

Economic efficiency of coal gasification in Poland in reference to the price of CO₂ emission rights

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Abstract. The article presents the impact of prices of carbon dioxide on the economic efficiency of 14 coal gasification technologies employed for producing electricity, hydrogen and methanol measured with the use of NPV method. All technical, technological and economic assumptions in the assessment have been made for Polish conditions. The impact of CO₂ prices were examined in the range of 30-200 PLN/Mg. The production capacity of the base technology corresponds with the fuel consumption of indicative coal having the calorific value of 20.5 GJ/Mg, used in the amount of 100 Mg/h. On the basis of the conducted research, with respect to all technical and economic assumptions, it can be stated that for the base scale there is a clear impact of prices of CO₂ emission allowances above the 90 PLN/Mg CO₂. Such a level of carbon dioxide prices makes the decision concerning construction of geological sequestration systems (CCS, carbon capture and storage) worthwhile. This applies in particular to the production of electric energy. For the variants focused on hydrogen production there is a dominance of variants with CCS system only at the price exceeding 120 PLN/Mg CO₂, and in the case of methanol such a situation occurs above 150 PLN/Mg CO₂.

1 Introduction

Gasification of coal has a relatively long history in Poland, although it has never been implemented on industrial scale. Globally, increasing interest in that technology has been noted for the production of power (and heat), hydrogen, or methanol, which are raw materials for chemical synthesis, and further processing [1, 2].

Hydrogen is used for the production of ammonia and – further on – chemical fertilizers [3,4]. Ammonia production capacity in Poland is assessed at some 3.0 Tg a year [5]. Methanol, among other things, is used as an intermediate product in MTO processes for production of olefins, gasoline, etc. [6, 7, 8].

At present, some 40 Tg of hydrogen are produced worldwide every year, which amounts to 1% of the world demand for primary energy. Increased interest in hydrogen production is also confirmed in the forecasts of EIA and BP; in future one may expect that the increase of demand for natural gas will be most noticeable, with less steep increase of demand for oil and coal [9, 10, 11]. Production of hydrogen by means of coal gasification appears to be also a technology competitive in terms of costs, feasible on industrial scale [12, 3].

Gasification of coal belongs to the so-called clean technologies, the aim of which is to minimize the negative influence of energy generation and chemical processes upon the environment. In the processes of methanol synthesis, the amount of carbon dioxide

emitted to the atmosphere is reduced [13]. CO₂ may also be stored underground, in the processes of geological sequestration, yet the development level of that type of CCS technology is not significant. That development depends on the substantial requirements concerning the place of storage, rock mass, environment, and safety of people on the surface.

2 Statement of reasons for dealing with the topic

Below, there are some arguments, which justify the author's interest in coal gasification in Poland, as well as the assessment of the influence of CO₂ upon the efficiency of that process:

- there is a substantial interest in coal gasification technologies for production of liquid and gas fuels worldwide, particularly in Asia [14],
- documented recoverable resources of hard coal, as of 31.12.2014, amount to some 52 billion Mg, while those of brown coal (lignite) amount to 23.5 billion Mg [15],
- the project of the Polish Ministry of Economy, entitled *Polityka Energetyczna Polski do 2050* (Energy Policy of Poland until 2050) assumes conducting development studies concerning technologies, the application of which will be advantageous over a longer time, such as: gasification of coal, CCS technology, and

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technologies for utilization of captured carbon dioxide [16],

