Chapter 4

Economic Benefits of the Introduction of Clean Coal Technology in the East Asia Summit Region

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Chapter 4
Economic Benefits of the Introduction of Clean Coal Technology in the East Asia Summit Region

4-1. Cost–benefit Analysis of USC

This chapter covers a cost–benefit analysis of ultra-supercritical (USC), supercritical (SC), and subcritical coal-fired power plants. In this analysis, levelised cost of electricity (LCOE) is calculated for three different coal prices.

This section outlines the general assumptions of the cost–benefit analysis. Section 4.2 explains the methodology of each cost component while Section 4.3 shows the results of the cost–benefit analysis.

4-1-1. General assumptions for cost–benefit analysis

This section outlines the general assumptions for power plant specifications and coal properties used in this analysis. These are summarised in Table 4-1.

Plant capacity is set at 1,000 megawatt (MW). For cash flow calculation purpose, operation is set at 25 years with an average of utilisation rate of 80 percent. Total annual generation is therefore 7,008 gigawatt-hours (GWh). Thermal efficiencies are set at 42.1 percent (USC), 41.1 percent (SC), and 38.2 percent (subcritical). Thermal efficiencies are taken from New Energy and Industrial Technology Development Organization (NEDO) study titled 'Promotion of High-Efficiency Coal-Fired Power Stations in Indonesia' in 2014

Coal specifications are set as follows: calorific value is 4,000 kcal/kg and CO_2 emissions, adjusted from the Intergovernmental Panel on Climate Change (IPCC) default emission factors, are 1.43 kg-CO_2/kg-coal.

Table 4-1. General Assumptions for Cost–Benefit Analysis

		Values	Remarks
Plant	Capacity	1,000 MW	
	Operation	25 years	For cash flow purposes
	Operation rate	80%	
	Thermal efficiencies	42.1% (USC), 41.1% (SC), 38.2% (subcritical)	LHV value from NEDO study "Promotion of high-efficiency coal-fired power stations in Indonesia"
	Annual generation	7,008 GWh	
Coal specifications	Heating value	4,000 kcal/kg	
	CO2 emissions	1.43 kg-CO2/kg coal	Based on IPCC 2006 default emission factors for stationary combustion in the energy sector.

Source: Author's assumption and calculation.

4-1-2. Cost components and calculation methodologies

This section explains the calculation methodologies for cost components included in this analysis. A breakdown of LCOE is illustrated in Figure 4-1.

For the purpose of this analysis, LCOE consists of base plant costs, desulphurisation and denitrification costs, and financing costs. CO_2 emission costs are also calculated.

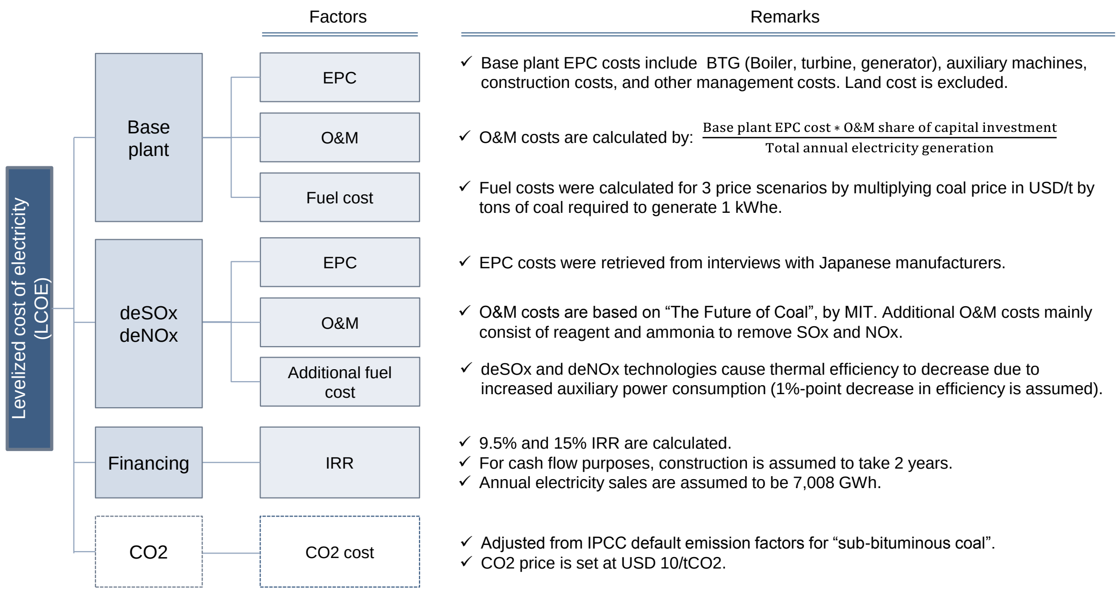
Base plant costs are divided into following costs: (1) engineering, procurement, and construction (EPC); (2) operation and maintenance (O&M); and (3) fuel costs.

