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CLEAN COAL TECHNOLOGIES IN EVERY STAGE OF COAL PRODUCTION IN POLISH INDUSTRY

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Abstract: Despite its poor environmental credentials, coal remains a crucial contributor to energy supply in numerous countries. It is the most widespread fossil fuel around the world, and more than 75 countries have coal deposits. The energy resource plays an important role in delivering energy access, which is a fundamental pre-requisite for modern life and a key tool in eradicating extreme poverty across the globe. Production and processing of coal has a negative influence on the environment. In order to minimize the changes of undesirable Clean Coal Technologies are introduced into the coal industry. This paper summarizes the different production technologies clean coal used at different stages of the manufacture of carbon trading, processing and conversion. Furthermore, it brings closer problems associated with the use of CCT in Poland. According to the EU's climate policy, Poland is obliged to reduce CO_2 emissions. Therefore, there is an urgent need to introduce new technologies that are the capture and storage of CO_2 gasification process and technology to increase the efficiency of electrical energy production from coal.

Keywords: clean coal technology, hard coal and lignite, gasification, CCS, limiting CO_2 emission

1. INTRODUCTION

The International Energy Agency and BP Statistical Review of World Energy have published data concerning global energy. The report shows that the coal provides 30.1% of global primary energy needs. Moreover, the coal generates 39.1% of the world’s electricity and 70% of the global steel. The World Coal Association publicized that the total world coal production reached a high level of 7 822.8 Mt in 2013. Comparing this data with the data of the previous year, the world coal production

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increased by 0.4%. Looking at the data in 1990, we can notice that total world production accrued by circa 67.3%.

The Polish coal production amounted to about 142.92 Mt in 2013, of which the production of hard coal was equal to 77.02 Mt and the production of lignite was equal to 65.85 Mt. According to IEA report, the coal-fired electricity comprised 83% of national electricity. Poland is one of the frontrunners in the production of coal-fired electricity. The leaders are also Mongolia, South Africa and China (Fig. 1).

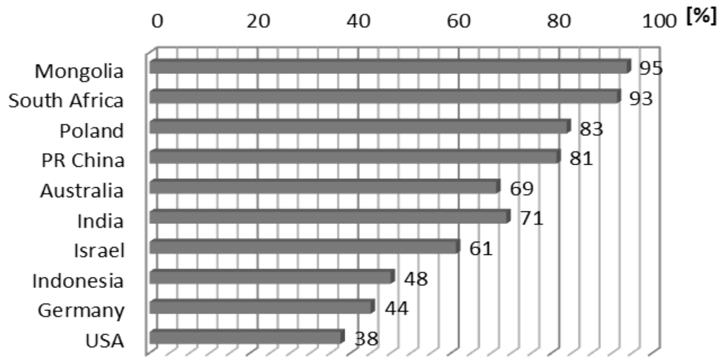

Fig. 1. Coal in electricity generation, 2012 (World Coal Association, 2015)

Technologies based on coal adversely impact the environment and the groundwater. Nevertheless, coal is a very important fuel and in many countries it is the primary source of energy. This energy resource is a widespread fossil fuel and more than 75 countries have coal deposits. The data provided by IEA and BP Statistical Review of World Energy announce that China, U.S., India and Indonesia are the world leaders in the production of coal (Fig. 2).

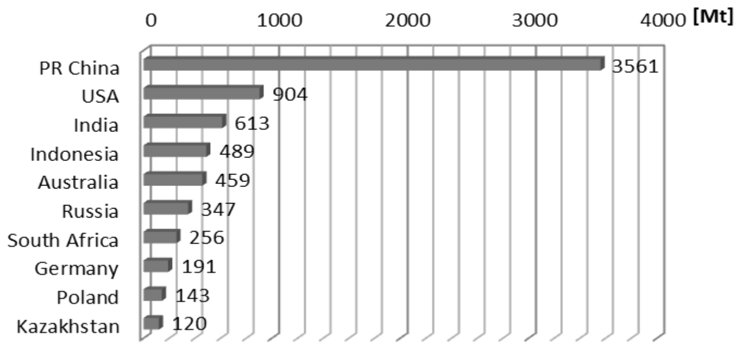

Fig. 2. Top ten coal producers, 2013 (World Coal Association, 2015)

2. CLEAN COAL TECHNOLOGY

In the 1980s, the U.S. transformation of energy sector began. It was directed by the energy reserves depletion and significant environment degradation. Irrational resources management caused the rapid increase in the prices of petroleum and natural gas. It was an imperative that the coal started to be used in energy industry in an eco-friendly way. This has resulted in the introduction of the idea of clean coal technologies (Soliński and Gawlik, 2012).

