SeparateExcel File

TE-Ch7_Cost-Allocation-Cogen-Ex-7-2-to-7-10.xls

Ex. 7-2_Reference PP

Item		Unit	Steam Rankine Cycle HFO	CCGT Natural gas
Dual purpose plant				
Live steam		bar / °C	140 /535	124/555
Type of steam turbine		-	back pressure	
Rated power output, gross		MW_e	294.0	302.6
HP Steam for desal	18.0 bar	MW_t	9.5	8.5
LP steam for desal	2.7 bar	MW_t	668	227
Efficiency: electrical/total		-	27.5% / 90%	49.7% / 87%
Equivalent cond. Power *)	$\beta = 0.23$	MW_e	450	357
Corresponding reference power plant, from public grid				
Live steam		bar / °C	160/535/535RH	124/555
Type of steam turbine		-	Condensing	
Rated power output, gross		MW_e	600	350
Electrical efficiency, gross		.	41.4%	57.3%

Source: Energy Efficiency Study, Saudi Aramco-Fichtner, 2010

*) average for 18bar and 2.7bar steam

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Ex. 7-3_Cost Reference_PP

Item		Unit	Steam Rankine Cycle HFO	CCGT Natural gas
Reference Power Plant (RPP) , Electricity Generation Cost [1)]				
Spec. Capacity cost		US$ / kWa	199.2	102.6
Spec. Energy cost		US$ / kWh_e	17.7	21.5
Composite cost	7920 h/a	US$ / MWh_e	42.83	34.42
Dual Purpose PP, Power and Energy balance				
Electrical output, gross	HFO	MW_e	294	303
Electrical output, net		MW_e	279	293
Steam output (18 bar + 2.7 bar)		MW_t	678	236
Electricity production	7920 h/a	GWh_e / a	2,210	2,321
Steam production for desal	7920 h/a	GWh_t / a	5,366	1,865
Annual costs dual purpose PP [1)]				
Fixed Costs, dual purpose		mln US$ / a	89.0	35.3
minus credit for fixed elec. costs; RPP		mln US$ / a	55.6	30.1
Residual capacity costs for steam		**mln US$ / a**	**33.4**	**5.2**
Variable costs, dual purpose		mln US$ / a	59.8	58.5
minus credit for variable elec. costs; RPP		mln US$ / a	39.1	49.8
Residual energy costs for steam		**mln US$ / a**	**20.7**	**8.7**
Residual costs dual purpose PP, total		**mln US$ / a**	**54.1**	**13.9**
Specific steam cost for desalination plant				
Capacity cost		US$ / kW_t a	49.3	22.2
Energy cost		US$ / MWh_t	3.86	4.66
Composite cost	7920 h/a	**US$ / MWh_t**	**10.09**	**7.47**

Source of data: Saudi Aramco Energy Efficiency Study

[1)] Detailed costs calculation in separate files

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Ex. 7-4_600MW_heat cost

Heat Extraction from a 600 MW power plant					
Electricity capacity cost c_C		€ / (kW_e a)	198.00		
Electricity energy cost c_e		€ / MWh_e	30.00		
Steam Extraction			Specific heat cost		
Steam-pressure	Steam Temperature	Electrical equivalent	Capacity cost	Energy cost	Equivalent full capacity hours
p	t_s	β	$\beta \times c_C$	$\beta \times c_e$	
bar	°C	kWh_e / kWh_t	€ / (kW_t a)	€ / MWh_t	h / a
12.0	218	0.251	49.70	7.53	6,000
6.0	189	0.220	43.56	6.60	6,000
1.7	145	0.164	32.47	4.92	6,000

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Ex. 7- 5_District heating Cost

Item			Formula	Unit	Value
Given					
Capacity cost, electricity			cc_e	€ / (kW*a)	198.00
Energy cost, electricity			ce_e	€ / MWh	30.00
Heat supply, peak load			Q_{max}	MW	75
3.2 bar / 0.9 bar			-	-	50%
Annual energy supply	5500 h/a		W_{DH}	MWh / a	412,500
of which 3.2 bar heat condenser			r_{3bar}	-	15%
of which 0.9 bar heat condenser			$r_{1.2bar}$	-	85%
Electrical equivalent, 3.2 bar steam			β_{3bar}	kWh_{el} / kWh_{th}	0.218
Electrical equivalent, 0.9 bar steam			β_{1bar}	kWh_{el} / kWh_{th}	0.115
Cost of District Heat					
Electrical equivalent, average of the two extractions					
for capacity cost	50%	50%	β_c	kW_{el} / kW_{th}	0.167
for energy cost	15%	85%	β_E	kWh_{el} / kWh_{th}	0.130
Specific capacity cost			$c_{C,DH} = \beta_C \times cc_e$	€ / (kW*a)	32.97
Specific energy cost			$c_{E,DH} = \beta_E \times ce_e$	€ / MWh	3.91
Annual cost			$\boldsymbol{C_{DH} = CC_{,DH} + C_{A,FW}}$	**th. € /a**	**4,087**
of which capacity costs			$C_{,DH} = cc_{DH} \times Q_{max}$	th. € /a	2,473
of which energy costs			$C_{EDH} = c_{E,DH} \times W_{FW}$	th. € /a	1,614
Composite cost			$\boldsymbol{c_{DH}}$	**€ / MWh**	**9.91**