- the European Commission, in its document entitled *Energy 2020* states the aim – reduction of greenhouse gases emission by 80-95% in 2050 [17]. In the *Roadmap 2050* it is proposed to reduce the greenhouse emissions by 80% by the year 2050, in comparison with emission level of 1990 (in the entire European Union), stating at the same time the required reduction of greenhouse gas emissions in subsequent years: 25% in 2020; 40% - 2030; 60% - 2040; 80% - 2050. In order to ensure the achievement of the goals set, the European Union Emissions Trade Scheme (EU ETS) has been envisaged, with the new emission reduction rate of >1.74% a year [18],
- Also in the Industrial Emissions Directive (IED) of 2010 [19], measures have been indicated to prevent environmental pollution and to control emission levels.
- In the provisions of the *Accession Treat* as well as the *Climate and Energy Package* it is additionally assumed to introduce new standards for construction of new power plants in the CCS-ready system, as well as to conduct research for geological sequestration of CO₂.
- In the documents referred to above, it is also indicated that – due to the policy conducted – a significant increase of CO₂ prices can be expected, which can result in diminishing the economic efficiency of power generation and chemical undertakings, which will have high levels of carbon dioxide emissions. Road Map 2050 assumes that the price of CO₂ emissions allowances in 2030 may exceed 25 EUR per 1 Mg of CO₂, whereas in IEA forecasts [20] those prices, depending on the scenario, may increase even to 75 EUR per 1 Mg of CO₂.
- Besides the above arguments, professional literature in Polish does not contain many studies, which would analyse the influence of prices of emissions allowances upon the efficiency of coal gasification technologies in a uniform assessment standard, and for common assumptions as to the scale and type of fuel consumed [21, 22, 23, 24]. The world professional literature contains studies on efficiency of coal gasification, taking into account the influence of prices of CO₂ emissions allowances, conducted among others by: Herzog, Simbeck, Rubin et al. [25, 26, 27]. The results of studies in that respect can also be found on the website of the US Department of Energy [28].

3 Approach to valuation and key assumptions

3.1 Approach to valuation

Income-based valuation has been used to assess the economic efficiency of the analysed coal gasification technologies – discount model based on the forecast of FCFE (free cash flow to firm). It is preferred when assessing technologies for power generation and chemical processing [29,30]. The net present value (NPV) has been calculated, as well as related indicators, such as IRR

or NPVR. In the publication, inference has been based solely only NPV.

In the investment outlays, the following have been identified: costs of technological infrastructure of processes, auxiliary infrastructure, construction works, project documentation, or replacement investments. The investment outlays have been calculated at the level of TPC (total plant costs), as well as after consideration of other overheads and provisions (working capital requirements, demand for materials and chemicals in the start-up phase, as well as provisions amounting to 15% of TPC) – as total as spent costs (TASC) [31].

The calculation of operating costs comprised the cost of fuel used as charge – coal – as well as raw materials and other materials, energy and utilities, services, taxes and fees (real property taxes and insurance premiums, cost of CO₂ emission, fees for use of the environment), remuneration and related costs, depreciation, as well as other costs of operation (cost of plant closure, costs of CO₂ monitoring, waste management). Costs related to general administration (administration and support) amounted to 30% of the cost of personnel. On the other hand, the costs of sales have been calculated as TPC overheads in the amount of 0.25%. The costs of taxes and fees have been calculated as 0.7% of TPC, while the costs of insurance as 0.5% of TPC. Costs of repairs, servicing, and overhauls are calculated individually. The costs of fixed asset depreciation have been calculated taking into account the depreciation rates used for balance sheet purposes, adjusted to the useful life of a given technology.

The value of revenues has been calculated by multiplying the quantities of main products (electricity, methanol, and hydrogen), as well as respective intermediate products (heat, sulphur), and their prices, in line with assumptions made in table (Tab. 3).

3.2 Key assumptions

3.2.1 Key technical and technological assumptions

Table 1 shows the mass balance with particular emphasis on the final products and the quantity of CO₂ emitted or stored. These calculations are the underlying assumptions in the assessment of economic efficiency of the analysed technologies.

Table 1. Technical and technological assumptions in the assessment – mass balance

Name of tech.	Coal	CCS	Final product	Raw input (flow rate)	Dried input (flow rate)	Capacity factor	Cal. value of dried coal	Cal. value of raw coal
Technology description				[Mg/h]	[Mg/h]	[%]	[GJ/Mg]	[GJ/Mg]
Shell	H.c.	0	E.en.	85,1	69,0	80%	24,9	20,2
Shell	H.c.	1	E.en.	85,1	69,0	80%	24,9	20,2
Shell	B.c.	0	E.en.	161,6	85,8	80%	20,1	10,6
Shell	B.c.	1	E.en.	161,6	85,8	80%	20,1	10,6
Shell	H.c.	0	H2	95,7	77,7	90%	24,9	20,2

