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Power and Energy Systems Technologies & Economics

Case Study Integrated Model Generation Cost Calculation for Fossil Fueled Power Plants

Notes:

1. Cells with black characters include inputs
2. Cells with red characters include formulas
3. Download of Add-Ins (macro) from website required
4. Read description of Case Study in section 3.5 of the book !

Last update March 2016



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Disclaimer

The Examples are solely and exclusively indented to provide support and assistance to the readers for practicing and better understanding of the theoretical part of this book.

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The author, Panos Konstantin, believes that all information and guidance provided and all calculations in these examples are correct. Nevertheless anyone using these examples should carry out their own due diligence and appraisal of the contents.

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Proposals for improvements of the contents are welcome and will be considered in upcoming updates!

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Note 1:

The generation cost can be calculated:

including escalation rates for O&M costs

excluding escalation rates for O&M costs

The user can choose one of the two options by typing "yes" or "no" in the cell E3 in Spreadsheet " Input financial"

The escalation rates "in real terms" are in the same spreadsheet and can be altered by the user

Note 2: The fuel prices are fixed with rates referred to the crude oil price.

The crude oil price can also be altered by the user in the cell F19 of the same spreadsheet

Note 3: The generation cost can also include cost for CO₂ allowances. Specific cost for allowances can be inserted in cell F15 in US\$/t_{CO2}

TE-CaseStudy-4_Integrated-Model-Techno-economics-Fossil_PPs.xls
SummaryResults

Item	Unit	Steam USC coal	Steam SubC coal	CCGT nat. gas	IC Engine HFO	IC Engine LFO	GT LFO
Energy balance							
Number of units	-	1	1	1	24	20	2
Power output net	MW	744	555	404	402	335	329
Net electricity production	GWh _e / a	5,566	4,152	1,959	2,009	502	478
Fuel consumption	GWh _t / a	11,843	10,127	3,320	4,481	1,120	1,462
Financial constraints							
Life time	a	35	35	25	25	25	20
Construction time	a	5.0	5.0	2.5	2.0	2.0	1.5
Discount rate (WACC), real terms	% / a	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%
Fuel price	US\$ / MWh _{LHV}	19.3	19.3	39.5	38.0	61.3	61.3
CAPEX, 2014 US\$, ±25%	mIn US\$	2,770.5	1,775.7	462.7	475.0	323.1	138.0
Annual power generation costs	mIn US\$ / a	505.1	379.2	191.8	241.8	109.0	115.6
Annualized CAPEX	mIn US\$ / a	201.7	129.3	37.8	38.8	26.4	12.5
OPEX fixed	mIn US\$ / a	54.9	38.1	9.2	8.5	6.5	3.4
OPEX variable, incl. fuel costs	mIn US\$ / a	248.4	211.8	144.8	194.4	76.0	99.8
Power generation cost, levelized							
Capacity (fixed OPEX + Annualized capex)	US\$ / (kW _a)	345.0	301.7	116.5	117.8	98.3	48.3
Energy (variable cost)	US\$ / MWh	44.6	51.0	73.9	96.7	151.4	208.6
Composite cost, excl. CO₂-cost *)	US\$ / MWh_e	90.74	91.33	97.93	120.31	216.88	241.82
Composite cost, incl. CO₂-cost **)	US\$ / MWh_e	94.38	95.50	99.65	123.44	219.85	245.89

*) referred to full load hours

h / a 7,481 7,481 4,850 5,000 1,500 1,455

**) Spec. Emission cost

US\$ / t_{CO2} 5.0 (for example, spreadsheet Input financial)

