF	62	60	59
2.8	27	GTCC	GTCC	Coal PF	59	60	59

Source: Estimates by the National Technical University of Athens for the European Commission
Notes: Calculations are for a base load power plant (7320 hours/annum)
Ratio= Ratio of the price of natural gas to coal; Carbon value= €t/CO2;
Coal PF = Coal Pulverised; GTCC=Gas turbine Combined Cycle;
Coal PF – post = Coal Pulverised - post combustion;
Coal IGCC – pre = Integrated Gasification Combined Cycle - Carbon Capture and Storage - pre combustion;
Coal PF - CCS oxyfuel=Coal Pulverised with oxyfuel technology - Carbon Capture and Storage

The following conclusions can be drawn from this analysis:

– Depending on the price ratio between gas and coal, either coal or gas could be the preferred fuel in the period up to 2020. With higher gas prices, coal becomes more profitable than gas;

– Under current price ratios (3.7) and carbon values of €27/tCO2 pulverized coal (without CCS) would be the chosen technology in terms of generation costs. The generation costs with these prices are projected to be about €c6.0 per kWh which generally corresponds to facts observed in reality at present;

– With a higher carbon value (€40/tCO2) pulverized coal with CCS would be the preferred technology in 2020. However, by 2030, Integrated Gasification Combined Cycle (IGCC) with pre-combustion CCS would become more profitable;

– The increase in cost of electricity produced due to the deployment of carbon capture and storage in high-CO2 price scenarios is relatively minor. For instance, using post combustion carbon capture with pulverised coal could increase the wholesale generation costs by 10% in 2020 (from €c6.0 to €c6.6 per kWh). The surcharge declines to practically zero (from €c6.0 to €c6.1 per kWh %) in 2030 in case of switch to an IGCC-based power generation from coal.

In the follow-up to the Commission Communication on Sustainable Coal, a more detailed impact assessment will be carried out to gain detailed understanding of the expected cost of electricity produced from coal-fired power plants fitted with CCS at different points in time between now and 2050. These cost estimates will need to be presented in relation to the expected market price of electricity at those points in time and with indication of the necessary CO2 price needed to make sustainable technologies competitive.

5.4. Price of CO2 as one of key determinants for policy choice

The analysis and evaluation of the considered policy options shows that much of the desired effects of the spread of Sustainable Coal technologies can be possible via either of the two "active" policy options. However, it is obvious from the characteristics of the two options that Policy Option 1 leaves the penetration of Sustainable Coal Technologies largely to the existing market framework. The incentives for commercial application of Sustainable Coal technologies would thus have to come through a system which effectively puts a price on CO2 emission and thus prices the cost of emitting CO2 into the cost base of each power generation business. It is therefore very pertinent to ask what price levels of such "CO2 penalty" could be considered sufficient to stimulate the adoption of Sustainable Coal Technologies over traditional coal-fired power generation. It has been seen in the previous section that a CO2 price of €40/tCO2 seems to provide sufficient incentive for large-scale penetration of coal-fired power generation with CCS. The question is which CO2 price represents the break-even above which CCS becomes clearly a commercially viable option.

With currently available technology, the cost of CCS in new coal-based power plants is estimated to be high (see section 5.3) and therefore even a price of CO2 at the level of €40/tCO2 may not be sufficient to provide the necessary incentive for the commercialization of CCS. Commission calculations made in the course of the preparation of this Impact Assessment study seem to indicate that sustained CO2 prices of no less than €49/tCO2 may be necessary for providing a systematic incentive in favour of Sustainable Coal technologies[52].

Future levels of the costs of CCS are difficult to predict but are generally expected to exhibit a downward trend. Through further technological development in the coal conversion and CO2 capture processes, and with the scaling up of transport and storage operations, <u>it is envisaged to lower the total cost for CO2 capture and storage to the level of €20 per tonne of CO2</u>. Such a level of CCS cost is considered to be an affordable charge for low-carbon electricity generation in the post 2020 period.

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52 The calculations were made for two main conversion technologies (Pulverized Coal and IGCC) and used several simplified methodologies to calculate the minimum price of CO2 necessary to provide a systematic incentive in favour of CCS. **Method 1**: Equating (for a 1kW installation) the investment +efficiency penalty cost +the differential CO2 allowance cost +CO2 transportation and storage costs (as applicable) for production with and without CCS. **Method 2**: Equating (for 1 kW produced) the cost of investment to be recuperated + CO2 allowance+ CO2 transportation and storage costs (as applicable) for production with and without CCS. **Method 3**: Comparing the cost of electricity needed to produce 1 t of storable CO2 using production with and without CCS, factoring in the costs of CO2 transportation and storage as applicable. Depending on the technology and method used, the calculations yielded a range of break even prices between €15/tCO2 and €49/tCO2.

Recent studies on the subject undertaken by various academic institutions, including Princeton University (Sokolow) and Columbia University (Sachs, Lackner) indicate that carbon emission charges of about USS 100/tC are predicted to enable commercialization of CCS in power generation in the near future. This translates into ETS prices of about €c20/tCO2[53].

The ability of the future regulatory framework and of the prevailing market mechanism to deliver consistently a CO2 price above the threshold price identifying a break-even point of the commercial benefits of CCS will clearly be a key factor in determining whether Policy Option 1 or 2 would be the most appropriate for full-scale implementation of the concept of Sustainable Coal. The CO2 price will reflect the ambition to mitigate climate change. If the resultant price is adequate to deliver the climate change objective, but insufficient to stimulate investment in CCS and thereby ensure the continued presence of coal in the mix, further work will need to be done to assess what other policy incentive could be developed to deliver on the security of supply objective. A more detailed analysis will need to be carried out in order to increase the knowledge both of the interplay between the coal and gas prices and the level of carbon values necessary to stimulate commercial deployment of CCS.

5.5. Overall Impacts of Individual Policy Options

5.5.1. Option 0: No Policy Change

With no policy change the development of coal-fired power generation in the EU cannot be guaranteed. CCS technologies are not developed or implemented in the EU due to the absence of an incentive under the present format of the EU ETS, which does not consider stored CO2 as CO2 not emitted.

Without a clear policy indication from the EU that there is support for future (cleaner) power production from coal, investments in new coal-fired power plants are not made at a sufficient rate to replace existing capacity as it is retired from the system. Such power plants have an economic lifetime of around 40 years and so their investors, operators, and suppliers require sufficient signals that coal could be used economically over this time (e.g. even with stricter emissions limits). The combination of these features leads to an insufficient replacement rate. On average, only two thirds of the retiring capacity is replaced. Due to the removal of the most inefficient plants from the system, however, the overall utilisation of available capacity increases. But as electricity demand increases in the EU, the outcome is that coal contributes significantly less, proportionally, to EU electricity generation.

Reduced electricity generation and the underlying efficiency improvement result in a 44% reduction of CO2 emissions from coal-fired power plants, but do not enable the target of 90% reduction of emissions to be reached by 2050.

In this option, technological know-how in coal-fired power generation in the EU is likely to decline. Investments in demonstration and, subsequently, commercial CCS technologies will move outside the EU and be developed in areas that facilitate their

53 Source: World Coal Institute presentation «Coal and its Advantages in Today's Energy Markets» delivered at Coaltrans 2006 Conference, Athens, Greece, 22-25 October 2006.

use. The developers of these technologies will also be likely to undertake tandem research into innovative efficiency improvements outside the EU to offset the energy penalty of CCS. The EU will thus lose its potential for furthering its technological leadership in these areas.

The opportunities for technology transfers from the EU to third countries will be progressively reduced, and later vanish, as new clean coal and CCS technologies are more and more developed outside the EU.

There are no benefits with regard to the Lisbon strategy envisaged under No Policy Change.

The following table summarizes the above evaluations:

	Option 0		
	2015	2030	2050
Overall ability to meet combined objectives	0	-	--
Security of Supply Impacts (Coal use contributes substantially to supply diversity)	-	-	--
Environmental Impacts[54]	+	-	--
Economic Impacts (Influence on the cost of electricity)	-	-	--
Technological Impacts (EU leadership furthered)	-	--	--
Impacts on Lisbon Goals 1. (Positive impact on EU competitiveness, jobs, SMEs, regions)	-	-	-

Table 5. Qualitative analysis of Option 0 against policy objectives

5.5.2. *Option 1: Removal of barriers to Sustainable Coal Technologies*

The share of coal in the electricity mix is reduced in the first period and then increases until 2030 but remaining below the 2005 level. In the period 2030-2050, some increase of the share of coal is envisaged, in the range of 27.5% to 30%. Such a range is very close to meeting our energy security of supply criteria (30% of coal in the electricity mix as observed today).

The increase in total electricity generation in the EU is also a driving factor for long term evolution, and translates into a net increase for both:

– Coal- generated electricity, by 51 % between 2005 and 2050;

– Coal-fired capacity, by between 18% and 28% for the same period, above the full replacement rate.

Closure of least efficient plant in the period until 2015, steady replacement of old plants after 2015, sustained improvement of the energy efficiency of BAT (before applying the energy penalty of CCS) throughout the time period and partial penetration of CCS (starting in 2020) are the key factors to higher average efficiency

54 Specific CO2 emissions reduced by 20-30% by 2030 and 70-90 % by 2050.

and lower absolute and specific CO_2 emissions. Indeed, after 2030, highly efficient plants can be introduced, such as IGCC, with close to 60% energy efficiency (without CCS) and close to 50% energy efficiency (with CCS).

The above evaluations can be summarized in the following table:

	Option 1		
	2015	2030	2050
Overall ability to meet combined objectives	0	++	+
Security of Supply Impacts (Coal use contributes substantially to supply diversity)	0	+	+
Environmental Impacts[55]	+	++	-
Economic Impacts (Influence on the cost of electricity)	0	-	0
Technological Impacts (EU leadership furthered)	+	+	+
Impacts on Lisbon Goals (Positive impact on EU competitiveness, jobs, SMEs, regions)	0	++	+

Table 6. Qualitative analysis of Option 1against policy objectives

5.5.3. *Option 2: Introduction of Incentives for the Penetration of Sustainable Coal Technologies*

The share of coal in the electricity mix is maintained at 29% until 2030 and is later increased to the 30% to 35% range. This enables the strategic objective of energy security supply to be achieved.