Shell	H.c.	1	H2	95,7	77,7	90%	24,9	20,2
Shell	B.c.	0	H2	181,8	96,5	90%	20,1	10,6
Shell	B.c.	1	H2	181,8	96,5	90%	20,1	10,6
GE	H.c.	0	H2	95,7	73,4	90%	26,4	20,2
GE	H.c.	1	H2	95,7	73,4	90%	26,4	20,2
Shell	H.c.	0	MeOH	95,7	77,7	90%	24,9	20,2
Shell	H.c.	1	MeOH	95,7	77,7	90%	24,9	20,2
Shell	B.c.	0	MeOH	181,8	96,5	90%	20,1	10,6
Shell	B.c.	1	MeOH	181,8	96,5	90%	20,1	10,6

H.c. – hard coal, B.c. – brown (lignite) coal, E.en. – electric energy, H2- hydrogen, MeOH – methanol. Own study.

Table 1a. Technical and technological assumptions in the assessment – mass balance (cont.)

Description	Coal	CCS	El. energy	MeOH	H2	CO ₂ emission	CO ₂ stored
			[GJ/h]	[kg/h]	[kg/h]	[kg/h]	[kg/h]
Shell	H.c.	0	736	-	-	164 921	-
Shell	H.c.	1	547	-	-	17 137	147 785
Shell	B.c.	0	737	-	-	171 778	-
Shell	B.c.	1	526	-	-	17 528	154 250
Shell	H.c.	0	-	-	9 306	184 850	-
Shell	H.c.	1	-	-	8 477	20 061	164 789
Shell	B.c.	0	-	-	8 421	192 799	-
Shell	B.c.	1	-	-	7 237	20 643	172 156
GE	H.c.	0	-	-	7 977	182 764	-
GE	H.c.	1	-	-	6 637	18 431	164 333
Shell	H.c.	0	-161	57372	-	105 662	-
Shell	H.c.	1	-254	57372	-	6 465	99 196
Shell	B.c.	0	-177	54214	-	118 024	-
Shell	B.c.	1	-276	54214	-	6 110	111 915

Own study.

The assessment period was 30 years for all the technologies, with the building phase of 3 years. The intensity of the capital expenditures was assumed 20%, 45% and 35% in the third year.

The useful life comprised the construction phase, operation (26 successive periods/cycles), preceded by the commissioning and start-up (half a year) and one year for liquidation. The manufacturing scale, expressed as the amount of energy at input to the system (equivalent of 100 Mg of coal with the calorific value of 21.5 GJ/Mg) was equal for all the technological variants analysed.

Table 2 contains the characteristics of physical and chemical parameters of coal grades that underwent gasification. Grades of similar characteristics may be considered the most frequently occurring in Poland.

Table 2. Elemental composition and energy specifications for hard and brown (lignite) coal

Description	U.m.	Hard coal	Brown coal /lignite
humidity	[%]	21.3	48.8
coal	[%]	54.26	32.00
hydrogen	[%]	3.11	2.48
nitrogen	[%]	0.84	0.39
chlorine	[%]	0.00	0.01

Description	U.m.	Hard coal	Brown coal /lignite
sulphur	[%]	1.10	0.03
ash	[%]	9.30	5.49
oxygen	[%]	10.09	10.80
Calorific value			
High heat value HHV	[GJ/Mg]	21.43	12.39
Low heat value LHV	[GJ/Mg]	20.22	10.65

Own study.

Gasification process in Shell technology is based on entrained-flow gasifier operating at full commercial scale. Gasification reaction takes place at 4.2 MPa and 1430°C to produce syngas. The Shell process uses a dry feed system (hard coal is crashed and dried to 6% of moisture and the lignite to 12%). The product gas from the gasifier is cooled using a syngas recycle quench. Syngas goes through a raw gas cooler, which lowers the gas temperature to a minimum of 230°C (450°F), and contributes to the production of high pressure steam for use in the steam cycle. The solids and liquid slag formed in a water bath are removed through a lock hopper system. Ash carried over with the syngas is removed in a ceramic candle filter. Syngas enters the scrubber for removal of chlorides and entrained particles, principally unconverted carbon, slag and metals. In the acid gas removal process, COS hydrolysis, mercury clean-up about 15 percent of the CO₂ along with the H₂S and COS is removed. The residual CO₂ passes through the SRU, the hydrogenation reactor and is recycled to the AGR. The SRU utilises oxygen instead of air. The Claus plant produces sulphur, of which recovery exceeds 99%. Clean syngas exiting the sulfinol absorber is reheated, diluted with nitrogen from the ASU, and enters the advanced F-Class gas turbine in the IGCC plant. Then exhaust gas is transported to the HRSG where additional heat is recovered. The steam from the HRSG is delivered to the steam turbine and generator.

