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CCS Cost Estimation Model Process and Analysis

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Abstract

This thesis proposed an objective and accurate fundamental numeric data for the economics and business analysis of applicable CCS technology to plant using existing fossil fuel by analyzing the influence of process improvement for commercialization of Carbon Capture and Storage(CCS) technology, which enables storing CO_2 generated by fossil fuel by extracting before emitting to air and press until it becomes liquid, and development and performance improvement of new solvent on Total Life Cycle Cost(TLC) of CCS.

Keywords: *CCS, TLC, CAPEX, OPEX*

1. Introduction

Since the industrial revolution, due to the increase in human activity, the greenhouse gas emission has been rapidly increasing, and this gas has become the most significant cause of climate change. Carbon dioxide takes most place in various greenhouse gas, and the two thirds of total CO_2 emission occurs in energy part which uses fossil fuel. Now the global society is focusing on how to reduce the CO_2 emission occurring in the energy industry. In such atmosphere, Korea which is ranked in 10th in greenhouse gas emission in 2003 with 5.82million tons, is receiving increased pressure for greenhouse gas emission reduction, and it is urgent to organize countermeasure foundation to create national benefit compared to the second greenhouse gas emission reduction starting from 2013. However, Korea makes national greenhouse emission statistics based on IPCC emission factor which is the basic emission amount calculation method proposed by IPCC.

The model analysis increased cost occurring when the post-combustion (MEA-Based CCS, Dry Sorbet CCS, Membrane CCS) technology for CO_2 combustion at the currently running Coal-fired electrical power plant. Also, the post-combustion is a technology which removes CO_2 from the gas emitted by fossil fuel, which can be retrofitted to existing plant or be installed with newly constructed plant facility, which enables its wider

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technological use (pre-combustion, oxy fuel combustion) and is quiet flexible in management by running independently apart from the plant.

2. Analysis subject

2.1 Coal-fired electrical power plant , SCPC

Hendriks(2004) classifies coal-fired electrical power plant, the subject of Retrofit as in Table 1.

Table 1. Characteristics by the types of coal-fired electrical power plant

Types of coal-fired electrical power plant	Temperature(℃)	Pressure(bar)	Typical maximum efficiency (LHV)
Subcritical (SUBCR)	538	167	39%
Supercritical (SUPERC)	540-566	250	42%
Ultra-supercritical (ULTRASC)	580-620	270-290	47%

Thesis has set the Retrofit subject selection standard proposed in IEA(2012) on whether or not retrofitting is economical for coal-fired electrical power plant to have CCS facility as in Table 2.

Table 2. Retrofit subject power plant selection standard

Retrofit Subject power plant	Electricity generation over **100MW**, operation period under **30years**
	Electricity generation over **300MW,** operation period under **20years**
	Electricity generation over **300MW,** operation period under **10years**

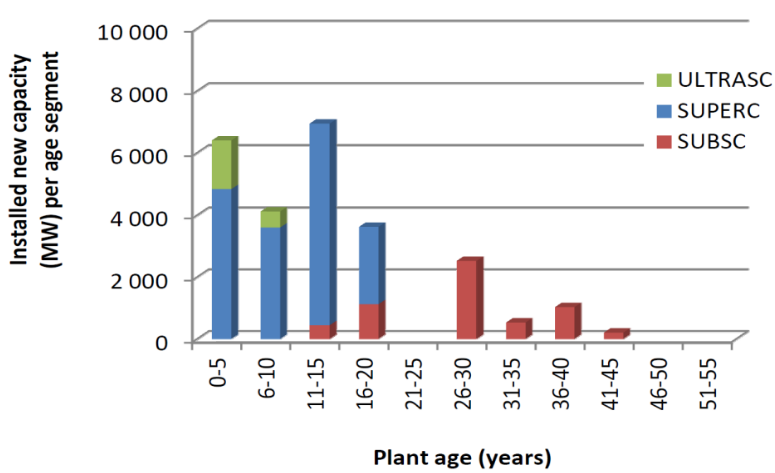

Figure 1. Type, operation period, electricity generation capacity of Korean coal-fueled electricity power plant

The type, operation period, generation capacity of Korean coal-fired electrical power plant is as in Figure 1, and the fundamental features of power plant are as follows. The 82% of overall operated coal-fired electrical power plant has been running under 20 years, and 40% are under 10 years. The 80% of overall coal-fired electrical power plant had generation capacity more than 300MW, while the 74% was in form of super critical or ultra-supercritical. Also, the 90% of coal-fired electrical power plant with operation period under 20 years were supercritical, ultra-supercritical and power plant with operation period under 10 was supercritical or ultra-supercritical. The total generation capacity of coal-fired electrical power plant is 26GW. Retrofit is the most proper access method as it applied the post-combustion technology regarding current condition in Korea.