Similarly, desulphurisation and denitrification also consist of: (1) EPC costs; (2) O&M costs; and (3) costs of additional fuel requirements.

Financing costs are calculated to generate 9.5 percent of internal rate of return (IRR) and 15 percent IRR. Plant construction is assumed to take two years. To calculate cash flows over operation, electricity sales are set equal to annual generation at 7,008 GWh for a period of 25 years, as mentioned in section 0.

CO_2 emission costs were calculated at US$10/tonne (t)-$CO_2$.

Figure 4-1. Breakdown of Levelised Cost of Electricity (LCOE)



Source: Author's assumption and calculation.

(1) Engineering, procurement, and construction (EPC) costs

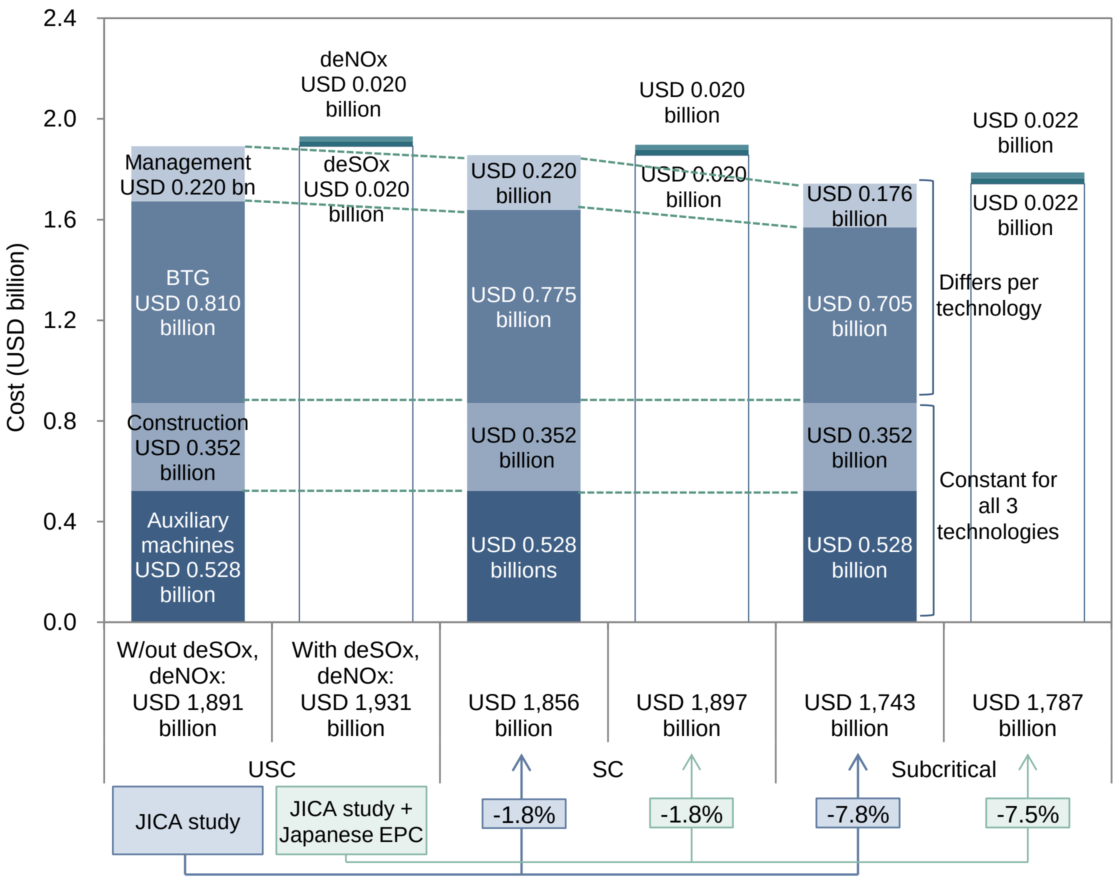
In this analysis, EPC costs consist of boiler, turbine, and generator (BTG), auxiliary machine costs, construction costs, and other management costs. Land costs are not included. Levelised EPC costs are calculated as total EPC costs divided by total electricity generation over the plant's lifetime.