The American Clean Coal Technology scheme includes 4 areas, which should be used in environment-friendly technologies. Precombustion consists in cleaning of coal before and preparing energy assortments of the required parameters. The second area is advanced combustion. This refers to the elimination of damaging additives during combustion by improving the process. The next two areas are: advanced postcombustion, which means cleaning fumes, and conversion – transformation of coal, for example during gasification, pyrolysis, and others (Blaschke, 2008).

Needless to say, clean coal technologies is a very extensive field. Nowadays, various solutions have been introduced to mining and energy industry. Still, R&D continues, and the subject-matter is focused mostly on two directions: postcombustion and conversion.

Analysing every stage of coal production, we can distinguish industrial areas, in which clean coal technologies are used. The apportionment is as follows:

1. exploitation and processing,
2. transportation and storage,
3. coal use in energy production and other branches of industry,
4. waste treatment.

According to CCT assumptions, high efficiency of every coal production stage plays an important role in environment-friendly functioning of coal production system (Kasztelewicz et al., 2009).

2.1. EXPLOITATION

In the case of exploitation, it is essential to obtain the high efficiency of resource use at commercially reasonable costs. The lower efficiency deposit exploitation is related to the concentration of production in one area and the unification technology. These factors characterize the majority of Polish hard coal mines. Contrary to the ideas of CCT is also leaving deposit residues. It significantly reduces the mining effectiveness, and causes complex land surface deformations (Dubański and Ture, 2014).

2.2. MECHANICAL PROCESSING

Clean coal technologies are an indispensable element of mechanical processing of coal. It focuses on production of the best possible quality of fossil fuel from coal output. Through a row of operations, contaminants and waste rock are removed from the feed. The separation of tailing improves efficiency production, because the amount of fossil fuel is reduced. The beneficiation of hard coal is possible through diverse technologies, which have developed over the last decades. The application of various beneficiation machines is related to raw materials parameters. Appropriate parameters of machines and processes ensure an accurate removal of rocks and pyrite grains from coal. In hard coal preparation plants there are used concentrators with heavy liquid or a jig, cyclone mostly with a heavy liquid, hydrocyclone, Humphrey's spiral, floatation machine and others (Soliński and Gawlik, 2012).

The other processing operations, which are important during clean coal production, are crushing, averaging parameters of coal assortment and their creation. Applications of those processes are required, when beneficiated coal does not comply with guidelines for reduced SO_2 emission during combustion. Averaging operations parameters of assortment is carried out in order to obtain the appropriate properties of coal assortments, which have to meet both requirements of customer and limits on SO_2 emission.

Averaging and mixing coal assortment or even desulfurization can leave out and selective grinding can be used instead of them. The selective grinding can be used, provided that the content of pyrite sulfure is higher than the content of organic sulphur. Crushing-grinding system is used to obtain coal dust and larger coal particulates. This process provides efficient selection (90% sulphur and majority of waste rock are deleted by grinding).

In the case when the amount of organic sulphur is higher than the amount of pyrite sulphur, the coal-limestone assortments production would be well advised. The process consists in crushing and grinding coal which was separated during a beneficiation operation. And then particulates of limestone and catalyst are added. The organic sulphur content is reduced by 80-90%.

A significant improvement in the hard coal quality is obtained mainly in deep beneficiation processes, which require fine-grained materials. For example, those processes are: flotation, bacterial leaching, beneficiation in liquid carbon dioxide, and others. In each of these methods, it is necessary to control strictly the process parameters and the added investment outlay to chemical reagents (Blaschke, 2008).

The preparation of lignite for further processing is not as complicated as in the case of hard coal. Increasing the efficiency of energy production and CO_2 emission reduction is possible to achieve by such treatments as: an increase fragmentation and drying of lignite. By these operations it will be possible to improve the net efficiency of electricity production from 4% to 6%. The technology involves crushing coal by hammer mills, and then the delivery of particular coal into the drying chamber.