The increase in total electricity generation in the EU translates into a net increase of both:

– Coal- generated electricity, by a range of 50 % to 75% between 2005 and 2050;

– Coal-fired capacity, by a range of 28% to 50%, well above the full replacement rate.

The average energy efficiency of the coal-base power plant fleet improves in the first period till 2015 (before CCS starts to impose its energy penalty), remains rather stable in the period 2015-2030 (efficiency gains equal CCS energy penalty) and

55 Specific CO_2 emissions reduced by 20-30% by 2030 and 70-90 % by 2050.

improves again in the last period (when a new generation of highly efficient IGCC power plants is introduced).

In this option, a sustained and systematic introduction of CCS after 2020, in a context of highly efficient coal conversion technologies, is the key factor to lower specific and total CO2 emissions in 2030 and to near zero emissions by 2050.

The increase in the net average efficiency compensates partly the higher investment and operational cost of coal-fired capacities fully equipped with and operating their CCS.

In this option, specific CO2 emissions are continuously reduced. Total CO2 emissions are slightly reduced in the first period until 2015 and strongly reduced later, reaching near zero emissions by 2050.

The above-stated evaluations can be summarized in the table below:

	Option 2		
	2015	2030	2050
Overall ability to meet combined objectives	+	+	++
Security of Supply Impacts (Coal use contributes substantially to supply diversity)	+	+	++
Environmental Impacts[56]	+	++	++
Economic Impacts (Influence on the cost of electricity)	+	-	0
Technological Impacts (EU leadership furthered)	+	++	++
Impacts on Lisbon Goals (Positive impact on EU competitiveness, jobs, SMEs, regions)	0	+	++

Table 7. Qualitative analysis of Option 2 against policy objectives

56 Specific CO2 emissions reduced by 20-30% by 2030 and 70-90 % by 2050.

6. SECTION 6: CONCLUSIONS

6.1. Overview of Key Effects of Individual Policy Options

6.1.1. Option 0: No policy Change

Key impacts:

– An important drop in CO_2 emissions from coal-fired power plants is observed without changing the current policy regimes (-44% by 2050, including the reduction owed to efficiency gains);

– This option cannot result in near-zero CO_2 emissions from coal-fired power plants by 2050;

– The missing electricity will need to be produced from other energy sources that may not be CO_2 neutral;

– This option appears to offer a significant disadvantage in terms of security of supply as it could result in coal-fired electricity generation contributing just half of its current share of EU electricity generation. Primarily this "missing electricity" is foreseen to be derived instead from natural gas, which offers less stable sources and less stable prices;

– Without policy change it is foreseen that the EU will not accrue any benefit from technology transfer or intellectual property as Sustainable Coal Technologies are more likely to be developed outside the EU.

Conclusions

– If the twin benefits of secure energy supplies and environmentally sustainable energy are to be secured in the EU, No Policy Change is not an option.

6.1.2. Option 1: Removal of Barriers to Sustainable Coal Technologies

Key Impacts

– If zero-emissions power generation from coal is voluntarily adopted by power generators once it is commercially available, as has been assumed in the assessment of Option 1, then coal-fired power generation will be enabled to deliver at least 27.5% of EU electricity until 2050 without significantly compromising either security of supply or climate change targets. It is likely to deliver a higher proportion of electricity if coal remains an economic fuel choice and can thus contribute to enhanced security of supply;

– Policy option 1 demonstrates through the above scenario that if the technologies are brought to maturity and competitiveness in the first 15 years then a strong reduction of CO_2 emissions to the atmosphere could be brought about. Reduction of the specific CO_2 emissions from coal-fired power generation, in the medium term (through upgrading and reconstruction using BAT each time) and in the longer term (with the partial implementation of CCS and the perspective of reaching much higher energy efficiencies in the coal-fired power plants) can be foreseen;

- However, even when reaching the technical limits of the improved energy efficiency, this option of partial implementation of CCS can not reach the objective of near zero CO2 emissions from coal-fired power plants;

- Improved efficiency in coal-fired power plants has the advantages of reducing the total coal intake and the total volume of CO2 emissions to be treated by CCS. Through sustained RD&D support, therefore, Policy Option 1 could yield benefits for the economics of electricity generation, especially when combined with CCS;

- It is considered that policy option 1 enhances the probability of Sustainable Coal Technologies reaching full commerciality by 2020 when compared to option 0. In this instance the EU could keep the political lead in climate change and acquire a lucrative technological advantage in the sustainable use of coal for electricity generation.

Conclusions

- Policy option 1 could deliver the general, specific and operational objectives. However, Policy Option 1 leaves the penetration of Sustainable Coal Technologies to the existing market framework. Its success is therefore entirely reliant upon the economics for clean coal and CCS being attractive to investors in the period after the technologies are demonstrated and are commercially available. It can be concluded that the benefits seen in the above quantitative assessment will be dependent on the comparative prices of competing fuel sources and the price of CO2 emissions permits under the ETS;

- Whilst policy option 1 would facilitate Sustainable Coal Technologies to meet the objectives of security of supply, deep CO2 emissions reductions and EU technological leadership, they would not be met unless the costs of CO2 and coal were favourable. If investors viewed reliance on the EU ETS carbon market to deliver sufficiently high CO2 emissions permit prices (€20-40/tCO2) as a high risk approach then investments in CCS for coal-fired generation would not occur on a large scale.

6.1.3. *Option 2: Pro-active Introduction of Incentives for the Penetration of Sustainable Coal Technologies*

Key Impacts

- If the actors in the EU electricity market can be provided with sufficient incentives to maintain the current proportion of coal-fired electricity in the EU electricity mix, whilst implementing the best available technologies in terms of specific CO2 emissions reduction, then all the policy objectives can be met;

- Policy Option 2 reduces the risk of policy failure by providing mechanisms that promote investment in Sustainable Coal Technologies even in situations where the EU ETS CO2 emissions permit price does not compensate for the cost of deploying CCS.

Conclusions

– The various measures considered in Policy Option 2 are all considered to have the potential to deliver greater penetration of Sustainable Coal Technologies in the EU;

– Measures such as state aids for R&D or a JTI/JU have the additional potential to accelerate the introduction of zero-emissions technologies as commercially viable. This is considered to offer a shortening of around 5 years depending on other parallel industrial activities in the EU and overseas. These measures are also considered to enhance the likelihood of profitable EU technological leadership in Sustainable Coal Technologies;

– Measures such as a JU/JTI have the additional potential to engage EU technologists in technology transfer projects overseas;

– The stakeholder community is divided over the use of strong regulatory measures to ensure high penetration rates. Coal industry and electricity industry representatives indicated during consultation that the strategic phase-out of non-zero emissions coal-fired power generation would be unwelcome and that penetration rates should be determined by the markets for electricity, fuels and CO2[57]. Environmental NGOs indicated during consultation that such regulatory measures would be favourable. It should therefore be concluded that their use would be dependent on sensitive justification of their necessity;

– Mandatory measures may have unintended effects on competitiveness of EU industry through additional costs of adopting state of the art technology.

6.2. Final Conclusions

Following careful assessment of anticipated impacts, through quantitative and qualitative means, this Impact Assessment concludes that a policy change is necessary to facilitate the introduction in the EU of Sustainable Coal Technologies on a sufficient scale to retain secure electricity supplies and environmental sustainability in the medium- and long-term.

Delivery of sustainable, secure and competitive technologies for electricity generation from coal is dependent on both energy efficiency gains in the coal-fired power generation sector, and the timely deployment of CO2 capture and storage. Policy changes should address both of these technology types.

Removal of the existing barriers to the deployment of Sustainable Coal Technologies is a conservative, and politically expedient, policy change that has the potential to deliver the policy objectives. However, it is dependent on a stable and high (compared to current levels) price of CO2 emissions permits in the EU ETS to enable CCS deployment rates that meet the objectives. These penetration rates are also reliant on natural gas prices that do not drop to low levels which would put coal at a disadvantage compared to gas in the short-, medium- or long-term.

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[57] Discussions were undertaken separately with industry and environmental representatives during July 2006.

In view of the above, policy option 1 will only deliver if the CO2 market is robust enough to incentive investment in low carbon technologies and CCS proves to be the most cost effective option. If there is too much uncertainty around Option 1 to ensure continued unhindered presence of coal in the mix,policy option 2 offers a range of measures that could be adopted to secure the objectives. In elaborating policy option 2 into a more concrete policy initiative, individual measures identified for this option would have to be subjected to further impact assessment to gauge the most effective selection, and combination, of such measures. This can be undertaken after the Communication for which this Impact Assessment document is intended has been published and reactions received.

7. SECTION 7: HOW COULD FUTURE MONITORING AND EVALUATION BE ORGANISED?

Following the Commission Communication on Sustainable Power Generation from Fossil Fuels, an extended impact assessment will be undertaken in 2007 in order to further analyze and evaluate the different policy tools and measures identified in this document and evoked in the Commission Communication. This impact assessment will provide in-depth evaluation of the issues addressed in this document and of the conditions and modalities of using the identified instruments for supporting commercialisation of sustainable coal technologies, including the CCS element.

A Commission Task Force consisting of the services most concerned and with the participation of other relevant EU institutions, including financial ones (namely EIB and EBRD) should support this work to come to practical conclusions on how to implement large scale demonstration plants focusing on Sustainable Coal technological solutions. The feasibility of future monitoring of Sustainable Coal development and its evaluation will be amongst the issues followed by the Task Force.

ANNEXES

ANNEX I: OVERVIEW OF CLEAN COAL AND CO2 CAPTURE AND STORAGE TECHNOLOGIES INSIDE AND OUTSIDE THE EU

1.1. Technologies for enhanced power plant efficiency

Further optimization of plant efficiency is a highly important precondition for achieving commercial viability when adding CO_2 capture installation to a power plant system. Governed by basic thermodynamic laws, the theoretically achievable maximum efficiency of thermal power generation is limited by a simple relation based only on the lowest and highest temperature of the cycle. This equation is well known as Carnot's law.

Currently, two different technological routes for coal-based power generation exist, the traditional steam cycle and the more recently developed Integrated Gasification Combined Cycle (IGCC) based on converting coal to a hydrogen-rich synthesis gas.