In the case of Shell hydrogen production the water-gas-shift reactor provides the optimal syngas composition. Hydrogen is separated with an efficiency of 80% and is purified to the required level of 99.9%. Tail gas is burned in the CT burner to produce heat and vapour for the turbine generator.

However, in the case of methanol production, cleaned syngas is sent to the methanol synthesis unit. Raw methanol is then subjected to purification (99.9% pure). The tail gas is combusted in a flare, or if it is sufficiently rich in combustible components, passes through the boiler and the turbine connected to the generator (fig. 1).

In the case of the General Electric hydrogen production plant a wet feed system is used and gasification process occurs at a temperature of 1320°C and pressure of 5,6 MPa. The oxidant is 99% oxygen separated in the ASU. Raw synthetic gas is then transported to battery filters and cyclones to remove particles, NH₃, SO₂ and other impurities and in the quench water system and scrubbers is cooled to 230°C. The 99,9% of particles, 90% of chlorides and the alkaline compounds are removed so far.

The water-gas-shift reaction takes place at 5.4 MPa enhancing the amount of

H₂. After WGS conversion syngas is cooled to 35°C and cleaned of mercury, acid components (COS) in the selexol unit. Hydrogen is separated at a level of 80% and purified to 99,9%. The tail gas is combusted in the boiler, and steam produced enters the turbine connected to the generator.

For technologies with the CCS, CO₂ extracted from syngas is compressed and then with the pipeline system is transported assuming geological sequestration.

In both technologies, the exhaust gases having a temperature of 140°C are sent to the chimney (fig 2).