Evaporation of water takes place in 110^{O}C under slightly overpressure. The residence time of coal is 60-90 minutes in the chamber (Kasztelewicz et al., 2009).

2.3. TRANSPORTATION AND STORAGE

The transportation and storage of coal are other elements of the production process, in which an unfavourable factor is dust. We can take two negative aspects of this phenomenon into account. The first is an environmental aspect – pollution, and the second is an economic aspect – the loss of fuel. The solution may be the use of preparations to strengthen the surface of coal particles. The coal transport effectiveness is dependent on the cost of the unit transportation of chemical energy contained in the fuel. It follows the clean coal production is basal. Currently, circa 60% of global coal transportation does not exceed the distance of 50 km, and only 10% of that is destined for international trade (Dubański and Ture, 2014).

2.4. PROCESSING AND DISPOSAL

Processing and disposal technologies of coal are currently being modernized on a great scale. And of course, it is in accordance with the CCT tenets. A report issued in 2013 by the World Energy Council determines total CO_2 production was 30 billion Mg. It is expected that it will gradually increase in the next years, and it will achieve 42 billion Mg in 2020. Over the past 20 years carbon dioxide was brought to the air as a result of the coal combustion, and the amount of that gas emission increased by 44%.

According to CCT, in the coal processing, the following methods are used: exhaust fumes treatment system, improving combustion, and gasification. The most common methods of exhausted gas treatment are:

1. desulfurization with sorbents,
2. selective catalytic reduction (SCR) involving the conversion of nitrogen oxides into non-toxic nitrogen and water vapour in the catalyst, and at the same time reduce emission of particular matter,
3. denitration by ammonia methods,
4. CO_2 reduction through the use of physical and chemical methods,
5. CO_2 sequestration in geological formations.

Today, a number of companies provide commercial capture systems for natural gas processing plants or slipstreams from coal-fired power plants. The Global Status of CCS: 2014 Summary Report indicates that the commencement of CCS operations at SaskPower's Boundary Dam coal-fired power station in October 2014 is a significant step forward. The Boundary Dam Integrated Carbon Capture and Sequestration Demonstration The project represents the first example of applying CCS in a power station on a large scale. Two further large-scale CCS projects in the power sector are under construction in the United States (US) – at Mississippi Power's

Kemper County Energy Facility in Mississippi and the Petra Nova Carbon Capture Project at NRG Energy’s W.A. Parish power station in Texas. Unfortunately, Europe cannot boast of such achievements in the field of CCS. On this continent no large-scale CCS project has entered construction in over a decade. The most advanced projects are projects ROAD (Netherlands) and Schwarze Pumpe (Germany) in Europe.

The efficiency increase of coal combustion system is one of the ways to implement clean coal technologies. In order to achieve optimal combustion efficiency modern technologies, which are presented below, are used. We are talking about (Kasztelewicz et al., 2009):

1. Coal combustion in supercritical conditions (27-29 MPa, 570-580 °C); it allows to achieve circa 44-46% of efficiency,
2. Coal combustion in ultra-supercritical conditions (35 MPa, 720 °C); the method is in the research phase, but it is intended to achieve by its use the power generation efficiency in the range of 55%,
3. Coal combustion in oxygen enriched atmosphere; the process results in the production of the exhaust gases containing mainly CO_2 and water vapour, which further expedites the storage of gases.

One of the permanent trends in the construction of coal-fired power plant is to increase the steam parameters. Currently, only few supercritical power units are in Poland: Pątnów II – 464 MW, Łagisza – 460 MW and Bełchatów II – 858 MW. Tests are carried out on increasing the efficiency of coal-fired power plants in Germany. One of the projects involves the testing cycle for steam temperature of 700 °C. It is estimated that the power unit should achieve efficiency of more than 50% (Kasztelewicz, 2014).

Another direction of coal-fired power generation development is the coal combustion in oxygen. As a result of this process, it produces only CO_2 and steam, which simplifies the storage of CO_2. However, a considerable difficulty is the suddenness of the process and the corrosion of equipment. The German company Vattenfall A.G. tests oxy-combustion technology in the Schwarze Pumpe power plant (30 MW), which uses the pilot plant for carbon capture and storage (Kasztelewicz, 2014).