TE-CaseStudy-4_Integrated-Model-Techno-economics-Fossil_PPs.xls
Input_Technical


Item	Unit	Steam USC coal	Steam SubC coal	CCGT nat. gas	IC Engine HFO	IC Engine LFO	GT LFO
Key technical parameters							
Selecte type	-	USC	SubC	Siemens SGT6 8000H 1GTx1ST	Wärtsilä W18V50DF	Wärtsilä W18V50DF	Siemens SGT5-2000E
Load segment	-	base	base	intermediate	intermediate	peak	peak
Number of units	-	1	1	1	24	20	2
Unit power output RSC, gross		800.0	600.0	410.0	17.0	17.0	166.0
Plant power output, RSC, gross	MW _e	800.0	600.0	410.0	408.0	340.0	332.0
Auxiliary power demand	-	7.0%	7.5%	1.5%	1.5%	1.5%	1.0%
Power output, net	MW _e	744	555	404	402	335	329
Electrical efficiency, gross	-	48.0%	42.0%	60.0%	45.3%	45.3%	34.7%
Rated efficiency, gross	-	48.0%	42.0%	60.0%	45.3%	45.3%	34.7%
Degradation *)	-	1.0%	1.0%	1.0%	0.5%	0.5%	2.0%
Average annual efficiency	-	47.0%	41.0%	59.0%	44.8%	44.8%	32.7%
Average heat rate	MJ / kWh _e	7.66	8.78	6.10	8.03	8.03	11.01
CO ₂ emission factors of fuels	kg/MWh _{LHV}	342	342	202	281	266	266

TE-CaseStudy-4_Integrated-Model-Techno-economics-Fossil_PPs.xls
Input_Financial

Item		Unit	Steam USC coal	Steam SubC coal	CCGT nat. gas	IC Engine HFO	IC Engine LFO	GT LFO
Financial constraints	Escalation *)	yes						
Life time	n.a.	a	35	35	25	25	25	20
Construction time	n.a.	a	5.0	5.0	2.5	2.0	2.0	1.5
Number of operating staff	n.a.	-	90	90	35	25	25	25
Discount rate (WACC), real terms	n.a.	% / a	6.47%	6.47%	6.47%	6.47%	6.47%	6.47%
Fixed O&M cost	0.5 %/a	%EPC / a	1.5%	1.5%	1.0%	1.0%	1.0%	0.5%
Costs of personnel	1.0 %/a	US\$ / (cap*a)	80,000	80,000	80,000	80,000	80,000	80,000
Insurance	0.5 %/a	%EPC / a	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Fuel price ref. to LHV, referred to crude oil price	0.5 %/a	US\$ / MWh _{LHV}	19.26	19.26	39.51	38.02	61.32	61.32
Non-fuel variable cost	0.5 %/a	US\$ / MWh _e	1.00	1.00	0.50	1.50	1.50	0.50
Maintenance contract, fixed **)	0.0 %/a	US\$ / MWa	n.a.	n.a.	5,500	7,875	7,875	5,500
Maintenance contract, variable **)	0.0 %/a	US\$ / MWh _e	n.a.	n.a.	2.67	5.95	5.95	4.00
CO ₂ emission allowance price	0.0 %/a	US\$ / t _{CO2}	5.0					

*) Escalation rates in real terms, excluding inflation

**) for Gas turbines and ICE, for CCGT 2/3 of variable part of the price referred to the total output

Input crude oil barrel price			80 US\$/bbl	1.62 MWh/bbl			
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Fuel	Unit	Crude oil	Steam Coal	Steam Coal	Natural gas	HFO	LFO	LFO
Ratio referred to crude oil *)	-	1.00	0.39	0.39	0.80	0.77	1.24	1.24
Specific cost free PP site	US\$ / MWh _{LHV}	49.38	19.26	19.26	39.51	38.02	61.32	61.32

TE-CaseStudy-4_Integrated-Model-Techno-economics-Fossil_PPs.xls
Input WACC

Item	Equity	Loan
Asset shares	30%	70%
Expected returns after tax		
Risk free rate of return / interest	5.0 %/a	5.0 %/a
Venture risks premium	6.0 %/a	1.0 %/a
Country risk premium (depends on country) *)	0.0 %/a	0.0 %/a
Cost of capital in nominal terms, after tax	11.0 %/a	6.0 %/a
Corporate tax 25%	3.7 %/a	0.0 %/a
Cost of capital in nominal terms, before tax	14.7 %/a	6.0 %/a
WACC_n in nominal terms, before tax	8.60 %/a	
./. Expected Inflation rate	2.00 %/a	
WACC_r inflation adjusted	6.47 %/a	