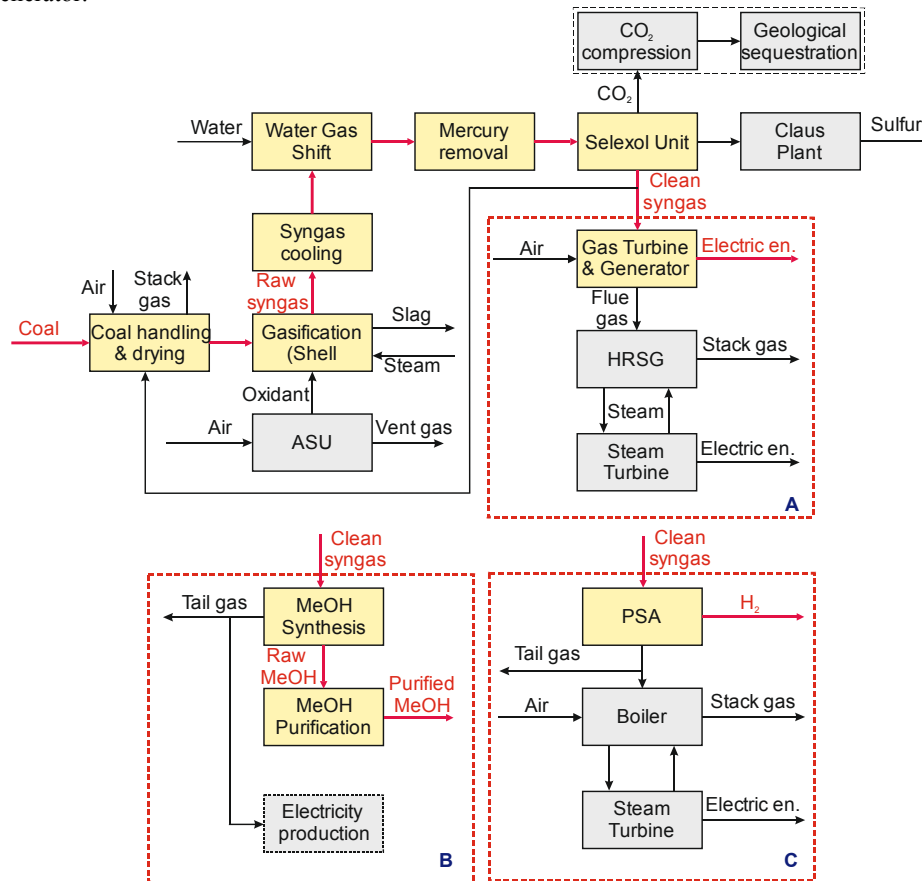


Figure 1. Block diagram of the Shell technology; A – electric energy, B – methanol, C – hydrogen production. Own study.

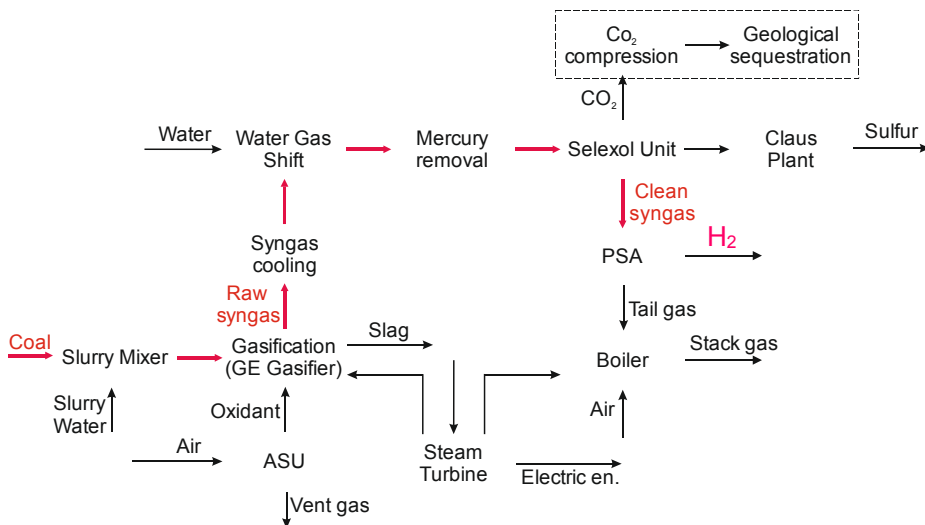


Figure 2. Block diagram of the General Electric technology; hydrogen production. Own study

3.2.2 Key economic and financial assumptions

Table 3 contains the key macroeconomic assumptions, which serve the purpose of evaluating the analysed technological variants of coal gasification. All the calculations have been made in nominal terms (the detailed forecast comprised 10 consecutive one year periods). The prices of specific end products and of coal have been estimated according to individual growth paths (Tab. 3).

Table 3. Gasification of coal to produce electricity

Description	2015	Assumptions in 2016-2025
Inflation CPI	1.1%	2016: +1.6%; 2017-2025: + 2.5%
Price of hard coal	197.0 [PLN/Mg] (9.74 PLN/GJ)	+ 0.25% y/y
Price of brown coal	76.6 [PLN/Mg] (7.2 PLN/GJ)	+ 0.3% y/y
Price of methanol	1,450 [PLN/Mg]	+ 1.25% y/y
Price of hydrogen	7,400 [PLN/Mg]	+ 0.75% y/y
Price of electricity (sold)	170.0 [PLN/MWh]	+ 1% y/y
Price of electricity (buy)	290.0 [PLN/MWh]	+ 1% y/y
Price of natural gas	1.11 [Nm ³] (110 PLN/MWh)	+ 0.25% y/y
Price of CO ₂ allowance	30.0 [PLN/Mg]	+ 1% y/y
Financing	50% of Debt	
Risk	RADR (risk adjusted discount rate 6-10%)	

Own study.

It has been assumed in the analyses that 50% of the capital expenditures will be financed by a loan, having the interest rate of 5.84% p.a. The discount rate has been assessed individually for each variant analysed by experts, while the results of such assessment are presented in Table 4. Variants with CCS demonstrate higher risk (premium of 2-3%), due to the fact that those technologies are not so advanced in Poland, for the time being.