Given the attention to the environment and reducing the unit cost of energy production, the key element is to increase the efficiency of coal-fired power plants, introducing modern technologies. The RWE company and Galetakisa’s analyses affirmed reliance between decrease in CO_2 emissions while increasing the efficiency of power plants and coal calorific value. Diagram (Fig. 3) presenting the relationship between these parameters shows that about 10% of the increase in the efficiency of power units reduces carbon dioxide emissions by approx. 19.4-22.4% (Jurdziak and Kawalec, 2010).

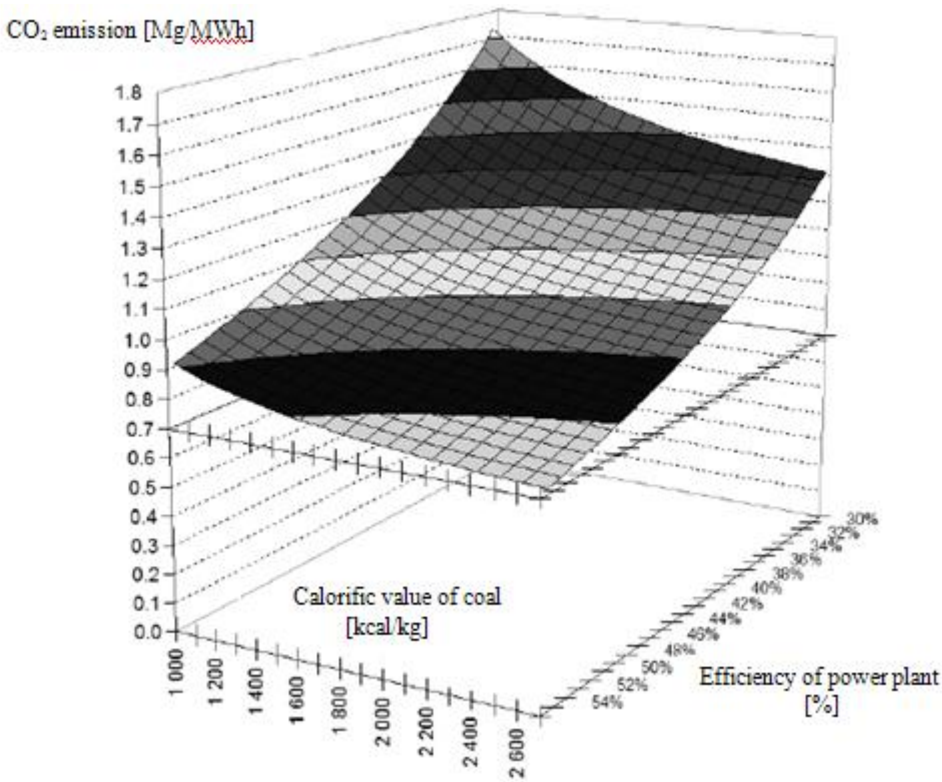

Fig. 3. Dependency of CO_2 emissions from power plant efficiency and calorific value of lignite (Jurdziak and Kawalec, 2010)

Today's advanced gasification technologies incorporate significant improvements over previous models and gain greater prominence than ever before. Polygeneration facilities can produce multiple products; one of them can be electricity and other valuable products, such as fertilizers, transportation fuel, substitute natural gas, chemicals, and hydrogen (Kerester, 2014).

The above-ground gasification process has received a lot of attention, especially in the U.S. The most well-known design for this purpose is the integrated gasification combated cycle (IGCC). It uses gas and steam turbines to generate electricity. Great experience in the development of this technology has also RWE Power, which implies that the efficiency of IGCC power plant installations may reach 52%, and combined with the removal of CO_2 is reduced to 40%. However, IGCC has also got some weaknesses, for instance, a high failure rate, and high investment costs. The technologies are quite complicated and their use in the Polish existing power plant is not possible. However, the data General Electric indicate that IGCC with CO_2 capture and storage can be more competitive than supercritical power plants with CCS (Kawabata et al., 2012).

Gasification typically takes places in an above-ground gasification plant. However, the gasification reaction can also take place below ground in the coal seams. Underground gasification can be used when some coal seams are non-mined. Currently, one industrial, large-scale installation of UCG works in Angren (Uzbekistan) and other pilot projects are in China, Australia and South Africa. This technology is the subject of interest and numerous studies; still its commercial application is not possible. The same is the case of biogasification - a microbial conversion of coal. This method has not been applied on an industrial scale, only tests were performed in laboratory conditions (Kasztelewicz, 2014).