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Ex. 7-6_600MW_Fuel-CO2

Technical Parameters		Symbol	Unit	Value
Efficiency, PP, net		η_e	-	42%
Electrical equivalent, 6 bar process steam		β	kWh_{el} / kWh_t	0.220
CO_2 fuel emission factor, hard coal		e_f	kg / MWh_t	342
Allocation				
Heat rate, electricity, net		$q_e = 1/\eta_e$	kWh_t / kWh_e	2.38
Heat rate, process steam, net		$q_s = q_e \times \beta$	kWh_t / kWh_t	0.52
Emission factor electricity		$e_e = e_f \times q_e$	kg / MWh_e	814
Emission factor process steam		$e_s = e_e \times \beta$	kg / MWh_t	179

TE-Ch7_Cost-Allocation-Cogen-Ex-7-2-to-7-10.xls
Ex. 7-7_Energy vs. Exergy

Energy carrier		bar	°C	Energy content	Exergy	
				kJ / kg	kJ / kg	%
Electricity		n.a.	n.a.	100%	n.a.	100%
Steam levels of steam turbines	live steam ultra super critical	245	620	3,557	1,702	48%
	live steam sub critical	180	540	3,390	1,555	46%
	extraction	20	250	2,903	1,018	35%
	extraction	6	159	2,756	810	29%
	cond. turbine discharge	0.045	31	2,641	2	0.1%
Condenser cooling Water		1	15	63	(0)	0%

Note: Exergy is the part of the embodied energy in an energy carrier that can be converted into mechanical energy in an ideal reversible process

TE-Ch7_Cost-Allocation-Cogen-Ex-7-2-to-7-10.xls

Ex. 7-8_AllocationExergy

Cost Allocation Based on Exergy

Item	Pressure [1] bar	Tempe-rature [1] °C	Heat content of extracted steam [3] kJ/kg	Specific exergy [2] kJ/kg	Exergy conversion ratio ζ	Exergy converted kJ / kg	Electrical equivalent kWh_e/kWh_t
Steam 12 bar	12.0	244	2,545	963	74.8%	720	0.283
Steam 6 bar	6.0	178	2,424	826	74.5%	615	0.254
Steam 3 bar	3.0	134	2,349	712	71.5%	509	0.217

1) from cycle calculation, do not change

2) zero exergy level, condenser cooling water, 1 bar — 15 °C

3) process steam condensate return 100%, 90°C — 377 kJ/kg

Item	Full load hours h / a	Electrical equivalent kWh_e/kWh_t	Capacity cost € /kW a	Energy cost € /MWh	Composite cost [5] € /MWh
Electricity, given [4]	7,500	1.000	243.89	29.86	62.38
Steam 12 bar	6,500	0.283	69.01	8.45	19.07
Steam 6 bar	4,500	0.254	61.89	7.58	21.33
Steam 3 bar	4,500	0.217	52.87	6.47	18.22

4) electricity costs taken from Case Study, cost allocation extraction-condensing CHP, electr. equivalent

5) referred to the stated full load hours only

TE-Ch7_Cost-Allocation-Cogen-Ex-7-2-to-7-10.xls
Ex. 7-9_CCGT_CHP_calorific

Power- and Energy balance					
Item	Power		Full load hours	Energy	
	Output MW	Share %	h/a	Production MWh/a	share %
Power, total, net	87.7	44.1%	7,500	657,750	45.6%
12 bar stean extraction	19.5	9.8%	5,000	97,500	6.8%
6 bar stean, backpressure	75.5	38.0%	7,500	566,250	39.2%
3 bar steam from HRSG	16.2	8.1%	7,500	121,500	8.4%
Total	**198.9**	**100.0%**	-	**1,443,000**	**100.0%**

Costs Allocation					
item	Capacity costs *)		Energy costs **)		Composite Costs
	Total T€ / a	specific € / (kW*a)	Total T€ / a	specific € / MWh	€ / MWh
Electricity	4,123	47.01	21,905	33.30	39.57
12 bar stean extraction	917	47.01	3,247	33.30	42.71
6 bar stean, backpressure	3,549	47.01	18,858	33.30	39.57
3 bar steam from HRSG	762	47.01	4,046	33.30	39.57
Total **)	**9,350**	**-**	**48,057**	**-**	**-**

*) allocation based on the power share
**) Allocation based on the energy share
***) Annual costs calculation in separate spreadsheet

TE-Ch7_Cost-Allocation-Cogen-Ex-7-2-to-7-10.xls
Example 7-10_ReplacementValue

Item			Unit	Cogen Plant	Status Quo HOB
Power & Energy Balance					
Heat base load, 12 bar steam *)			MW_t	25	
Annual heat consumption *)		7,000 h/a	MWh_t / a	175,000	
Fuel consumption HOBs		η=85.0%	MWh_t / a	n.a	205,882
Electricity for pumping **)	0.8 MW	7,000 h/a	MWh_e / a	5,600	n.a
CAPEX, total			**mln €**	**8.0**	**0.0**
Pipeline (2 km, DN 300)			mln €	4.0	0.0
Heat substation at the factory			mln €	2.5	0.0
Heat substation at CHP plant			mln €	1.5	0.0
Fuel price for HOB			€ /MWh_t	n.a	25.0
Electricity generation cost, cogen plant, given ***)			€ /MWh_e	70.0	n.a
Heat generation cost CHP gate		β=0.25	€ /MWh_t	17.6	n.a.
Annual costs			th.. € /a	**4,213**	**5,147**
Annualized CAPEX	6 %/a	25 a	th. € /a	626	0
O&M cost	1.5 %/a	-	th. € /a	120	0
Heat generation cost			th. € /a	3,075	5,147
Electricity for condensate pumping			th. € /a	392	0
Spec. heat cost, free factory			**€ / MWh_t**	**24.07**	**29.41**
Replacement value			**€ / MWh_t**	**24.07**	
Cogen heat premium			**€ / MWh_t**	**5.34**	

*) base load heat only **) for condensate return ***) rqrd for heat cost calculation