Table 4. Risk assessment and discount rates (RADR)

Sp.	Tech.	Coal	CCS	Final product	Base [%]	Risk premium [%]	RADR
1	Shell	H.c.	0	El.en.	4.2%	1.8%	6.0%
2	Shell	B.c.	0	El.en.	4.4%	1.8%	6.2%
3	Shell	H.c.	1	El.en.	5.3%	3.7%	9.0%
4	Shell	B.c.	1	El.en.	5.3%	3.7%	9.0%
5	Shell	H.c.	0	H ₂	4.2%	1.7%	5.9%
6	Shell	B.c.	0	H ₂	4.2%	1.7%	5.9%
7	Shell	H.c.	1	H ₂	5.3%	3.7%	9.0%
8	Shell	B.c.	1	H ₂	5.3%	3.7%	9.0%
9	GE	H.c.	1	H ₂	5.3%	3.6%	8.9%
10	GE	H.c.	0	H ₂	4.2%	1.8%	6.0%
11	Shell	H.c.	0	MeOH	4.2%	1.7%	5.9%
12	Shell	B.c.	0	MeOH	4.2%	1.7%	5.9%
13	Shell	H.c.	1	MeOH	5.3%	3.7%	9.0%
14	Shell	B.c.	1	MeOH	5.3%	3.7%	9.0%

H.c. – hard coal, B.c. – brown coal (lignite).

Table 5 presents the investment outlays related to construction of installations. Additionally, the expenditures concerning geological sequestration of carbon dioxide have been specified (if applicable). In case of CO₂ storage, its previous compression has been assumed and transport by pipeline along a distance of some 80 km. The investment outlays are in the range of 2.91-3.91 billion PLN. The investment costs concerning CCS module amount from 300 to 430 million PLN, depending on the variant.

Table 5. Capital expenditure for the coal gasification technologies – electricity production [mln PLN]

Description	Shell technologies			
	Hard coal		Brown coal/Lignite	
	w/o CCS	CCS	w/o CCS	CCS
Total Capex	2 990	3 450	3 440	3 910
Capex for CCS	-	390	-	400

Own study.

Table 5a. Capital expenditure for the coal gasification technologies – hydrogen production [mln PLN]

Description	Shell technologies				GE technologies	
	Hard coal		Brown coal/Lignite		Hard coal	
	w/o CCS	CCS	w/o CCS	CCS	w/o CCS	CCS
Total Capex	2 910	3 400	3 510	4 010	2 680	3 160
Capex for CCS	-	420	-	430	-	420

Own study.

Table 5b. Capital expenditure for the coal gasification technologies – methanol production [mln PLN]

Description	Shell technologies			
	Hard coal		Brown coal/Lignite	
	w/o CCS	CCS	w/o CCS	CCS
Total Capex	2 900	3 200	3 240	3 570
Capex for CCS	-	300	-	330

Own study.

Table 6 contains the key assumptions used calculation of operating costs pertaining to the consumption of chemicals and materials, whereas Table 6a, respectively, contains the assumptions for salary cost estimation. Total employment amounted to 50 people (including 24 persons of maintenance personnel and 3 persons of technical inspection).

Table 6. Costs of production – key assumptions

Description	U.m.	Value
Carbon (Mercury Removal)	[PLN/kg]	12.6
Claus catalyst	[PLN/m ³]	23,500
COS catalyst	[PLN/m ³]	13,000
MU & WT chem.	[PLN/kg]	2.1
Slag	[PLN/Mg]	30.0
Spent mercury catalyst	[PLN/kg]	5.0
Sulfinol solution	[PLN/l]	9.5

Description	U.m.	Value
Water	[PLN/m ³]	1.3
Water gas shift catalyst	[PLN/m ³]	90,000.0
Selexol solution	[PLN/l]	33.5

Own study.

Tabela 6a. Labour costs – key assumptions

Description: labour	U.m.	Cost
Operator	[PLN/mth]	5,000
Skilled operator	[PLN/mth]	10,000
Foremen and administration	[PLN/mth]	12,000

Own study.