A breakdown of EPC costs is illustrated in Figure 4-2. Based on assumptions in the Japan International Cooperation Agency (JICA) study titled 'Project for Promotion of Clean Coal Technology in Indonesia' (henceforth, JICA study), USC capital cost is estimated at US$1.891 trillion. This amount excludes desulphurisation and denitrification EPC costs, which are discussed below in (4). SC and subcritical capital costs are discounted from USC capital costs based on a cost index from the JICA study. Subcritical power plant capital costs are indexed at 100 while SC and USC are indexed at 106.5 and 108.5, respectively. Based on these indexes, capital costs for SC are estimated at US$1.856 trillion and capital costs for subcritical are estimated at US$1.743 trillion.

Breakdown of total EPC costs is obtained by study team analysis based on expert interviews. BTG costs and management costs differ per technology while auxiliary machine costs and construction costs are assumed to be the same for all three plants.

Excluding desulphurisation and denitrification costs, SC capital costs are 1.8 percent lower than USC capital costs. For subcritical, capital costs are 7.8 percent lower. When desulphurisation and denitrification costs are included, cost divergence amongst USC, SC, and subcritical costs decreases.[4] Note that SC capital costs are 1.8 percent lower than USC capital costs. Subcritical capital costs are 7.5 percent lower than USC capital costs.

Figure 4-2. Breakdown of EPC Costs



EPC = engineering, procurement, and construction.
Source: Japan International Cooperation Agency (JICA), 2014, 'Project for Promotion of Clean Coal Technology in Indonesia' and other resources.

(2) Operation and maintenance (O&M) costs

Base plant levelised O&M costs are calculated by dividing annual non-fuel O&M costs by annual generation (7,008 GWh). The process of calculating annual O&M costs is shown in Figure 4-3.

[4] Note that while SC capital costs are 1.8 percent lower in both cases, this is due to rounding. Actual results are 1.84 percent for capital costs excluding desulphurisation and denitrification, and 1.75 percent including desulphurisation and denitrification.

Annual O&M costs for USC are estimated at US$51.2 million based on the JICA study. In order to calculate O&M cost differences between USC, SC, and subcritical types, the annual O&M costs from the US Environmental Protection Agency (EPA) study titled 'New Coal-Fired Power Plant Performance and Cost Estimates' (henceforth, EPA study) were used as references. Annual non-fuel O&M costs for three hypothetical 900 MW coal-fired power plants firing bituminous coal were compared. Compared with USC O&M costs, SC O&M costs are 0.29 percent higher, and subcritical O&M costs are 1.02 percent higher.

Annual O&M costs for this analysis were calculated by applying the O&M cost differences from the EPA study to the annual O&M costs for USC from the JICA study.

There are two major reasons why USC O&M costs are lower than SC and subcritical O&M costs. First, although tubing materials for USC power plants are more expensive, which results in higher maintenance and replacement costs, replacement is only necessary after about 10 years instead of annually. Second, lower thermal efficiencies of SC and subcritical power plants require higher coal and water consumption, which causes auxiliary power use of pumps and fans, leading to higher maintenance costs. Therefore, annual USC O&M costs are lower than SC and subcritical O&M costs.

Figure 4-3. Calculation of O&M Costs

		USC	SC	Subcritical	Remarks
Data	O&M cost for 1,000 MW CFPP (USD/year)	51,160,000	NA	NA	Source: JICA study "Project for Promotion of Clean Coal Technology in Indonesia"
Data	Non-fuel O&M cost 900 MW CFPP firing bituminous coal (USD/year)	46,935,000	47,073,000 (+ 0.29%)	47,415,000 (+ 1.02%)	Source: "New Coal-Fired Power Plant Performance and Cost Estimates", prepared by Sargent and Lundy for EPA
Assumptions for CBA	O&M cost for 1,000 MW CFPP (USD/year)	Used as annual O&M costs: 51,160,000	51,310,422 (+ 0.29%)	51,683,209 (+ 1.02%)	Apply difference of annual O&M costs from EPA study to annual USC O&M costs from JICA study
Assumptions for CBA	EPC cost of medium scenario (USD)	1,931,000,000	1,897,000,000	1,787,000,000	See slide 24 for calculation details and assumptions (Values are rounded)
Assumptions for CBA	O&M share of capital investment	2.65%	2.70%	2.89%	Annual O&M cost divided by EPC cost

O&M = operation and maintenance.
Sources: Japan International Cooperation Agency (JICA), 2014 'Project for Promotion of Clean Coal Technology in Indonesia,' and United States Environmental Protection Agency (EPA), 2014 'New Coal-Fired Power Plant Performance and Cost Estimates.'