Whilst the steam cycle route based on pulverized fuel combustion is preferred for the advantage of load flexibility, the more complex IGCC route can better cope with pollutants and has the potential of a higher achievable overall efficiency.

1.1.1. Ultra super-critical steam cycle (700 °C and higher)

Efficiency primarily depends on the characteristics of the thermodynamic steam cycle, which has undergone considerable changes in the past decades. Steam pressure and temperature have steadily increased, following improved characteristics of available materials. Further progress is still achievable by taking advantage of new materials to accommodate even higher steam conditions and thus enable cycle characteristics to be further improved.

Conventional super-critical pulverized fuel boilers, based on hard coal, reach efficiency level of more than 46%, depending on the location of the plant (located at sea-level and by using sea water for cooling, around 48% can be reached). A similar efficiency level is under way for lignite-fired plants. By using best available techniques (BAT), such as the BoA[58] technology, a rated efficiency of more than 43% will be achieved. The next development phase will integrate lignite pre-drying which is expected to enhance efficiency by four percentage points.

Based on Carnot's law, by further increasing steam pressure and temperature towards ultra super-critical conditions, i. e. ca. 300 bar and 700 °C, overall plant efficiency can be enhanced beyond 53%.

1.1.2. Enhancing the IGCC route

The Integrated Gasification Combined Cycle (IGCC) technology is based on the gasification of coal. By means of oxygen (or air) a synthetic fuel gas is produced which consists essentially of hydrogen and carbon monoxide. This gas is treated and

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58 Optimised lignite installation.

purified, thus yielding a high-quality fuel gas. Subsequently, this gas is used in a conventional combined cycle system consisting of gas and steam turbines. Given the fact that through the IGCC process a hydrogen-rich gas is produced, this route features the potential of hydrogen production from a variety of solid fuels[59].

Overall energy efficiency currently stands at around 45% and has the potential of reaching 54% and more in the foreseeable future, i.e. by 2020.

The current main challenges for IGCC technology are generally considered to be the need for improved plant reliability as well as availability, improved gasification technology (oxygen blown gasifiers appear to have advantages over air blown gasifiers since the latter ones have difficulties in removing nitrogen from hydrogen)[60], lower investment costs, further improvements in environmental performance and the introduction of CO_2 capture installations.

1.2. CO_2 Capture & Storage

1.2.1. What is CO_2 capture?

CO_2 capture applies in electricity production mainly to large power plants fired with hard coal, lignite, natural gas and oil[61]. It also applies to large, single point emission processes such as refineries, cement plants, chemical plants and steel mills that can use the same or similar technology - as well as transport infrastructure – thus potentially increasing the efficiency of the entire CCS system. It can even apply to biomass combustion, paving the way for negative emissions (as biomass actually consumes CO_2 when it is grown).

The purpose of CO_2 capture (when efficiently integrated into a steam or gas & steam power plant) is to produce a concentrated stream that can be easily transported to a CO_2 storage site – a deep underground geological formation or to an industrial application. There are three main technology options under development:

– ***Post-combustion*** systems separate CO_2 from the flue gases produced by combustion of a primary fuel (coal, natural gas, oil or biomass) in air. ***Can be retrofitted to existing power plants, as well as included in new builds;***

– ***Pre-combustion*** systems process the primary fuel (natural gas or synthetic gas from coal gasification) in a shift reaction to produce separate streams of CO_2 and hydrogen. ***The hydrogen can then be used for either electricity or as a fuel - assisting the transition to a hydrogen economy;***

– ***Oxy-fuel combustion*** systems use oxygen instead of air for combustion, producing a flue gas that is mainly H_2O and CO_2, which can be readily captured. ***Still under development.***

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59 This option is currently pursued by the HYPOGEN initiative.

60 See Report : Near-Term IGCC and Steam Reforming Processes for the Hydrogen Economy : The Development Issues, JRC, July 2006.

61 Although several CO2 capture technology developments for coal also apply to oil, it is not considered an economically preferred fuel for future power generation (except for niche application).

In principle, all can be applied using commercially available equipment, but with varying degrees of system modification. Indeed, a significant scale-up will be required - 20-50 times - no power plant in the world today being equipped with capture technology on such a scale. Minimising the energy requirements for capture, thus reducing the efficiency penalty on the overall energy conversion processes will also continue to be high priorities in order to minimise overall environmental impacts and cost.

R&D therefore focuses on reducing the costs of power generation with CO_2 capture by:

– Further developing CO_2 capture techniques;

– reducing the energy consumption ("efficiency penalty") of CO_2 treatment;

– reducing the energy consumption of oxygen production (in oxy-fuel combustion).

It is considered that, with further intensive development, optimisation and experience, the three main technology options are capable of reaching CO_2 avoidance costs of €15 – €25/t CO_2 (for coal). This could lead to zero emissions power from coal at the cost of €45 – €55/MWh (calculated with current fuel prices)[62].

However, when evaluating different CO_2 capture technologies and comparing them, it is also important to consider the following technical key parameters:

– Thermal efficiency;

– Flexibility of plant fuel;

– Exhaust gas composition;

– Efficiency of CO_2 removal;

– Size of plant, including cost and availability of area required ("footprint");

– Integration of CO_2 capture technologies with power plant;

– Flexibility and load-following capability of power plant;

– Possibility of producing other energy carriers.

[62] Sources:ZEP technology Platform : Strategic Research Agenda, September 2006.

1.2.2. CO2 Capture options

1.2.2.1. Post-combustion technology

It should be noted that post-combustion CO_2 capture technologies, based on chemical absorption processes, are already proven and commercially available[63]. Indeed, because of its long track record, it is the current capture technology of choice, especially as it can be retrofitted to existing fossil fuelled power plants.

However, a significant scale-up will be required – up to 20−50 times – which would lead to prohibitively high CO_2 capture costs. Since economically viable capture is not possible with existing solvents, new ones must therefore be developed which significantly lower energy consumption.

Sulphur oxide (SO_2), nitrous oxides (NO_x) and particulates must also be reduced, as they reduce the effectiveness of the chemical absorber. Finally, there is real potential for process optimisation - new absorbers, contactors and processes are currently being researched in order to achieve the cheapest capture costs possible.

1.2.2.2. Pre-combustion technology

The idea behind pre-combustion is to remove the carbon from natural gas, oil or coal prior to combustion, leaving only hydrogen to burn. This can then be used as fuel in power plants or fuel cells[64]. Indeed, the gasification of solid fuels has been a well-known and industrially available technology for many years, simply not widely utilised for power purposes in an Integrated Gasification Combined Cycle process (IGCC).

While large-scale demonstration plants exist, they have obviously not yet incorporated all the lessons learnt during their operation. A highly efficient hydrogen turbine is also still not yet available.. As with post-combustion technology, there is real potential for up-scaling and process optimisation.

Maturity of pre-combustion capture technology is fairly advanced for several components. However, it has not been utilised for power purposes in the IGCC. The key issue is therefore to improve overall optimisation by developing the turbo machinery, integrating processes and improving components. Finally, the gasification process, either based on air or oxygen, needs further improvements.

1.2.2.3. Oxy-fuel combustion technology

In oxy-fuel combustion, nitrogen is removed from the air, usually using an air separation unit. The fuel is then combusted with oxygen in an atmosphere of CO_2, which is re-circulated to control the combustion temperature. This gives a flue gas

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63 A detailed description of the current status for CO2 capture technology can be found in a report published by the Intergovernmental Panel on Climate Change (IPCC), « Carbon Dioxide Capture and Storage », Cambridge University Press, Cambridge, United Kingdom, 2005.

64 Different types of fuel cells may require different hydrogen purity levels, which may impact the flue gas cleaning.

consisting mainly of CO_2 and water vapour, which can be condensed to give a highly concentrated CO_2 stream for transport and storage.

Firing with pure oxygen generates higher gas temperatures than existing power plant equipments can handle and no commercial oxy-fuel combustors have yet been built. It is certainly possible to use such high temperatures for power generation, but steam and gas turbine systems must be perfected to handle them.

With respect to the maturity of oxy-fuel combustion technology it can be stated that all the major components applied to boilers exist on an industrial scale, but the process is currently only demonstrated on laboratory-sized equipment. However, all our experience shows that there is no significant difference from air combustion. The desulphurisation is also conventional, but with CO_2 instead of nitrogen as the main gas component. As with the other technologies, process integration will be a major task.

1.2.3. Enhancing CO_2 transportation

The transportation of CO2 is already well understood – it has been shipped regionally in small liquid quantities for the last 15 years and a 4,000km onshore network has been in operation in the US for the past 30 years. In Europe, at the Snøhvit LNG processing facility in the Norwegian Sea, a pipeline to an offshore CO2 storage site is due to start operating in 2007 comprising a length of more than 160 km and the capacity of ca. 1 million tonnes/y.

There is also extensive knowledge of the liquid propane gas (LPG) and liquid natural gas (LNG) industries that can be drawn upon. Indeed, experience in hydrocarbon pipeline transportation can be transferred directly to CO2 transport. However, while there are very few major research gaps regarding CO2 transportation, it can certainly be enhanced to Europe's competitive advantage.

What are the options? In general, pipelines are used for large volumes over shorter distances, while ships can be used for smaller volumes over long distances; trains and trucks are rarely used. Nevertheless, the best transport system will vary according to individual CCS infrastructure projects, according to:

– CO2 volume;

– Distance between source and storage location;

– Geography and geology of the route taken;

– Costs.

Pipeline options include CO2 in gas and supercritical phase. Most of the CO2 pipelines in the world today are high pressure, supercritical phase lines, being the most economic method of moving CO2 over long distances. CO2 transport by ship will be in liquid form.

With many potential storage sites both onshore and offshore in Europe, new studies (together with ongoing studies, such as the EU GeoCapacity project) are therefore required to determine the best infrastructure routing, aimed at minimising costs and the environmental footprint. (Experience from the natural gas industry could be a good starting point.)

Europe's dense population means that CO2 transport routes onshore must be carefully planned, with urban areas avoided if possible, as for hydrocarbon and chemical pipelines. Extensive use of pipeline modelling and gas dispersion modelling will therefore be essential. Special care must also be taken with offshore pipelines to ensure that they are laid in sufficiently stable areas (a regulatory requirement for all offshore pipelines in Europe today.)