Item		Unit	Steam USC coal	Steam SubC coal	CCGT nat. gas	IC Engine HFO	IC Engine LFO	GT LFO	
Specific capex, EPC		US\$ /kW	2,750	2,350	950	980	800	350	
Construction time		a	5.0	5.0	2.5	2.0	2.0	1.5	
Bank Interest rate, nominal (see WACC)		%!a	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	
Installments per year		-	4	4	4	4	4	4	
CAPEX, 2014 US\$, ±25%		mIn US\$	2,770.5	1,775.7	462.7	475.0	323.1	138.0	
Overnight cost, EPC		mIn US\$	2,200.0	1,410.0	389.5	399.8	272.0	116.2	
Owner's cost	15%	mIn US\$	330.0	211.5	58.4	60.0	40.8	17.4	
Interest during construction IDC	70% debt	mIn US\$	240.5	154.2	14.8	15.1	10.3	4.4	IDC Add In

TE-CaseStudy-4_Integrated-Model-Techno-economics-Fossil_PPs.xls
EOH_O&M Contract

Item	Unit	Steam USC coal	Steam SubC coal	CCGT nat. gas	IC Engine HFO	IC Engine LFO	GT LFO
Full load hours							
Full load hours, for load segment	h / a	7,500	7,500	5,000	5,000	1,500	1,500
forced outages *)	%	0.25%	0.25%	3.00%	0.00%	0.00%	3.00%
Actual full load hours	h / a	7,481	7,481	4,850	5,000	1,500	1,455
Equivalent operating hours							
Startups	-	1 / month	1 / month	1 / week	multiunit plant		daily
Number of startups	-	12	12	52	unlimited	unlimited	300
Addition for startups * 10 h/start	h / a	120	120	520	-	-	3,000
Equivalent operating hours *)	h / a	7,620	7,620	5,520	5,000	1,500	4,500
O&M contract for GT/ICE							
Fixed price O&M contract	US\$ / a	n.a.	n.a.	5,500	7,875	7,875	5,500
Variable price O&M contract **)	US\$ / MWh _e	n.a.	n.a.	2.67	5.95	5.95	4.00

TE-CaseStudy-4_Integrated-Model-Techno-economics-Fossil_PPs.xls
GenCosts_Calculation