2.5. MANAGEMENT OF WASTE FROM COAL PRODUCTION AND PROCESSING

During the production of coal waste rock permanently arises. It is separated from beneficiation processes and preparatory actions. In the past, the useless part of coal production was collected in heaps. Nowadays, the situation is changing, and there is an emphasis on clean coal production. Directions of management of waste rock focus on:

1. Recycling useful component of the waste rock, which is deposited in heaps, and production of aggregates for the use of road construction sites and construction industry in general,
2. Using waste rock for mine reclamation.

Furnace waste (ash and slug) can be used for reclamation actions, levelling large areas of land, filling mining excavations, as well as the construction of road or railway embankments. Further development of science may result in using furnace waste in other areas, taking advantage of the sorption properties of these materials (Dubański and Ture, 2014).

3.CCT IN THE POLISH INDUSTRY

3.1. PROBLEMS

Clean Coal Technologies in the Polish coal mines, preparation plants and energy plants have been introduced relatively late in comparison with other EU members. The size of modernization due to the improvement of the production and utilization of coal in accordance with CCT program leaves much to be desired. The coal industry requires huge changes in the three areas defined as: precombustion, combustion, and advanced postcombustion (Soliński and Gawlik, 2012).

Still, the research on optimization of the coal averaging and mixing systems is being carried out, yet huge amounts of fine coal is left uncleaned in Polish preparation plants. Moreover, in most of the Polish coal preparation plants, deep enrichment processes are ignored mostly, however in a few places there is used flotation process to separate coking coal from waste rock.

On the one hand, problem consists in impaired technical capabilities of coal beneficiation, because not everywhere the proper equipment is implemented. But it is a minor problem; there are private preparation plants that could provide the service for the mine. The real problems are the largest customers, which are power plants equipped with obsolete technologies adapted to uncleaned fine coal. Despite the modernization of power plants in Poland, the number of modern coal-fired power plants is almost 4 times less than the old ones. The older power plants require lower quality of coal, so Polish mines produce coal that suits their needs, and do not comply with assumptions of CCT (Blaschke, 2008).

The dominant, obsolete technology, energy production is not consistent with the EU requirements on reducing CO_2 emissions. Poland is inevitably approaching to the date of redemption of ETS permits for the whole CO_2 emitted, which significantly affect the increase in production costs of fossil fuels and electricity price levels. In this situation a modernization of coal sector is priority due to the dependence between Polish power plant and hard coal and lignite. It can be assumed that in the future ETS prices will grow and the cost will charge the whole society and economy. Therefore, it seems advisable to replace the old with new power units of 45-48% efficiency, which sustain Polish coal energy while fighting global warming. This will reduce the unit cost of energy production, reduce carbon emissions and ensuring the development of the country through the use of their own resources and the creation of new workplaces (Jurdziak and Kawalec, 2010).

3.2. PROBLEMS

The European Union has decided that its position in the international arena will be strengthened by the introduction of low carbon economy model. It should solve two important issues, national energy security and climate change. In accordance with the EU’s energy and climate policy, EU Member States are obliged to achieve its targets until 2020. These aims are determined briefly as *20-20-20*:

1. A 20% reduction in EU greenhouse gas emissions in comparison to those of 1990 levels,
2. Raising the share of EU energy consumption produced from renewable resources to 20%,
3. A 20% improvement in the EU's energy efficiency,
4. Increasing the share of biofuels in the overall transport fuel consumption at least to 10%.

Power industry in Poland is based on coal, so the move towards a low carbon economy must be related to the introduction of clean coal technologies to extend the hard coal and lignite exploitation. The need to transform the economy and obligations to the EU imposes the modernization of this industry.

The Polish Energy Policy until 2030 assumes a rational and effective management of coal deposits, and maintenance of these row materials as the main fuel in the energy sector. Coal preparation technologies and the identification of the resource base of fossil fuels need to be modernized. The assumptions of the Energy Policy will be possible to be fulfilled through the application of CCT. It seems that the Polish direction of the development will be new supercritical power units, coal combustion technologies in oxygen, gasification, and the introduction of CCS.