1.2.4. *Options for CO2 geological storage*

Experts already agree[65] that storing CO2 underground should pose no health, safety or environmental hazard - either over the short- or long-term. Indeed, CO2 is essentially benign – it will neither burn nor explode and is even normally part of the air we breathe.

Nevertheless, public perception may differ and R&D aims not only at filling gaps in our knowledge, but proving unequivocally that CO2 geological storage is both safe and desirable.

There is certainly no shortage of suitable storage options which would be sufficient for storing CO2 produced in power generation for several centuries. A number of the suitable storage options are in the million to billion tonnes range. How much of that potential can actually be utilised will be closely linked to the research and demonstration activities carried out over the next few years.

For example, the Utsira geological formation in the Norwegian part of the North Sea which has been used by Statoil since 1996 to store around 1 million tonnes/y CO2 removed from gas production, stands at over 400 km by 50-100 km and stretches over 26,000 km². It is capable of storing up to 600 billion tonnes of CO2[66]. It is estimated that by 2050, it could be used for the removal of 2 billion tonnes of CO2 each year from the atmosphere[67] (assuming CCS technology is established by 2015-20). To put this into perspective, this means that from 2050, utilising this formation alone, the volume of CO2 from EU sources over 300 years (at current emissions levels) could be stored there. (This time horizon twice surpasses the expected lifetime of available global coal reserves, believed to be around 150 years!)

CO2 can be stored using a variety of different mechanisms (single free phase, dissolved in water, absorbed on surfaces, trapped by relative permeability and fixed in minerals), with several options for underground storage. Storage in the deep oceans is not considered an option for Europe. International work on defining methods and standards for geological storage capacity assessments has already begun and as a leading player in CCS, Europe has a key role to play.

The relative order-of-magnitude potential of the various storage methods may be expressed, very simply, as follows:

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65 See IEA Greenhouse gas website : http://www.ieagreen.org.uk and Sleipner CO_2 project reports.
66 Dtto.
67 In accordance with the calculated CO_2 capture potential presented in the ZEP Vision Paper, May 2006.

1000 Saline aquifer storage

100 Oil/gas field use and storage

10 Deep unmineable coal bed use and storage

1 Mineral sequestration.

Deep saline formations (or saline aquifers) have the largest storage potential globally, but are the least well explored and researched as, up till now, they have not had any economic potential. A more comprehensive dataset of their geological characteristic, therefore, is needed through considerable research and larger-scale injection projects.

The GESTCO and GeoCapacity projects (under FP5 and FP6) have already begun the task of identifying saline formations that are accessible to large CO2 emissions sources, both on land and close to the shore.

Although it is widely believed regional saline formations hold the most promise, there is a need to demonstrate storage in a variety of types and settings in order to realise the full potential of this type of geological formation. It means exploring as many countries as possible, especially those with few hydrocarbon deposits and less knowledge of deep geology, in order to include them in overall evaluations.

Using CO2 for **Enhanced Oil Recovery (EOR)** and **Natural Gas Storage (NGS)** are the most attractive options for early deployment: not only is the geology well understood and existing infrastructure recyclable, there is even the opportunity to offset costs from the additional oil and gas production.

Indeed, when used in this way, CCS could contribute to improved energy security for Europe through increasing oil and gas production rates, as well as the overall recovery of reserves. (Typically, CO2 can increase oil recovery by around 10%). EOR may also be combined with the storage of even more CO2 after the commercial life of the fields ends. The best opportunities for EOR in Europe are in the North Sea and the use of anthropogenic CO2 for this purpose would constitute a normal hydrocarbon operation[68].

[68] See JRC report on CO2 injection for enhanced hydrocarbon production, 2005.

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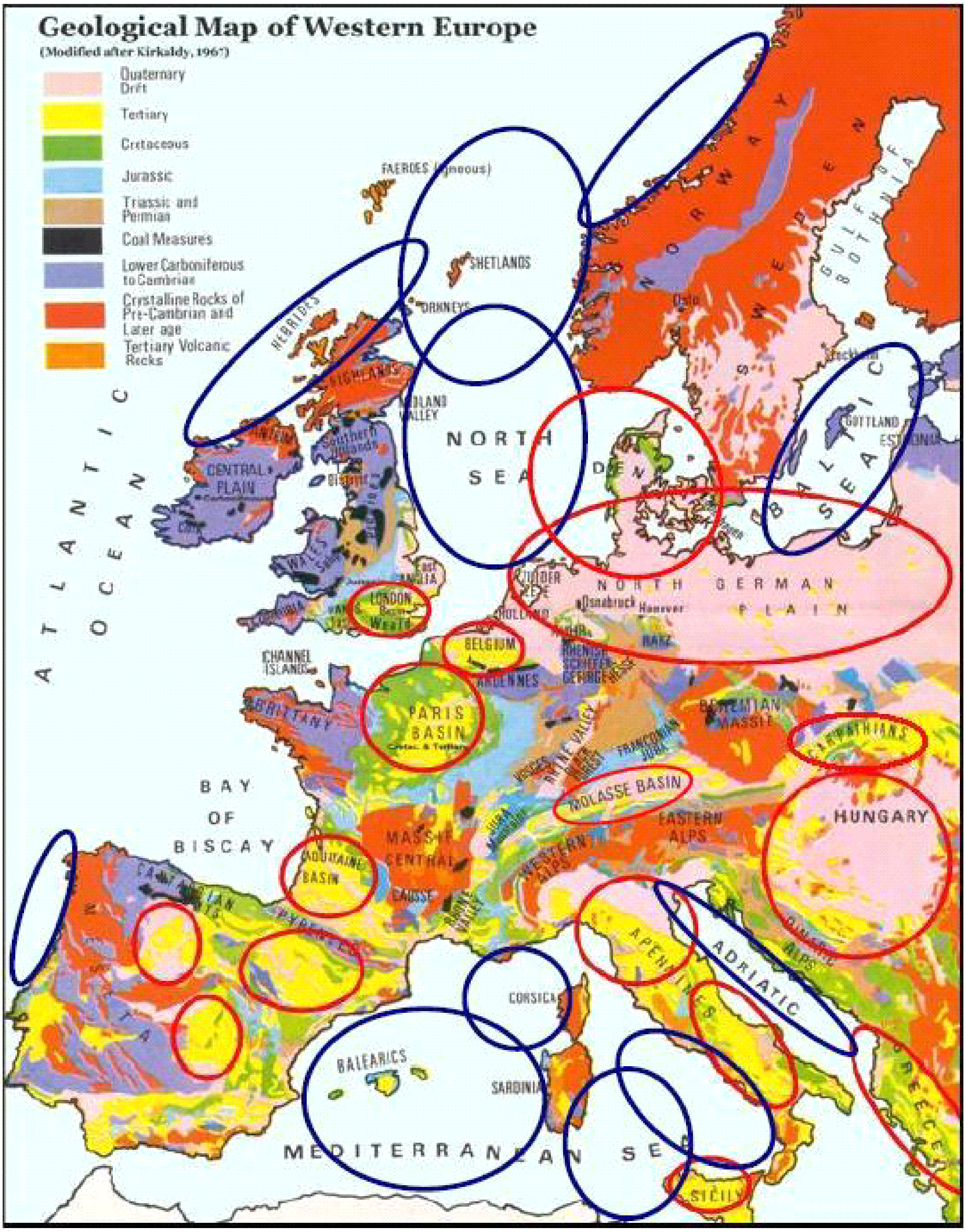

Fig. 1 shows major on- and offshore sedimentary basins in Europe which are possible storage sites. Cost analyses must be performed to identify the most cost-effective

Although at the experimental stages, ***Enhanced Gas Recovery*** (EGR) is also a promising technology for CCS that would further increase European fossil fuel resources. ***Depleted oil and gas fields***, too, are attractive because the geology is well understood and the existing infrastructure recyclable.

Enhanced Coal Bed Methane (ECBM) has similar potential and the geological aspects of the main European coal basins are, in most cases, quite well-known. Indeed, many Member States also have methane-bearing coal basins on which operations could be carried out. The main disadvantages are a) lower capacities compared to saline formations b) most European coal basins are placed in fractured areas, with risks of leakage and a higher complexity of field studies.

Other options, although limited, include ***deep unmineable coal beds***, which may become quite important in some coal provinces. ***Mineral sequestration***, which consists of trapping CO_2 by reacting with basic rock material, is still at an exploratory stage.

2. OVERVIEW ON REGIONAL DEVELOPMENTS

Currently, more than 110 research, development and demonstration projects on CO2 capture and storage are being conducted worldwide. In geographic terms, the focus is in Europe, Northern America and Japan. More details on individual projects are available via the data base of IEA Greenhouse Gas R & D Programme, which can be accessed through http://www.co2captureandstorage.info/search.php4.

2.1. Europe

According to a recent study, almost 70,000MW of coal based generation capacity (56,400MW hard coal and 13,500MW lignite) will need to be replaced in EU-25 in the period 2006 to 2015 calculated on an average operational life span of 40 years. Furthermore, in the period 2016 to 2025, total replacement capacity is estimated at 40,000MW. These projections put the current developments in Europe regarding advancement of CCT and CCS in useful perspective.

Current research activities in the IGCC route are also beneficial to the long-term goal of hydrogen production from fossil fuels which is supported by the European Commission in the margins of the HYPOGEN Initiative. Phase I (Measures) of this programme is being carried through the DYNAMIS project co-funded under FP6.

2.1.1. France

In 2005, the French government has created new R&D agencies and has increased its support to CCS. In that year, € 8 million were assigned by the new National Research Agency (ANR) to CCS programmes. The same amount is expected in 2006. At last, the new Agency for Industrial Innovation (AII) will help the funding of industrial CCS projects.

2.1.2. Germany

COORETEC, Germany's R & D concept for low-emission fossil-fuel power plants

Facing the challenge of replacing some 40,000 megawatts in electricity generation capacity during the next decade, the German Federal Ministry of Economics and

Labour in 2002 initiated a kind of 'brainstorming exercise' known as COORETEC[69]. Published in July 2003, this concept on highly efficient, low-emission fossil fuel power plants is intended to create the basis for new and replacement installations in electricity generation sector after the year 2010.