Item		Unit	Steam USC coal	Steam SubC coal	CCGT nat. gas	IC Engine HFO	IC Engine LFO	GT LFO
Energy and emission balance								
Power output net		MW	744	555	404	402	335	329
Full load hours, actual *)		h / a	7,481	7,481	4,850	5,000	1,500	1,455
Net electricity production		GWh _e / a	5,566	4,152	1,959	2,009	502	478
Annual average, gross efficiency **)		-	47.0%	41.0%	59.0%	44.8%	44.8%	32.7%
Equivalent operating hours		h / a	7,601	7,601	5,370	5,000	1,500	4,455
Fuel consumption		GWh _t / a	11,843	10,127	3,320	4,481	1,120	1,462
CO ₂ emission factors		kg /MWh _t	342	342	202	281	266	266
CO ₂ emissions		kt / a	4,050	3,463	671	1,259	298	389
Financial constraints								
Life time		a	35	35	25	25	25	20
Construction time		a	5.0	5.0	2.5	2.0	2.0	1.5
Number of operating staff		-	90	90	35	25	25	25
Discount rate (WACC), real terms		% / a	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%
Fixed O&M cost		%EPC / a	1.5%	1.5%	1.0%	1.0%	1.0%	0.5%
Insurance		%EPC / a	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Costs of personnel		US\$ / (cap*a)	80,000	80,000	80,000	80,000	80,000	80,000
Fuel price ref. to LHV, based on	80 US\$/bbl	US\$ / MWh _t	19.26	19.26	39.51	38.02	61.32	61.32
Non-fuel variable cost		US\$ / MWh _e	1.00	1.00	0.50	1.50	1.50	0.50
Maintenance contract, fixed		US\$ / MW a	n.a.	n.a.	5,500	7,875	7,875	5,500
Maintenance contract, variable		US\$ / MWh _e	n.a.	n.a.	2.67	5.95	5.95	4.00
CAPEX, 2014 US\$, ±25%		mIn US\$	2,770.5	1,775.7	462.7	475.0	323.1	138.0
Annualized CAPEX		mIn US\$ / a	201.7	129.3	37.8	38.8	26.4	12.5
OPEX, fixed, levelized	1.000	mIn US\$ / a	54.9	38.1	9.2	8.5	6.5	3.4
Maintenance	0.5 %/a	mIn US\$ / a	35.1	22.5	4.1	4.2	2.9	0.6
Personnel	1.0 %/a	mIn US\$ / a	8.2	8.2	3.1	2.2	2.2	2.2
Insurance	0.5 %/a	mIn US\$ / a	11.7	7.5	2.0	2.1	1.4	0.6
OPEX, variable, levelized		mIn US\$ / a	248.4	211.8	144.8	194.4	76.0	99.8
Fuel costs	0.5 %/a	mIn US\$ / a	242.5	207.3	137.8	179.1	72.2	93.6
Non-fuel variable cost	0.5 %/a	mIn US\$ / a	5.9	4.4	1.0	3.2	0.8	0.2
GT - maintenance	0.0 %/a	mIn US\$ / a	0.0	0.0	5.9	12.1	3.0	5.9
Levelized total annual costs		mIn US\$ / a	505.1	379.2	191.8	241.8	109.0	115.6
Power generation cost, Levelized								
Capacity (fixed OPEX + annualized CAPEX)		US\$ / (kW*a)	345.0	301.7	116.5	117.8	98.3	48.3
Energy (variable costs)		US\$ / MWh	44.63	51.00	73.90	96.75	151.36	208.59
of which fuel cost, only		US\$ / MWh	43.56	49.94	70.38	89.13	143.74	195.70
Full load hours, effective *)		h / a	7,481	7,481	4,850	5,000	1,500	1,455
Composite cost, excl. CO₂ cost		US\$ / MWh_e	90.74	91.33	97.93	120.31	216.88	241.82

*) forced outages during operation considered

**) incl. allowance for wear, deterioration and part load

Table LEC h-a excl CO2

Composite power generation cost			US\$/MWh			
1000 h/a	Steam USC coal	Steam SubC coal	CCGT nat. gas	IC Engine HFO	IC Engine LFO	GT LFO
	390	353	190	215	250	257
200	1770	1559	657	686	643	450
400	907	805	365	391	397	329
600	620	554	268	293	315	289
800	476	428	220	244	274	269
1000	390	353	190	215	250	257
1200	332	302	171	195	233	249
1400	291	266	157	181	222	243
1600	260	240	147	170	213	239
1800	236	219	139	162	206	235
2000	217	202	132	156	201	233
2200	201	188	127	150	196	231
2400	188	177	122	146	192	229
2600	177	167	119	142	189	227
2800	168	159	116	139	186	226
3000	160	152	113	136	184	225
3200	152	145	110	134	182	224
3400	146	140	108	131	180	223
3600	140	135	106	129	179	222
3800	135	130	105	128	177	221
4000	131	126	103	126	176	221
4200	127	123	102	125	175	220
4400	123	120	100	124	174	220
4600	120	117	99	122	173	219
4800	117	114	98	121	172	219
5000	114	111	97	120	171	218
5200	111	109	96	119	170	218
5400	109	107	95	119	170	218
5600	106	105	95	118	169	217
5800	104	103	94	117	168	217
6000	102	101	93	116	168	217
6200	100	100	93	116	167	216
6400	99	98	92	115	167	216
6600	97	97	92	115	166	216
6800	95	95	91	114	166	216
7000	94	94	91	114	165	216
7200	93	93	90	113	165	215
7400	91	92	90	113	165	215
7600	90	91	89	112	164	215
7800	89	90	89	112	164	215
8000	88	89	88	111	164	215
8200	87	88	88	111	163	214
8400	86	87	88	111	163	214
8600	85	86	87	110	163	214
8800	84	85	87	110	163	214