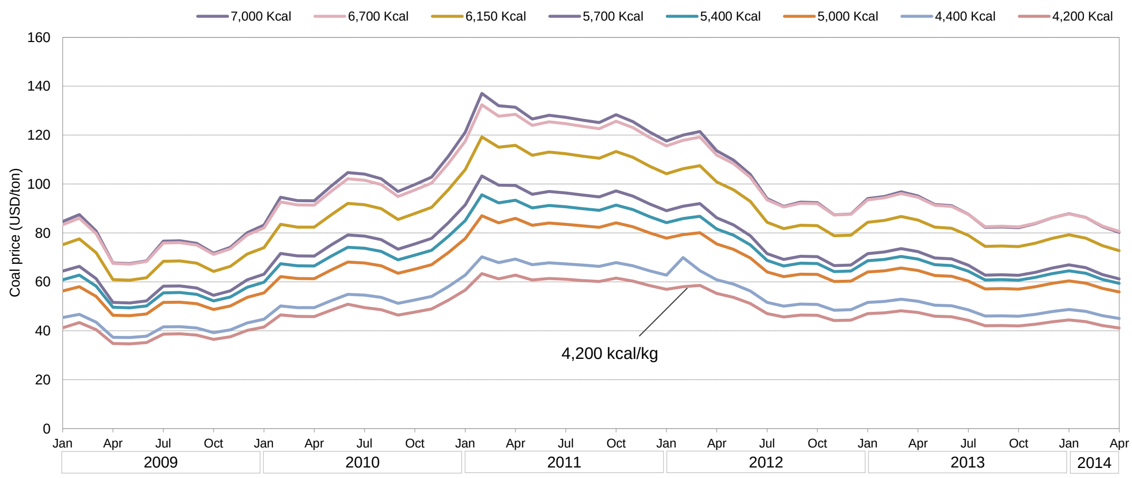
(3) Fuel Costs

In this cost–benefit analysis, LCOEs are calculated for three coal price scenarios. Figure 4-4 displays coal prices for Indonesia's most common markers where 4,200 kcal/kg coal prices (from EcoCoal) are used as a reference to decide the price scenarios. From 2009 up to the first quarter of 2014, coal prices for 4,200 kcal/kg coal ranged from US$35/t to US$63/t.

Based on this price range, price scenarios of US$40/t (low scenario), US$50/t (medium scenario), and US$60/t (high scenario) were chosen.

Levelised fuel costs are then calculated by converting the required weight of coal to generate one kilowatt-hour (kWh) of electricity into kcal and multiplying the result by the price of coal per tonne.

Figure 4-4. Average Monthly Coal Prices in Indonesia (2009–2014)



Source: Directorate General of Minerals and Coal, Ministry of Energy and Mineral Resources, Indonesia.

(4) Desulphurisation and denitrification costs

Desulphurisation and denitrification costs consist of three components: EPC costs, O&M costs and additional fuel requirements. In the final results, these three components are aggregated to form deSOx and deNOx costs. A breakdown of these values and calculations is illustrated in Figure 4-5, and explained below.

Desulphurisation

EPC costs for a 1,000 MW-capacity desulphurisation facility retrieved from interviews with Japanese manufacturers were estimated at US$20 million. This value is assumed as EPC cost for USC. EPC costs for SC and subcritical are assumed to increase accordingly due to higher coal consumption at 2.4 percent and 10.2 percent, respectively. As a result, EPC costs for desulphurisation at an SC power plant are estimated at US$20.5 million. Similarly, for a subcritical power plant, EPC costs are estimated at US$22.0 million.

O&M costs for desulphurisation are based on a study by the Massachusetts Institute of Technology (MIT) titled 'The Future of Coal' (henceforth, MIT study). In the study, O&M costs at an SC power plant are estimated at US$0.22/kWh. Similar to EPC costs, O&M costs are adjusted according to difference in coal consumption. For USC, O&M costs are estimated at US$0.21/kWh, and for subcritical, O&M costs are estimated at US$0.24/kWh.