Based on requirements formulated by the experts from industry, academia and trade associations, a three-staged R & D concept was developed. In the *short to medium term*, efforts should be directed to the rigorous further development of process control for fossil fuelled plants, an improvement in power plant components and the application of new high-temperature materials with the result of increasing efficiency to 50 % and more for coal-fired power plants, and to 60 % and above for NGCC[70]plants. I this way, about 30 % of CO_2 emissions could be avoided in comparison to the technology currently installed in Germany. Above all, measures for improved efficiency should therefore be pursued which would benefit all power plant options, i.e. conforming to a "no regret strategy". In this context, attention should be concentrated on essential R & D priority projects.

In parallel, additional R & D activities should be encouraged for novel power plants concepts, by means of which in the medium to long term further improvements in efficiency and CO_2 reductions will be possible. Various processes for CO_2 capture and storage shall be discussed and evaluated[71]. The objective of these longer-term R & D activities should be the systematic development of complete process chains up to reliable CO_2 storage. This also requires an intensification of R & D activities, which should be increasingly shifted to universities and research institutions with simultaneous support for the related training capacities.

It was concluded by the expert groups, that the situation in Germany requires a thoroughly new technology offensive which can only be realized with the aid of a balanced national and European research programme. A comparison with the USA and Japan showed that there are already ongoing extensive activities for the development of highly efficient fossil fuel power stations with low or zero CO_2 emissions, supported to a considerable degree by government funded programmes.

As a complement to such a new R & D programme, it was agreed that public acceptance of a sustainable energy supply must be improved. This includes political support for the economic and energy situation as well as the utilization of all resources in the energy mix.

Funding for the COORETEC R & D concept is supplied by the Federal Ministry for Economic Affairs and Technology, BMWI, and it is reported to comprise about EUR 15 million/y.

2.1.3. Spain

The Spanish Government is supporting the development of a test facility for advanced technologies such as CO_2 capture and storage in coal-based power

[69] Acronym for **CO_2 Re**duction **Tec**hnology.

[70] Natural Gas Combined Circle.

[71] In fact, geological storage only by means of injections into (depleted) oil and gas reservoirs, deepsaline aquifers and unmineable coal seams.

generation at the El Bierzo Centre of CIEMAT[72]. The Centre will provide a focal point for the activities in Spain by addressing clean coal and related technologies, bringing together industry, researchers and other stakeholders.

Oxyfuel combustion as the focus of the new test facility in conjunction with CO_2 separation alternatives will target one of the critical areas for cost effective capture of CO_2 and so will provide a national facility capable of dealing with a variety of coals/bio-fuels in this respect.

The planned experimental testing capabilities at 3-5 MW (thermal) are meant to act as an intermediary step to capture demonstration at industrial scale, but they should also address the issue of providing technologies for retrofitting applications and for appropriating the CO_2 'capture ready' approach.

The centre will cover R&D activities on CO_2 geological storage by identifying potential storage areas in Spain. The total investment of this centre that is supported directly by the Government will be around 70 million € from 2006 to 2009.

This initiative is now part of a "Strategic Project" supported by the Ministry of Education and Science under the Energy National Programme, covering most part of the Spanish activities for CO_2 abatement at the power generation sector, CO_2 storage as well as public acceptance of these processes. This project is divided into five subprojects with a total budget of around 120 million €; the five subprojects are:

– CO2 capture: pre-combustion technologies at Puertollano IGCC power plant;

– CO2 capture: post-combustion technologies at PF Teruel power station;

– CO2 capture: oxyfuel technologies at Ciemat's El Bierzo Centre ;

– CO2 geological storage: Ciemat's El Bierzo Centre;

– Communication and public acceptance of CO2 storage projects.

This project will be supported by the Ministry of Education and Science and the regional administrations, in accordance with the annual budget shift among the different priority lines of the Energy National Programme.

2.14. United Kingdom

The objective of the CAT Strategy on Carbon Abatement Technologies introduced in 2005 is: "*To ensure the UK takes a leading role in the development and commercialisation of Carbon Abatement Technologies (CATs), that can make a significant and affordable reduction in CO2 emissions from fossil fuel use.*"

The Strategy has defined ten areas for action:

– Support for research, development and demonstration of CATs;

[72] Centro de Investigaciones Energéticas, Medioambientales y Technologicas.

- Support for the demonstration of CO_2 capture-ready plant;
- Support for the demonstration of CO_2 storage;
- Facilitation of international collaboration in UK based CAT development and demonstration projects;
- Facilitation of and support for UK collaboration in CAT development and demonstration projects based in other countries;
- Within the Climate Change Programme Review (CCPR), examine possible measures to encourage the initial commercial deployment of CCS technologies in the UK;
- Facilitation of the acquisition and transfer of knowledge about CATs and know-how stemming from their innovation both in the UK and abroad to businesses and other organisations involved with their commercialisation;
- Leading the preparation of the national and international regulatory frameworks and market mechanisms needed to support CATs;
- Increasing public awareness and stimulating an informed debate on the role of CATs in mitigating climate change;
- Development and maintenance of a route map for the development of CATs in the UK.

Under the 2004 Spending Round the Cleaner Fossil Fuels Programme was allocated £20M in total for the period 2005/06 to 2007/08. This funds industry-led R&D under the Technology Programme, together with policy development on issues around sustainable fossil fuel energy technologies. It is considered from past experience that at this stage this budget should be sufficient to support laboratory-based R&D. This budget is also intended to assist UK collaboration in international R&D Programmes including the Memoranda of Understanding with the USA and China.

The Strategy recognises that a point is reached where demonstrations up to full-scale may be necessary. There are a number of areas of potential demonstration that extend beyond low to zero CO_2 emission technologies to the related areas of hydrogen production and fuel cells. Therefore the British government will provide a funding package of £40M over four years commencing in 2006/07 for demonstrations across CATs, hydrogen and fuel cells. Of the total around £25M is expected to be dedicated to CATs with the balance split approximately 50:50 between hydrogen and fuel cells.

2.2. Northern America

2.2.1. Canada

Canadian Clean Power Coalition (CCPC)

The Canadian Clean Power Coalition is a public-private partnership that aims to demonstrate CO_2 removal from an existing coal-fired power plant by 2007 and from a new power plant by 2010. CCPC comprises seven founding member companies representing over 90% of Canada’s coal-fired electricity generation capacity, together with the Electric Power Research Institute, based in the USA.

Phase I funding of C$5 million has allowed initial feasibility studies to proceed. The cost of the two plants will be around C$1 billion for CCPC over the next decade.

2.2.2. USA

FutureGen Programme

The US$1 billion FutureGen initiative was announced in 2003 to demonstrate a near-zero emission 275MWe coal-fuelled IGCC plus hydrogen production plant, incorporating CO2 capture together with geological storage. The project is intended to create the world’s first zero-emissions fossil fuel plant which, when becoming operational in 2012, could be the cleanest fossil fuel-fired power plant in the world. Cooperation between government, industry and international partners is a key element of the FutureGen project. An industry-based consortium of companies that includes also China Huaneng Group, one of China's largest energy companies, is expected to contribute around US$250 million, while the remainder shall be provided by public sources.

The Government of India signed a Framework Protocol agreement on April 3, 2006 to become the first foreign government to join the FutureGen project with a financial commitment of $10 million. On June 26, 2006, South Korea signed an agreement with the United States to join the initiative as well. In October 2006 China (through MoST, the Ministry of Science & Technology of the People’s Republic of China) agreed to participate in the programme with an financial commitment similar to India.

ZECA – USA/Canada

ZECA Corporation is the successor to The Zero Emission Coal Alliance, which was founded in 1999 by The Coal Association of Canada, Los Alamos National Laboratory and 16 other organisations. The ZECA Corporation is researching the development of the hydro-gasification process, whilst also cooperating with researchers who are looking into mineral carbonation as a route to CO2 disposal.

2.3. Asia

2.3.1. China

The Chinese government also announced to build a 400 MW zero emissions power plant by 2020 with a plant efficiency of up to 55%-60%. With a budget of about $1 billion, a new company, known as Green Coal Power Co., will develop the IGCC technology to produce hydrogen, too, and to store the carbon dioxide separated from syngas produced. The company hopes to build the GREENGEN power plant within 15 years by using a 400MW hydrogen turbine, generating units and fuel cells. The company is set up by China Huaneng Group, the country's leading power generation company which joined the industry alliance associated to the US FutureGen programme in 2005.

The European Commission (EC) and MoST have signed together a Memorandum of Understanding (MoU) on co-operation on *Near-Zero Emissions Power Generation Technology through Carbon Dioxide Capture and Storage (NZEC*) which aims to reduce significantly the climate change impact from coal-fired electricity generation.

The NZEC initiative aims to demonstrate near-zero emissions coal fired power generation with carbon dioxide capture and storage technology in China by 2020. The NZEC proposal was announced at the EU-China Summit in September 2005 as part of the EU-China Partnership on Climate Change and developed through further agreements signed between MoST and the UK Government (December 2005) and also with the European Commission (February 2006).

The NZEC MoU addresses the first phase of the co-operation consisting of exploring the feasibility of, and options for, near-zero emissions coal technology in China through carbon dioxide capture and storage in this country.

2.3.2. Japan

As recently as May 2006, Japan has endorsed a new *National Energy Strategy* which aims at making this economy "the world's most advanced fossil fuel-using country, through means such as the development and utilization of methane hydrates and clean utilization of coal".

In this context, the New Energy and Industrial Technology Development Organization (NEDO) is undertaking a major project to develop coal gasification for use in fuel cells. The project is known as EAGLE (coal Energy Application for Gas, Liquid and Electricity). A pilot plant has been constructed, with a coal processing capacity of 150 tonnes/day, which aims to develop a coal gasifier suitable for IGFC.

The project, which started in 1998 and is due to run until 2006, is part of a broader initiative involving the incorporation of fuel cells within an integrated gasification combined cycle. The integrated coal gasification fuel cell combined cycle system should achieve efficiencies of at least 53-55%. Deployment of IGCC-fuel cells in Japan is expected to begin in 2010, with the introduction of 50MWe distributed power generation installations, followed by the introduction of a 600MWe system for utility use by 2020.