2.2 Cost component

The cost flow is as in Figure 2. The cost over TLC is distinguished by Capital Expenditure (CAPEX), Operating Expenditure (OPEX) for calculation. The cost necessary for combusting CO_2 is classified into combustion-storage-transportation to calculate individual cost and add up the total cost to suppose it as combustion cost. CO_2 combusted from the combustion facility applying MEA-based CCS, dry sorbent CCS, membrane CCS is assumed to have same transportation-storage route.

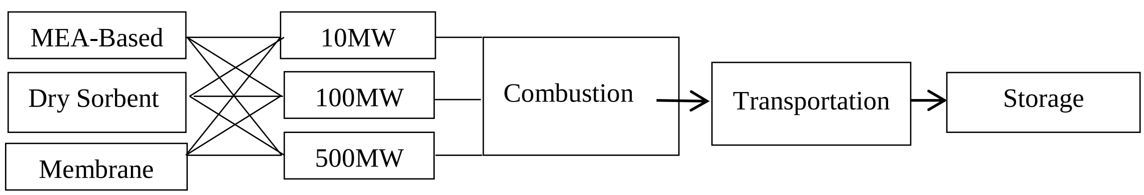

Figure 2. Cost flow chart

3. Analysis model

3.1 Cost assumption method comparison of existing model and developing model

The model developed in this thesis distinguishes cost increased by CCS into combustion-transportation-storage and the individual cost as CAPEX, and OPEX to assume the combustion cost, and focus on calculating the $/t$CO_2$ rather than LCOE calculation. In case of constructing power plant including retrofit or CCS, the total generation cost can be calculated by adding the CCS cost to the original generation cost with LCOE. To sum up, the model in this thesis calculates the increased cost of generation cost unlike other existing models.

The Hamiton (2009) from the existing model increases fuel cost by the lower generation efficiency due to facility(38.50% →29.30%), which recognizes such cost increase as individual cost component. It calculates LCOE of reference power plant, calculate LCOE from the CCS power plant and sees the difference as LCOE cost increase due to CCS. This calculation contains cost evasion concept for the cost necessary to process 1 ton of CO_2 in CO_2 combustion facility, which is described in formula (1).

$$Cost\ of CO_2 \text{ Avoided}\left(\frac{\$}{tCO_2}\right) = \frac{(\frac{\$}{MWh})ccs-(\frac{\$}{MWh})reference}{(\frac{tCO_2}{MWh})ref-(\frac{tCO_2}{MWh})rccs} \quad (1)$$

3.2 Major difference of cost assumption in existing and developing model

In the existing study, when the power plant is equipped with combustion equipment, the energy penalty is generated, which calculates the energy part(the degraded generation efficiency part) is assumed as increase of fuel cost($/tonne) while this thesis aims to assume the combustion price ($/t$CO_2$) and increased generation cost by dividing into fuel cost($/GJ) and electric energy ($/MWh). The combustion price assumption is calculated along with formula (2) and (3) by setting the basic assumption and classifying the cost element into CAPEX and OPEX.

CAPEX : TOC(Total Overnight Cost) = TPC(Total Plant Cost) + Extra
TPC = EPC(Engineering, Procurement and Construction cost) + Contingency (2)
EPC = Equipment + Engineering+ Procurement

OPEX = Steam & Electricity+ Solvent+ Labor & Maintenance+ Property taxes & Insurance+ Water & By-product (3)

3.3 Annual factor

This thesis assumes that the combustion equipment not regarding the year will show the same completion rate during the construction and set as equality investment during the construction period. If the initial investment cost is not equalized, the initial l\$/tCO_2 can be overstates, so calculate as in formula(4) by distributing the cost for years by multiplying the annual equalization factor.

$$Annual\ Factor = \frac{r(1+r)^n}{(1+r)^n-1} \tag{4}$$

r : Discount rate, n : Economic service life

Compared to formula (4), the annual equalization factor of this thesis is calculated with 10% discount rate, 30 economic service life years presumption and it comes out as formula(5).