Denitrification

EPC costs for a 1,000 MW-capacity denitrification facility retrieved from interviews with Japanese manufacturers were estimated at US$20 million. Using the same calculations from the desulphurisation facilities, EPC costs for a denitrification unit are estimated at US$20.5 million for an SC power plant and US$22.0 million for a subcritical plant.

O&M costs for denitrification are also based on the MIT study. In an SC power plant, estimate is at US$0.10/kWh. Again, O&M costs are adjusted according to difference in coal consumption. For USC, O&M costs are estimated at US$0.10/kWh, and for subcritical, O&M costs are estimated at US$0.11/kWh.

Additional fuel costs

Installation of desulphurisation and denitrification units reduces thermal efficiency. Based on a study for the European Commission titled 'Efficiency and Capture-Readiness of New Fossil Power Plants in the EU,' this reduction of thermal efficiency is set at one percent. Additional fuel costs associated with desulphurisation and denitrification are calculated as levelised fuel costs at reduced thermal efficiency less levelised fuel costs from (3) above. The total additional fuel costs for both desulphurisation and denitrification are estimated at US$0.07/kWh for USC, US$0.08/kWh for SC, and US$0.09/kWh for subcritical. These values are assumed to be evenly allocated among desulphurisation and denitrification.

Figure 4-5. Calculation Desulphurisation and Denitrification Costs

		USC	SC	Subcritical	Remarks
deSOx	Capital cost /1,000 MW (USD)	20,000,000	20,487,000 + 2.4%	22,042,000 + 10.2%	USC: Actual EPC value from Japanese manufacturer SC: Japanese EPC value + 2.4% (higher coal demand) Sub: Japanese EPC value + 10.2% (higher coal demand)
deSOx	SC O&M costs (USDcents/kWe)	NA	0.22	NA	Source: "The Future of Coal", MIT.
deSOx	O&M costs without efficiency decrease (USDcents/kWh)	Used as deSOx O&M costs 0.22 - 2.4%	0.22	0.24 + 7.6%	MIT report value is used for SC. USC and Subcritical values are adjusted according to coal consumption
deNOx	Capital cost /1,000 MW (USD)	20,000,000	20,486,000 + 2.4%	22,042,000 + 10.2%	USC: Actual EPC value from Japanese manufacturer SC: Japanese EPC value + 2.4% (higher coal demand) Sub: Japanese EPC value + 10.2% (higher coal demand)
deNOx	SC O&M costs (USDcents/kWh)	NA	0.10	NA	Source: "The Future of Coal", MIT.
deNOx	O&M costs without efficiency decrease (USDcents/kWh)	Used as deNOx O&M costs 0.10 - 2.4%	0.10	0.11 + 7.6%	MIT report value is used for SC. USC and Subcritical values are adjusted according to coal consumption
Both	Additional fuel costs	(Fuel cost at reduced thermal efficiency) – (Fuel cost at average thermal efficiency)			A 1%-point decrease in thermal efficiency is assumed. Additional fuel costs were allocated evenly among deSOx and deNOx costs.

Source: Massachusetts Institute of Technology (MIT), 2013, 'The Future of Coal.'

(5) Financing costs

Financing cost is calculated to generate 9.5 to 15 percent IRR. For cash flow calculation purposes, the following assumptions were made: Plant construction takes two years. Cash flow is calculated for 25 years of operation with annual electricity sales equal to annual generation at 7,008 GWh.

Financing cost is defined as generation cost that includes non-fuel O&M cost, fuel cost, desulphurisation costs, and denitrification costs less the price of electricity required to generate 9.5 and 15.0 percent IRR, respectively.

(6) Carbon dioxide costs

CO_2 emissions are adjusted from the IPCC default emission factors for stationary sources in the energy sector. Of the four coal types listed, the sub-bituminous coal's heating value of 4,514 kcal/kg is closest to the assumed heating value used in this analysis. Therefore, default CO_2 emission factors of sub-bituminous coal were selected and adjusted to a 4,000 kcal/kg calorific value. This results in 1.43 kg-CO_2/kg-coal. Coal requirements to generate one kWh of electricity are multiplied by this emission factor to obtain levelised CO_2 emissions per kWh.

CO_2 emission cost is then set at US$10/t-$CO_2$. This results in the following levelised CO_2 emission costs: US$0.73/kWh for USC, US$0.75/kWh for SC, and US$0.80/kWh for subcritical.

However, as no CO_2 price is currently implemented, CO_2 emission cost is not weighed heavily in this analysis, and mainly included as a reference.