Furthermore, coal gasification technology is also advanced by the BRIAN-C Programme (Basic Research Associate for Innovated Coal Utilisation Programme), whilst the HYPER Coal Production Project aims at producing ash-less coal for several conversion purposes.

2.4. Australia

COAL21 is a major initiative of the Australian Coal Association, involving key stakeholders across industry, government and researchers, working to develop and initiate a strategy to move Australia along the road towards near-zero emission electricity production from coal. The programme started in early 2003 with an extensive, 12 month consultative process. This culminated in the release in early 2004 of a zero-emissions coal technology roadmap and action plan for Australia focusing on the trial and demonstration of key technologies. The second phase of the project will include the development of an implementation strategy to realise the action plan.

The Australian coal industry has committed €300 million for COAL21.

2.5. List of CCS projects in Europe

Proposed full-scale (~100 MWel and above) CCS projects in the electricity sector:

Company/Project Name	**Fuel**	**Plant output/cost**	**Technology**	**Start**
BP/Scottish & Southern Energy/ Peterhead, Scotland	Natural gas	350MW, ($600m)	Autothermal reformer + pre-com-bustion, storage in oilfield + EOR	2010
E.ON UK/ Killingholme, Lincolnshire coast, UK	Coal (+petcoke?)	450MW (£1bn)	IGCC + shif t+ pre-combustion?	2011
Scottish & Southern Energy/ Ferrybridge, UK	Coal	500MW	PC (supercritical retrofit) + post-combustion capture	2011
Statoil/Karstø, Norway	Natural gas	400MW	NGCC + post-combustion amine, storage in the oilfield – EOR	2009
Nuon/ Eemshaven, The Netherlands	Coal/biomass/natural gas	1200MW	IGCC with option to capture	2011
Powerfuel/ Hatfield Colliery, UK	Coal	~900MW	IGCC + shift + pre-combustion	2010
Progressive Energy/ Teeside, UK	Coal (petcoke)	800MW (+H2 to grid) $1.5bn	IGCC + shift + pre-combustion	2009
Siemens/Spreetal, Germany	Coal	1000MW €1.7bn	IGCC + shift + precombustion	2011
Statoil/Shell, Draugen, Norway	Natural gas	860MW	NGCC + post-combustion amine, storage in the oilfield – EOR	2011
Vattenfall/Schwarze Pumpe, Germany	Lignite	300MW	Oxyfuel+post-combustion	2012
RWE, Germany	Coal	450MW €1bn	IGCC + shift + precombustion, storage in saline reservoir	2014
RWE, Tilbury, UK	Coal	1000MW £800m	PC (supercriticial retrofit) + post-combustion (may be capture ready)	2016

Major commercial and R&D storage projects (besides projects listed above)

Project name and location	**Source of CO_2**	**Type of geological formation**	**CO_2 stored**
Sleipner (Norwegian North Sea)	Stripped from natural gas	Saline reservoir	1Mt/year since 1996
In Salah (Algeria)	Stripped from natural gas	Gas/saline reservoir	1.2Mt/year since 2004
K12b (Netherlands)	Stripped from natural gas	Gas field - EGR	Over 0.1Mt/year since 2004
Snohvit (Norwegian North Sea)	Stripped from natural gas	Gas/saline reservoir	0.75Mt/year, starting from 2007
Ketzin, Germany		Saline reservoir	60Kt total, starting 2006

For comparison, a 500 MW coal-fired power station emits around 3 Mt of CO2 per year.

ANNEX II : CHOICE OF POLICY FOCUS: BACKGROUND AND CALCULATIONS FOR THE ASSESSMENT OF THE THREE GENERIC TECHNOLOGY ROUTES

The impacts of each route have been assessed on the basis of their likely outcomes with respect to a series of underlying assumptions. To recapitulate, the three generic routes considered are:

A. Seeking to achieve CO2 emissions reductions through the implementation of energy efficiency measures in coal-fired power plants, without using CCS;

B. Seeking to achieve the reduction of CO2 emissions through the implementation of CCS measures in coal-fired power plants, without putting further emphasis on the improvement of energy efficiency in these power plants;

C. Seeking to achieve the reduction of CO2 emissions through both the implementation of energy efficiency measures and the use of CCS in coal-fired power plants.

The following are the assumptions that are common to each technology route and represent a set of model conditions:

- The total electricity generated in the EU25 from all sources (in TWh) is taken from the TRENDS baseline scenario. In this scenario, electricity generation is expected to increase from 3177 TWh in 2005 to 4367 TWh in 2030. The extrapolated figure is 4631 TWh in 2050;
- The share of coal in the electricity mix was 29% in 2005. A continued share of 30% is assumed for the years 2015, 2030 and 2050 for the purposes of direct comparison of the effects on coal use and emissions due to the technologies implemented. Whilst this presupposes the achievement of continuing diversification of electricity supply, it is necessary to set one non-technological variable as constant in order to directly compare the others;
- The capacity factor (or utilisation rate) of the coal-fired generation capacity was 56% in 2005. In line with the TRENDS baseline scenario, an increased capacity factor of 66% is assumed for the years 2015, 2030 and 2050;
- The carbon dioxide produced from conversion of 1 tonne of coal equivalent for power generation is assumed to be 3 tonnes.

The exact prediction value of these assumptions is not crucial; it is important that while they represent one of possible development scenarios, they are common to analyses of all three routes allowing for comparisons to be drawn. The evaluations of each of the three routes are presented in turn below:

Route A (focus only on energy efficiency; no CCS)

Route-specific Assumptions

- BAT energy efficiency improvements of coal-fired power plants are strategically enhanced through sustained RD&D programmes at EU level, with proper use of other EU financial instruments. Between 2005 and 2015 BAT efficiency is improved by 2.5% each 5 years on average. Between 2015 and 2050 BAT efficiency is improved by 1.2% each 5 years on average[73];

– New plants are installed using an average of 1-2% below BAT energy efficiency;

– All least efficient plants are retrofitted or replaced with new plants.

Quantitative Changes

	2005	**2015**	**2030**	**2050**
Coal-Fired Capacity (GWe)	187	195	227	240
Electricity Generated from Coal (TWh) (% change from 2005)	922	1129 (+ 22%)	1310 (+ 42 %)	1389 (+ 51 %)
Capacity factor (%)	56	66	66	66
Percentage of coal-generated electricity in the electricity mix (%)	29	30	30	30
Average Energy Efficiency of EU coal-generated electricity, without CCS (%)	35	42	46	52
BAT efficiency, without CCS (%)	45	50	54	58
Coal intake of power plants (Mtce)	324	330	350	328
Absolute CO_2 emissions ($MtCO_2$) (% change from 2005)	971	991 (+ 2%)	1050 (+ 8%)	985 (+ 1%)
Specific CO_2 emissions (gCO_2/kWh) (% change from 2005)	1053	878(-17%)	801(-24%)	709(-33%)

Qualitative Changes

The increase in total electricity generation in the EU translates into a net increase of both:

– Coal-fired generation, by 50 % between 2005 and 2050 and

– Coal-fired capacity, by approximately one third above the full replacement rate.

Steady replacement of old plants and sustained improvement of the BAT for efficiency throughout the all period are the likely key factors to much higher average efficiency and lower specific CO_2 emissions. After 2030, highly efficient plants are introduced, such as IGCC with close to 60% efficiency. These highly efficient plants provide substantial specific CO_2 reductions without CCS.

However, without CCS, the total CO_2 emissions are not anticipated to be reduced under this technology route, as the envisaged efficiency improvements are just sufficient to compensate the anticipated increase in the production of electricity from coal.

Route B (focus only on CO_2 Capture and Storage)

Route-specific Assumptions

– Application of CCS to new build and suitable coal-fired power plants is commercially viable by 2020. This is the result of demonstration projects undertaken between 2010 and 2020 gaining approximately 20 years of cumulative

[73] Industry estimate

experience. After 2020, all new coal-fired power plants are equipped with CCS and a retrofitting of capture-ready pre-2020 plants is begun. By 2050 all coal-fired power plants constructed after 2010 are equipped with CCS;

- BAT for energy efficiency improvements continue through RD&D programmes financed mainly by industry, with the support from some of the Member States, continuing the underlying trend. Efficiency improvements are made at a rate of 0.5 percentage points every 5 years[74];
- New plants are installed using an average of 1-2% below BAT energy efficiency;
- All least efficient plants are retrofitted or replaced with BAT;
- Use of CCS imposes an energy penalty of 10% efficiency on plants built by 2030. By 2050 this is reduced to 8%.

Quantitative Changes

	2005	**2015**	**2030**	**2050**
Coal-Fired Capacity (GWe)	187	195	227	240
Electricity Generated from Coal (TWh) (% change from 2005)	922	1129 (+ 22%)	1310 (+ 42 %)	1389 (+51 %)
Capacity factor (%)	56	66	66	66
Percentage of coal-generated electricity in the electricity mix (%)	29	30	30	30
Average Energy Efficiency of EU coal-generated electricity (%) (% of coal-fired generation using CCS)	35 (0%)	39 (0%)	41 (25%)	39 (100%)
BAT efficiency (%)	45 without CCS	46 without CCS	38 with CCS	41 with CCS
Coal intake of power plants (Mtce)	324	356	393	438
Absolute CO2 emissions (MtCO2) (% change from 2005)	971	1067 (+ 10%)	895 (- 8%)	131 (- 87%)
Specific CO2 emissions (gCO2/kWh) (% change from 2005)	1053	945 (- 10%)	683 (- 35%)	94 (- 91%)

Qualitative Changes

The increase in total electricity generation in the EU translates into a net increase of both:

- Coal-fired generation, by 50 % between 2005 and 2050 and
- Coal-fired capacity, by approximately one third above the full replacement rate.

The average energy efficiency of coal generated electricity slightly improves in the first period till 2030 and but comes back to lower levels after 2030. Indeed, all efficiency improvements achieved in the conversion process after 2015 are consumed by the energy

[74] Extrapolation of achievements in power plant efficiency made in the past 15 yeares with limited support from Framework Programmes 5 and 6.

penalty of CCS (which is equivalent to minus 10 percentage points in the first period till 2030 and to minus 8 percentage points in the second period).

Under this technology route, a sustained and systematic introduction of CCS after 2020 is the key factor to lower total CO2 emissions in 2030 and to near zero emissions by 2050.