$$Annual\ Factor = \frac{0.1(1+0.1)^{30}}{(1+0.1)^{30}-1} = 0.10608 \tag{5}$$

Table 3. Common fact of cost analysis regarding combustion technology

Composition	Assumption	Note
Power plant	SCPC (Supercritical Pulverized Coal power plant) Pure electricity generation: 500MW	Commercial
	Capacity Factor: 90%	Refer to capacity factor of Korean power plant(5)
Generation efficiency	38.4%	EPRI(2010)
Fuel type	11,660btu/lb(27.113MJ/kg)	Bituminous Illinois No.6 (NETL 2010)
CO_2 emission (tCO_2/h)	395.35	CO_2 occurring when burning 1 ton of fuel(bituminous fuel) when applying fuel conversion variable as 2.287087 ton
Captured efficiency	90%	removal efficiency
CO_2 combustion amount (tCO_2/h)	320.23 (2,805,253tCO_2/yearly standard-500MW-annual combustion)	Operation rate90%, combustion rate90% CO_2 combustion per hour after application
Construction period	3 years Assuming equal rate investment (completion process rate equal every year	Davision(2007) - 3 years NETL(2010) - 3year(NGCC), 5year(PC, IGCC)
Economic service life	30 years CCS content operation(operation period) after construction period	Assume the operation period as 30 years after Retrofit

Fuel(Coal) price	$100/tonne($3.2/GJ)	range $44-134/tonne
Cost of Electricity	$66/MWh(LCOE)	OECD average(IEA, 2011)
Discount rate	10%(weighted average cost of capital)	Apply 10% reflecting CCS risk (ROE 5.4% average of Korean power plant)
Annual Factor	10.608%	Estimated average ROE of power plant : 5.4% Apply 10% of reflected CCS risk by equity capital(Consider discount rate from existing literature)
Financing	100% equity capital	

Table 4. Analysis result

Combustion technology		Post-combustion								
		MEA-Based CCS			Dry Sorbent CCS			Membrane CCS		
Scenario(MW)		10	100	500	10	100	500	10	100	500
Combustion price ($ / t CO_2)	**CAPEX**	**54.57**	**22.65**	**15.91**	**52.33**	**21.54**	**14.73**	**72.60**	**40.18**	**29.41**
	Equipment	23.64	9.66	6.72	22.81	9.33	6.35	31.77	17.58	12.87
	Engineering	1.42	0.58	0.40	1.37	0.56	0.38	1.91	1.06	0.77
	Procurement	17.73	7.25	5.04	17.11	7.00	4.76	23.83	13.19	9.65
	Contingency	8.56	3.50	2.43	8.26	3.38	2.30	11.50	6.37	4.66
	Extra	3.24	1.66	1.33	2.79	1.27	0.93	3.59	1.99	1.46
	OPEX	**93.45**	**45.17**	**35.49**	**89.11**	**44.63**	**35.94**	**94.68**	**59.22**	**51.76**
	Steam & Electricity	21.64	21.64	21.64	24.27	24.27	24.27	26.33	26.33	26.33
	Solvent	1.29	1.29	1.29	0.62	0.62	0.62	10.87	10.87	10.87
	Labor & Maintenance	39.16	9.66	5.28	38.62	9.45	5.05	44.46	14.82	9.29
	Property taxes & Insurance	9.68	3.96	2.75	9.34	3.82	2.60	13.01	7.20	5.27
	Water & By-product	21.68	8.63	4.53	16.26	6.47	3.40	0.00	0.00	0.00
Combustion CAPEX &OPEX		148.02	67.82	51.41	141.44	66.17	50.66	167.28	99.40	81.18

4. Conclusion

According to the CAPEX analysis result, 500MW level MEA-Based CCS, Dry Sorbent CCS, and Membrane CCS was each \$15.91/t CO_2, \$14.73/t CO_2, \$29.41/t CO_2 while the OPEX was \$35.19/t CO_2, \$35.94/t CO_2, \$51.76/t CO_2 each. The entire combustion cost (CAPEX & OPEX) was each \$51.41/t CO_2, \$50.66t CO_2, \$81.18/t CO_2 which indicates the MEA-Based CCS is the most economic choice.

As for the future study, there is a need for business strategy considering the life cycle of CCS to include transportation/storage analysis based on simple process to expand various network transportation/storage method, various storage environment, mass storage scale. After conducting compare evaluation on CCS alternative(competing) technology for its economics, the major study development field of CCS will be deducted and prepare the standard for business evaluation of the technology. By conducting the comparative analysis on CCS combustion cost, the economics of alternative(competing) technology is compared, utilize the individual technology, and set the strategy to conduct concentrated investment of applicable technology application field and initial business object of technology.

By applying the economics analysis method applied in national R&D business preliminary validity evaluation, as the part of economic analysis CCS element technology and creative economics, the business strategy combining the contribution analysis of technology toward national economics should be pursued.

In order to achieve this, the R&D, promotion status, commitment element, technique commercialization, licensing, application effect in other industry field and export effect of the technology, import alternative effects are analyzed to create strategy which will achieve the direct and indirect achievement from the valid investment source distribution of governmental technology development.

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