4-1-3. Sensitivity Analysis

This section summarises the results of the cost–benefit analysis. Figure 4-6 lists aggregated levelised costs, excluding financing and CO_2 costs.

Figure 4-6. Sensitivity Analysis: Overview of Results

		Ultra-Supercritical (42.1%)			Supercritical (41.1%)			Subcritical (38.2%)		
		High EPC (USD 2,076 million)	Medium EPC (USD 1,941 million)	Low EPC (USD 1,867 million)	High EPC (USD 2,043 million)	Medium EPC (USD 1,908 million)	Low EPC (USD 1,796 million)	High EPC (USD 1,925 million)	Medium EPC (USD 1,796 million)	Low EPC (USD 1,688 million)
Coal prices	High (USD 60/ton)	5.39	5.27	5.20	5.46	5.34	5.23	5.68	5.55	5.45
	Medium (USD 50/ton)	4.87	4.74	4.68	4.93	4.80	4.69	5.10	4.97	4.87
	Low (USD 40/ton)	4.35	4.22	4.15	4.39	4.26	4.16	4.52	4.39	4.29

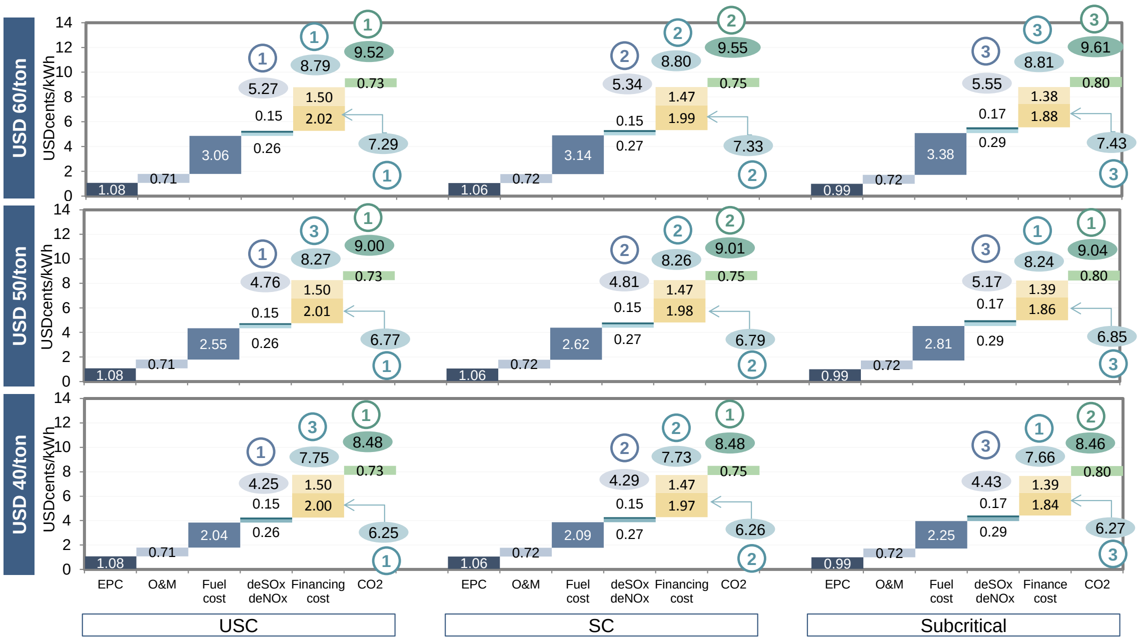
Source: Author's assumption and calculation

Figure 4-7 illustrates costs breakdown for each component from the three coal price scenarios. The graphs include four aggregates and rankings. First, base plant costs plus desulphurisation and denitrification cost. The second aggregate includes financing cost to generate 9.5 percent IRR. The third aggregate includes financing cost to generate 15percent IRR. The fourth aggregate includes a hypothetical CO_2 emission cost. Rankings are also included above the aggregates (below in the case of the second aggregate).

Without financing cost, USC is more competitive in every coal price scenario. However, as initial capital costs are higher, USC is less competitive when financing costs to generate 15 percent IRR are considered. If financing costs are set to generate 9.5 percent IRR, USC is again most competitive even at a coal price of US$40/t.

In conclusion, USC is generally competitive. At any price, it is important to provide concessional loans, especially for advanced technologies with high upfront cost.

Figure 4-7. Sensitivity Analysis: Cost Breakdown Comparison at Per Coal Prices Scenario



Source: Author's assumption and calculation.