Route C (Focus on both energy efficiency and CO2 capture and storage)

Route-specific Assumptions

– CCS is introduced commercially as per Route B, i.e. after 2020, all new coal-fired power plants are equipped with CCS;

– BAT energy efficiency improvements are made at the same rate as in Route A, i.e. 2.5% each 5 years between 2005 and 2015, 1.2% each 5 years between 2015 and 2050;

– New plants are installed using an average of 1-2% below BAT energy efficiency;

– All least efficient plants are retrofitted or replaced with BAT in this option;

– Use of CCS imposes an energy penalty of 10% efficiency on plants built by 2030. By 2050 this is reduced to 8%.

Quantitative Changes

	2005	**2015**	**2030**	**2050**
Coal-Fired Capacity (GWe)	187	195	227	240
Electricity Generated from Coal (TWh) (% change from 2005)	922	1129 (+ 22%)	1310 (+ 42%)	1389 (+ 51%)
Capacity factor (%)	56	66	66	66
Percentage of coal-generated electricity in the electricity mix (%)	29	30	30	30
Average Energy Efficiency of EU coal-generated electricity (%) (% of coal-fired generation using CCS)	35 (0%)	42 (0%)	44 (25%)	43 (100%)
BAT efficiency, without CCS (%)	45 without CCS	50 without CCS	44 with CCS	50 with CCS
Coal intake of power plants (Mtce)	324	330	366	397
CO2 emissions (MtCO2) (% change from 2005)	971	991 (+ 2%)	817 (- 16%)	119 (- 88%)
Specific CO2 emissions (gCO2/kWh) (% change from 2005)	1053	878 (- 17%)	624 (- 41%)	86 (- 92%)

Qualitative Changes

The increase in total electricity generation in the EU translates into a net increase of both:

– Coal-fired generation, by 50 % between 2005 and 2050 and

– Coal-fired capacity, by approximately one third above the full replacement rate.

The average energy efficiency of coal generated electricity improves significantly the first period till 2030 but remains almost flat till 2050. Also in this option, nearly all efficiency improvements achieved in the conversion process after 2015 are "eaten" by the energy penalty of CCS (which is equivalent to minus 10 percentage points in the first period till 2030 and to minus 8 percentage points in the second period).

The increase in the net average efficiency can partially compensate the higher investment cost of such sophisticated electricity production facilities.

In this option, specific CO2 emissions can be continuously reduced. Total CO2 emissions are stabilised in the first period till 2015 and strongly reduced later, reaching near zero emissions by 2050.

Comparison of the three routes

Route A can achieve a substantial reduction of the specific CO2 emission from coal fired power generation, in the medium term (through upgrading and reconstruction using each time the "best of the art" technology) and in the longer term (with the perspective of reaching much higher energy efficiencies in the coal-fired power plants). However, even when reaching the technical limits of the improved energy efficiency, this route can not offer near zero CO2 emissions from coal-fired power plants. This route is considered to be a 'no-regret' option by the Zero Emission Technology Platform.

Route B offers a radical solution for avoiding the emission in the atmosphere of large amounts of CO2 from coal-fired power plants. This route is able to reach near zero CO2 emission from coal-fired power plants. However, CO2 capture processes require a lot of electricity so larger volumes of coal are needed in order to generate the same quantity of electricity delivered to the grid. This could be interpreted as 'spoiling' the finite solid fuels reserves available in the world. Implementing CO2 capture in low efficiency power plants makes it disadvantaged from the security of supply point of view and possibly from the economic point of view.

Technology Route C combines the advantages of Routes A and B. Important reductions of specific CO2 emissions from coal generation can be achieved in the medium term. This route also provides the opportunity to reach near zero CO2 emissions. Improved efficiency rates can be secured in coal-fired power plants in the medium and longer term, with the benefits of reducing the total coal intake and the total volume of CO2 emissions to be treated. The economics of electricity generation with CCS are also improved, as increased efficiency partially compensates the additional investment cost of fully CO2 capture equipped coal-fired power plants. Europe is able to retain the political and technological lead in climate change and in the sustainable use of coal for electricity generation. Route C is considered to optimise the possibilities for sustainability.

Overall**, Route A** strongly reduces specific CO2 emissions and uses relatively less coal but it can not reach near zero emission. Route B can achieve near zero CO2 emissions but it uses more coal, it produces more CO2 to be treated and it brings an upward risk for the electricity price. Route C is the most favourable option from several points of views (security of supply, environmental, economics, technological leadership, international competition, the Lisbon objectives.

Technology Route 3 offers definite advantages when compared to the more narrow technological approaches of Routes 1 and 2. To promote efficiency gains or CCS in isolation of one another would sacrifice both environmental benefits and economic rewards. It can therefore be concluded that the chosen objectives should align with the facilitation of both energy efficient coal technologies, and those that enable the implementation of CO_2 capture and storage.

ANNEX III: CALCULATIONS FOR THE EVALUATION OF IMPACTS OF ASSESSED POLICY OPTIONS

1. COMMON ASSUMPTIONS 75

The calculations of likely outcomes of the policy options have been built upon a set of key assumptions that define the development of the technologies between 2005 and 2050. These assumptions generate logical scenarios of technological development and penetration that have been quantified for the comparison of options. For each option the specific assumptions and their impacts are presented in Sections 2 to 4. The common assumptions which apply to more than one policy option are explained hereafter:

1.1. Electricity Demand

The electricity generated in the EU25 from all sources follows the European Commission's *European energy and transport – Trends to 2030* (TRENDS). Under this baseline scenario, total electricity generation is expected to increases from 3177 TWh in 2005 to 4367 TWh in 2030. The figures have been extrapolated to 4631 TWh in 2050.

1.2. Technical Aspects of Coal-Based Power Generation

The capacity factor (or utilisation rate) of the coal-fired generation capacity was 56% in 2005. In line with the TRENDS baseline scenario, an increased capacity factor of 66 % is assumed for the three policy options in 2015, 2030 and 2050. The conversion of 1 tonne of coal equivalent (tce) for power generation is assumed to produce 3 tonnes of CO2, in all three options, throughout the all period.

2. ANALYSIS OF POLICY OPTION 0 (NO POLICY CHANGE)

2.1. Option-Specific Assumptions

Technology

- BAT for energy efficiency improvements continue through RD&D programmes financed mainly by industry, with the support from some of the Member States, continuing the underlying trend. Efficiency improvements are made at a rate of 0.5 percentage points every 5 years[75];
- New plants are running effectively at an average of 1-2 points below BAT for energy efficiency;
- Consequently, the average energy efficiency of coal-based power generation increases at the rate of approximately 2 percentage points every 5 years between 2005 and 2015 (mainly because of the retirement of the least efficient plants) and

[75] Extrapolation of achievements in power plant efficiency made in the past 15 years with limited support from Framework Programme 5 and 6.

1 point every 5 years between 2015 and 2050 (mainly because of the replacement by more efficient new plant).

Penetration of CCS

– With 'No Policy Change', CCS is not envisaged to achieve any commercial penetration. All coal-fired capacity remains unequipped with CCS throughout the period 2005-2050.

2.2. Quantitative Analysis

OPTION 0	**2005**	**2015**	**2030**	**2050**
Coal-fired capacity (GWe) (% change from 2005)	187	143 -14%	128 -32%	118 -37%
Coal-generated electricity (TWh) (% change from 2005)	922	824 -11%	740 -20%	682 -26%
Capacity factor (%)	56	66	66	66
Share of coal-generated electricity in the electricity mix (%)	29	22	17	15
Average energy efficiency of coal-generated electricity (%) (without CCS)	35	39	42	46
BAT for energy efficiency (%) (without CCS)	45	46	48	49
Coal intake of power plants (Mtce) (% change from 2005)	320	260 -19%	216 -32%	182 -43%
Absolute CO2 emissions from coal-fired capacity (MtCO2) (% change from 2005)	960	779 -19%	649 -32%	546 -43%
Specific CO2 emissions of coal-generated electricity (gCO2/kWh) (% change from 2005)	1041	945 - 9%	878 -16%	801 -23%

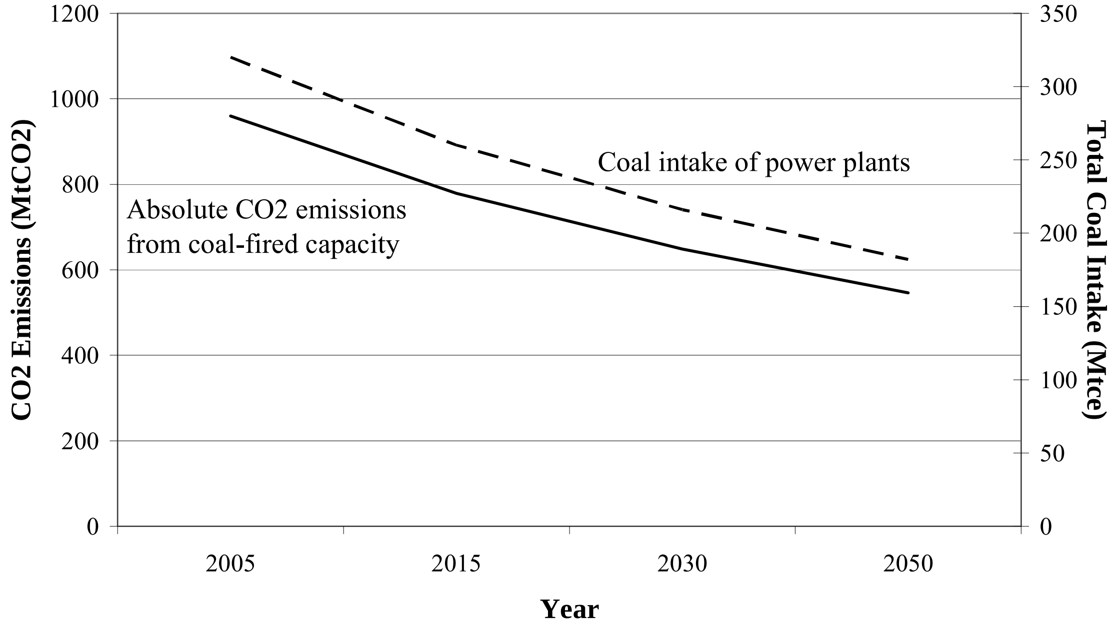

Figure 1. Anticipated effect of Policy Option 0 on CO2 emissions and Coal Intake for power generation in the EU25

3. ANALYSIS OF POLICY OPTION 1

3.1. Option-specific Assumptions

Technology

- Clean coal and C02 capture and storage technologies are improved through sustained RD&D programmes at EU level;
- Between 2005 and 2015, BAT efficiency (without CCS) is improved by 3.5 percentage points each 5 years on average. Between 2015 and 2050 BAT efficiency (without CCS) is improved by 1.2 percentage points each 5 years on average[76];
- The introduction of CCS results in an energy penalty which reduces BAT efficiency by 10 percentage points until 2030 and by 8 percentage points by 2050. The resulting net energy efficiency of BAT (where CCS is used) is only improved by 1 percentage point each 5 years on average between 2015 and 2050;
- New plants are installed using an average of 1-2 percentage points below BAT energy efficiency.