The relationship between the already mentioned EU's energy and climate policy and sulfur coal combustion is regulated by the directive on the quality of the fuel. It aims at reducing greenhouse gas emissions from the fuel or energy supply. This includes all relevant stages from extraction through land-use changes, transport and distribution, processing and combustion.

The reduction of greenhouse gases is carried out gradually, e.g. by establishing partial objectives of emission reductions by the Member States. At the beginning, about 2% by the end of 2014, followed by another 4% by the end of 2017 and next 2% should be achieved by CCS technologies.

November 24th, 2013, Law of 27th September 2013 amending the Act – Geological and Mining Law and other laws implementing the CCS Directive into Polish law came into force. It defines the legal framework for the implementation of projects involving carbon capture and its storage in geological formations.

The installation of this technology is associated with high investment costs. In 2009 in Poland began working on CCS demonstration project. This technology was created in the PGE Bełchatów Power Plant S.A. and it should be integrated with the new power unit 858 MW. However, the lack of domestic funds to support the project, the financial crisis, and therefore the lack of access to European funds from the EU NER300 project, meant that in 2013 Bełchatów CCS project has been closed (Gurgul, 2015). It has not been CCS technology in Poland.

Another disadvantage of this technology is the necessity to provide additional energy to capture processes, separation, transport and storage. Hence, there arises another problem, namely the decrease in the efficiency of power units. Silesian University of Technology carried out CCS cost analysis, taking into account the Polish fuel and climatic conditions, with the possible use of three installations: the postcombustion, oxy-combustion and IGCC, meeting the guidelines of the modern, supercritical carbon unit for an estimated 44.3% efficiency. The introduction of CO_2 capture in each of the installations caused a decrease in the efficiency of energy production respectively 12.2%, 10.2% and 8.3% for the IGCC. Resulting in this, the new power units are not as efficient as the old ones. At current prices ETS, CCS is unprofitable. Boundary purchase prices of emission allowances above which the removal of CO_2 from the power unit is profitable for IGCC - 23 €/Mg CO_2, oxy-combustion - 30 €/Mg CO_2, and post-combustion - 46 €/Mg CO_2 (Gąsiorowska, 2010). Moreover, high costs of CCS demonstration projects constrict its application. Most studies estimate that CCS would add 40-80% to the cost of electricity from coal and cost from $40-70/Mg CO_2 avoided (Herzog and Eide, 2013).

4.CCT IN THE POLISH INDUSTRY

Coal plays an important role in global energy production, because it is a raw material widely available, reliable and relatively cheap, but at the same time, taking into account the production and processing of which, having a negative impact on the environment. Thinking about the role of this raw material in the production of energy in the world, ensuring energy security and reducing greenhouse gas emissions makes it clear that clean coal technologies have become an indispensable part of the energy model.

In Poland, coal and lignite have a basic meaning in ensuring energy security. Moreover, they are the main fuels used in the production of electricity and heat. With predictions of energy demand its consumption in the coming years will systematically increase. Therefore, it is essential to make investments in mining and energy. It is important to maintain continuity and trouble-free operation of power plants and mines. In addition, technical and technological restructuring should ensure the improvement of the quality of products in the case of mines, and improving the efficiency of energy production in power plants, without ignoring the environmental aspects.

In the energy sector innovative solutions, which are part of the clean coal technologies, have already been introduced. However, the technology is still used in Polish mining and energy sectors stands out as old-fashioned in comparison with the technology of leading coal producers.

As a part of the reduction of CO_2 emissions in Poland, the provisions of the Directive of the European Parliament and Council Directive 2009/31/EC of 23th April 2009 on the geological storage of carbon dioxide and other regulations were accepted. Analyzing the advantages and disadvantages of CCS it can be concluded that this technology will be used in the coming years, to the point where they will find another system capable of low carbon dioxide emission during energy generation from coal. It is difficult to determine whether the future introduction of CCS is profitable, because of the uncertainty of prices of ETS. Some authors have suggested the construction of high-performance power units prepared to implement CO_2 capture, but without these facilities. These are technologies ready for capture of CO_2. This option ensures high flexibility for the future, and this increases the value of such an investment. No matter which solution government choose (redemption licenses or implementation of CCS technologies) EU policy will lead to the emergence of the additional cost of sales or production of energy, which appears on the expenditure side. However, it should be remembered that the replacement of old power units for the new technology is the only one that does not raise unit costs of energy production.

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