4 Results of studies

Tables 7, 8, and 9 show the results of assessing the economic efficiency of coal gasification, as well as recommendation of the most favourable investment decisions, as regards the generation of carbon dioxide. Also the assessment of NPV result sensitivity to the change in the price of CO₂ emissions allowances in the range of 30-200 PLN/Mg has been added.

When Table 7 is analysed, one can notice that – for the assumptions made – the technologies of hard coal and lignite gasification to produce electricity are not efficient. At the price of CO₂ emissions allowances below 90 PLN/Mg of carbon dioxide, it is more profitable to emit the gas to the atmosphere. Only when the price exceeds 120 PLN/Mg of CO₂, efficiency advantage measured by means NPV is gained by the variants with CCS. The sensitivity of NPV results in case of gasification for power generation from coal grades analysed was relatively low, which is due to the conditions of the valuation model and low NPV values in the base scenario (CO₂ emissions allowance trading at 30 PLN/Mg).

Table 7. Gasification of coal for power generation

Description	Shell Technology			
	Hard coal		Brown coal/Lignite	
	w/o CCS	CCS	w/o CCS	CCS
CO₂ price [PLN/Mg]	NPV [FCFF] [mln PLN]			
30 (ref. Scen)	-2 818	-3 952	-3 014	-4 338
60	-3 325	-3 994	-3 542	-4 380
90	-3 831	-4 036	-4 070	-4 423
120	-4 338	-4 077	-4 597	-4 466
150	-4 844	-4 119	-5 125	-4 508
200	-5 689	-4 189	-6 004	-4 579
CO₂ price [PLN/Mg]	Decision to invest			
30 (ref. Scen)				
60	EU ETS	-	EU ETS	-
90		-		
120	-			
150		CCS	-	CCS
200				
CO₂ price [PLN/Mg]	NPV sensitivity (to reference scenario)			
60	18%	1%	18%	1%
90	36%	2%	35%	2%
120	54%	3%	53%	3%

Description	Shell Technology			
	Hard coal		Brown coal/Lignite	
	w/o CCS	CCS	w/o CCS	CCS
150	72%	4%	70%	4%
200	102%	6%	99%	6%

Own study.

In case of gasification of coal to hydrogen, all the technological variants are also inefficient, taking into consideration the NPV criterion and assessment conditions. It can be stated that generally better results are achieved in case of hard coal gasification using the technology of Shell than that of General Electric (GE). Higher NPV values have been achieved in case of hard coal gasification. The analysis of Table 8 leads to the conclusion that only in case of prices of CO₂ emissions allowances exceeding 120 PLN/Mg, the decisions concerning construction of CCS are justified (in case of lower prices, the purchase of emissions allowances is more advantageous). The net present value is particularly sensitive to changes in the emissions allowances price level, in particular for those variants, for which the economic efficiency measured by means of the NPV indicator is close to 0.

Table 8. Coal gasification to hydrogen

Description	Shell Technology				GE Technology	
	Hard coal		Brown coal/Lignite		Hard coal	
	w/o CCS	CCS	w/o CCS	CCS	w/o CCS	CCS
CO₂ price [PLN/Mg]	NPV [FCFF] [mln PLN]					
30 (ref. Scen)	-339	-1 497	-1 040	-2 547	-745	-2 185
60	-687	-1 531	-1 470	-2 597	-1 149	-2 230
90	-1 061	-1 566	-2 046	-2 648	-1 701	-2 275
120	-1 567	-1 601	-2 638	-2 698	-2 262	-2 320
150	-2 135	-1 636	-3 231	-2 748	-2 824	-2 364
200	-3 081	-1 696	-4 218	-2 832	-3 759	-2 439
CO₂ price [PLN/Mg]	Decision to invest					
30 (ref. Scen)						
60	EU ETS	-	EU ETS	-	EU ETS	-
90						
120						
150	-	CCS	-	CCS	-	CCS
200						
CO₂ price [PLN/Mg]	NPV sensitivity (to reference scenario)					
60	103%	2%	41%	2%	54%	2%
90	213%	5%	97%	4%	128%	4%
120	363%	7%	154%	6%	204%	6%
150	530%	9%	211%	8%	279%	8%
200	809%	13%	306%	11%	405%	12%

Own study.