Penetration of CCS

- CCS technologies are fully demonstrated by 2020[77]. This is the result of large scale projects undertaken between 2010 and 2020 gaining up to 10 years of cumulative experience. By 2020, CCS technologies start to be implemented in the majority of new build coal-fired power plants and in coal plants suitable for such retrofit. The resulting penetration of CCS technologies is estimated to be in the order of 25% of the coal-fired capacity in 2030 and 75% by 2050;
- The CCS technologies would not be used for full capture of the CO2 generated in the power plant equipped with CCS, as lower rates of capture could mean smaller unit costs and less additional investment. Switching CCS on and off depending on the actual carbon price could also take place. Consequently, an average rate of capture of 45% will be assumed for the coal-fired capacity equipped with CCS, when calculating CO2 emissions.

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76 Industry estimate : reference needed.

77 As per the ZEFFPP Technology Platform vision.

3.2. Quantitative Analysis

OPTION 1	**2005**	**2015**	**2030**	**2050**
Coal-fired capacity (GWe) (% change from 2005)	187	143 -24%	210 +12%	220 – 240 +18% +28%
Coal-generated electricity (TWh) (% change from 2005)	922	824 - 11%	1203 +30%	1273 – 1389 +38% +51 %
Capacity factor (%)	56	66	66	66
Share of coal-generated electricity in the electricity mix (%)	29	22	27.5	27.5 – 30
Average energy efficiency of coal-generated electricity (%) (% of coal-fired capacity with CCS)	35 0%	42 0%	43 25%	47 75%
BAT for energy efficiency (%)	45 without CCS	50 without CCS	44 with CCS	50 with CCS
Coal intake of power plants (Mtce) (% change from 2005)	320	283 -12%	343 +7%	333 – 363 +4% +13%
Absolute CO2 emissions from coal-fired capacity (MtCO2) (% change from 2005)	960	849 -12 %	869 -9%	573 – 625 -40% -35%
Specific CO2 emissions of coal-generated electricity (gCO2/kWh) (% change from 2005)	1041	1030 (- 1%)	772 -31%	450 -55%

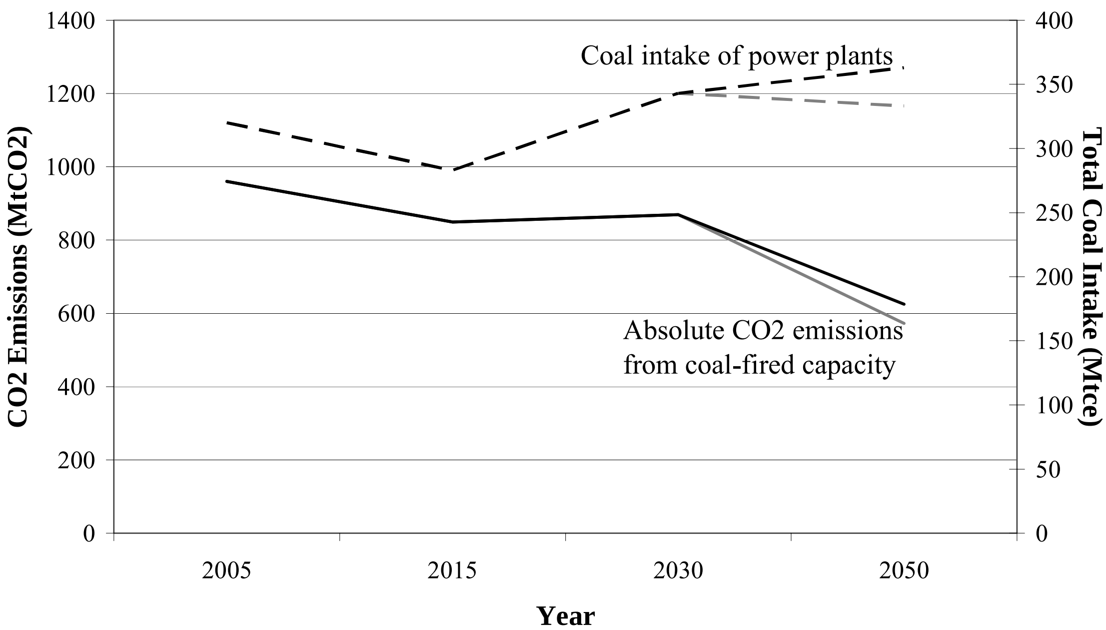

Figure 2. Anticipated effect of Policy Option 1 on CO_2 emissions and Coal Intake for power generation in the EU25

4. ANALYSIS OF POLICY OPTION 2

4.1. Option-specific Assumptions

Technology

- Carbon capture and storage technologies are improved through a sustained RTD & Demonstration programmes at EU level. BAT for energy efficiency (without and with CCS) improves at the same rate as in Policy Option 1;
- New plants are installed using an average of 1-2 points below BAT for energy efficiency;
- All least efficient plants are progressively replaced or retrofitted with BAT in this option;
- For the energy penalty of CCS, we use the same assumptions as in Policy Option 1.

Penetration of CCS

- CCS technologies are fully demonstrated by 2020. This is the result of large scale projects undertaken between 2010 and 2020 gaining up to 10 years of cumulative experience;
- In this option, we also assume that CCS is commercially viable throughout the period 2020-2050. After 2020, all new coal-fired power plants are equipped with CCS and a retrofitting of capture-ready pre-2020 plants is begun. By 2050 all coal-fired power plants constructed after 2010 are equipped with CCS. The resulting penetration of CCS technologies is estimated to be in the order of 30% of the coal-fired capacity in 2030 and 100% by 2050;
- The CCS technologies used would achieve full capture (with a rate of 90%) of the CO_2 generated in the power plant equipped with CCS.

4.2. Quantitative Analysis

OPTION 2	**2005**	**2015**	**2030**	**2050**
Coal-fired capacity (GWe) (% change from 2005)	187	189 +1%	219 +17%	240 – 280 +28% +50%
Coal-generated electricity (TWh) (% change from 2005)	922	1092 +18%	1266 +37 %	1389 – 1621 +51% +75 %
Capacity factor (%)	56	66	66	66
Share of coal-generated electricity in the electricity mix (%)	29	29	29	30 - 35

Average energy efficiency of coal-generated electricity (%) (% of coal-fired capacity with CCS)	35 (0%)	43 (0%)	42 (30%)	46 (100%)
BAT for energy efficiency (%)	45 without CCS	50 without CCS	44 with CCS	50 with CCS
Coal intake of power plants (Mtce) (% change from 2005)	320	312 -3%	370 +16%	371 – 433 +16% +35%
Absolute CO2 emissions from coal-fired capacity (MtCO2) (% change from 2005)	960	936 - 3%	778 -18%	111 – 130 -89% -86%
Specific CO2 emissions of coal-generated electricity (gCO2/kWh) (% change from 2005)	1041	876 - 16%	615 -41%	80 -92%

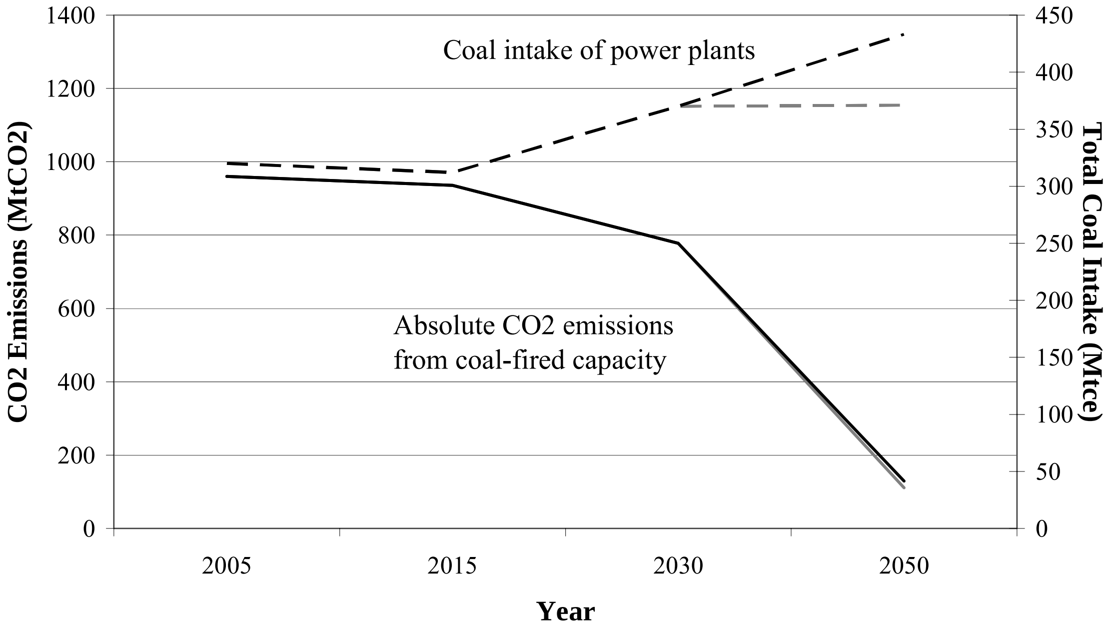

Figure 3. Anticipated effect of Policy Option 2 on CO2 emissions and Coal Intake for power generation in the EU25.