In case of gasification of selected grades of coal to methanol, the base variant – for the emissions allowances price of about 30 PLN/Mg CO₂, assumed prices of coal and methanol over the next 30 years generates the positive value of NPV at the level of 135 million PLN. In other cases the net present value was negative. Only in case of lignite (brown coal) gasification

and prices of emission allowances exceeding 150 PLN/Mg of CO₂ the option of constructing CCS has an efficiency advantage. NPV sensitivity to the change of emission allowances varies depending on the variant. The highest level NPV variability is demonstrated for those variants, for which the base NPV was relatively close to 0. The least sensitivity is demonstrated by the variants with strongly negative NPV (they include CCS systems, and the emission to air does not exceed 10%).

Table 9. Coal gasification to methanol

Description	Shell Technology			
	Hard coal		Brown coal/ Lignite	
	w/o CCS	CCS	w/o CCS	CCS
CO₂ price [PLN/Mg]	NPV [FCFF] [mln PLN]			
30 (ref. Scen)	135	-1 072	-261	-1 513
60	-64	-1 082	-483	-1 523
90	-263	-1 093	-708	-1 533
120	-462	-1 103	-938	-1 543
150	-664	-1 113	-1 188	-1 553
200	-1 021	-1 130	-1 716	-1 571
CO₂ price [PLN/Mg]	Decision to invest			
30 (ref. Scen)	EU ETS	-	EU ETS	-
60			EU ETS	-
90			EU ETS	-
120			EU ETS	-
150			EU ETS	-
200	-	-	CCS	
CO₂ price [PLN/Mg]	NPV sensitivity (to reference scenario)			
60	148%	1%	85%	1%
90	295%	2%	171%	1%
120	443%	3%	259%	2%
150	593%	4%	354%	3%
200	858%	5%	557%	4%

Own study.

5 Summary and conclusions

The study presents the results of economic efficiency assessment for 14 technological variants of hard and brown coal (lignite) gasification to produce electricity, hydrogen, and methanol. Higher NPV was decisive for the selection of a more advantageous economic decision (purchase of EU ETS or construction of CCS system). In the entire assessment process, also other criteria of costs, values, or risks have been considered, such as: COE – cost of electricity, LCOE, yearly costs of operations, investment outlays (also individual ones), levels of CO₂ emission, dynamic discount rate, RADR (risk-adjusted discount rate), IRR, or NPVR, they have not been presented in this paper, though. The entire results of analyses may be found in [24].

The analysis concerned technological solutions of two producers, namely Shell and General Electric (Texaco).

The analyses conducted allow to state that for the assumed scale of energy consumption analysis in the charge fuel, parameters of selected coal grades, and specified prices of end products of gasification, most

of the technological variants failed to obtain efficiency confirmation, using NPV as base. Only one variant of hard coal gasification achieved the NPV value of nearly 135 million PLN. However, this is a case in which the entire fuel is converted into end products, while the internal consumption is covered by external purchase of electricity. In case of gasification for power generation, at allowances prices exceeding 90 PLN/Mg of CO₂, geological sequestration of carbon dioxide seems to be more advantageous. In case of hydrogen production, the justification for decision change occurs at the allowance price of 120 PLN per 1 Mg of CO₂ or higher. In case of methanol, only the allowance price level higher than 150 PLN/Mg of CO₂ may justify decisions to invest in the construction of CCS systems.

The results sensitivity of NPV to change of the price level of CO₂ emissions allowances differs in different variants, with the most significant changes occurring in case of methanol production, similar in case of methanol, and less profound in case of electricity.

In conclusion, one can state that the assumptions of rigorous requirements concerning CO₂ emission limits, which result in significant increases of the emissions allowance price, may greatly influence the assessment of coal gasification efficiency. This applies in particular to the production of electricity and hydrogen. In case of methanol production, a part of CO₂ is bound in end products, which significantly enhances the efficiency and attractiveness of MeOH generation. A significant increase of the price of emissions allowances will also result in substantial reduction of attractiveness of investment in conventional power engineering and heat generation.

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