



ReCAP Project

Understanding the Cost of Retrofitting CO₂ Capture in an Integrated Oil Refinery

Reference Base Case Plants:
Economic Evaluation



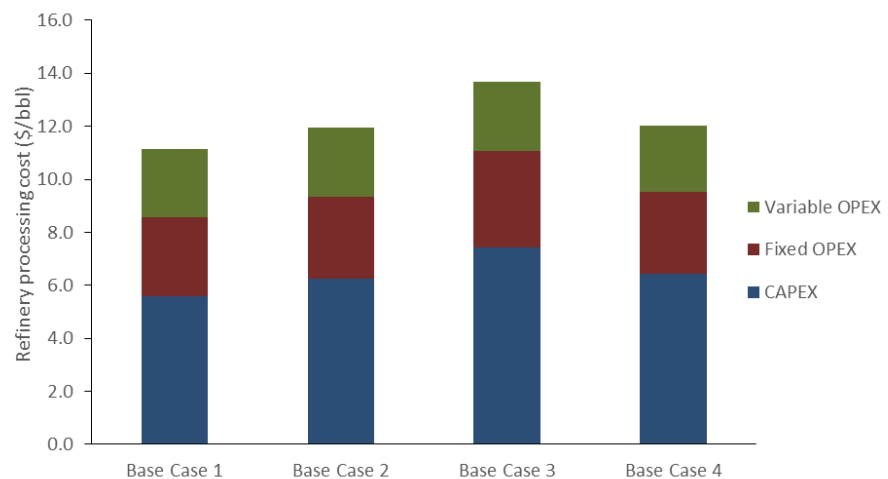
Report

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Sigurd Sannan

Kristin Jordal, Simon Roussanaly, Chiara Giraldi, Annalisa Clapis



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Report

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AUTHORS

Sigurd Sannan (SINTEF), Kristin Jordal (SINTEF), Simon Roussanaly (SINTEF), Chiara Giraldi (Amec FosterWheeler), Annalisa Clapis (Amec FosterWheeler)

CLIENTS

Gassnova, IEAGHG, Concawe

CLIENT'S REF.Svein Bekken, John Gale,
Damien Valdenaire**PROJECT NO.**

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ABSTRACT

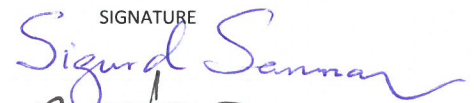
This report provides estimates of CAPEX and fixed and variable OPEX for four different generic refineries ("Base Case refineries"). The performance of the four refinery Base Cases, in terms of mass and energy balances and CO₂ emissions, is described in the report *Performance Analysis – Refinery Reference Plants*, issued by Amec FosterWheeler, which is available on www.sintef.no/recap.

The estimated refinery processing cost is for the four refineries:

- Base Case 1 (crude processing capacity 100 000 bbl/day): 11.13 \$/bbl
- Base Case 2 (crude processing capacity 220 000 bbl/day): 11.96 \$/bbl
- Base Case 3 (crude processing capacity 220 000 bbl/day): 13.70 \$/bbl
- Base Case 4 (crude processing capacity 350 000 bbl/day): 12.01 \$/bbl

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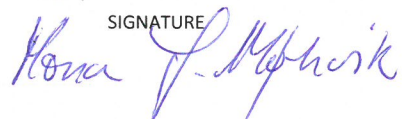
Sigurd Sannan

SIGNATURE**CHECKED BY**

Petter Nekså

SIGNATURE**APPROVED BY**

Mona Mølnevik

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1	2017-04-07	Draft with calculation of CAPEX and OPEX for refinery base cases
2	2017-04-28	Used TIC values from Amec FW that are not rounded off for increased accuracy of costs. Minor corrections in text as suggested by Concawe.
3	2017-08-16	Final version

Table of contents

1	Introduction.....	5
2	CAPEX for refinery base cases	6
3	Annual operating costs for refinery base cases	7
4	Refinery processing cost	8
A	Estimated investment cost and manpower requirements for the refinery base cases	9
A.1	Estimated Investment Cost	9
A.2	Estimated Operating Costs	11

1 Introduction

The scope of this report is to provide CAPEX, and fixed and variable OPEX for the four different generic refineries:

- Base Case 1) Simple refinery with a nominal capacity of 100 000 bbl/d
- Base Case 2 and 3) Medium to highly complex refineries with nominal capacity of 220 000 bbl/d
- Base case 4) Highly complex refinery with a nominal capacity of 350 000 bbl/d

These costs are thereafter presented as the refinery processing cost in \$/bbl crude. This means that the values for CAPEX and OPEX in this report are not based on any specific existing refineries. The performance of the four generic refinery Base Cases, in terms of mass and energy balances and CO₂ emissions, is described in the report *Performance Analysis – Refinery Reference Plants*, issued by Amec Foster Wheeler. Amec Foster Wheeler has in the present report contributed with estimated investment costs for the four refinery Base Cases, as well as estimated manpower requirements. The contributions from Amec Foster Wheeler are included in Appendix A.

It should be noted that the amount of processed crude is assumed to remain constant in the work presented in the subsequent reports *Performance analysis of CO₂ capture options* and *Cost estimation and economic evaluation of CO₂ capture options for refineries*. This means that there is no direct connection between the results of the economic evaluation presented in the present report and the results presented in the report on economic evaluation of CO₂ capture. Both reports, however, rely on the same economic criteria and assumptions, as described in the *Reference Document – Economic assumptions*. Also, the method for calculating CAPEX and OPEX has followed the same structure in both reports. The Excel sheet made available in connection with the report *Cost estimation and economic evaluation of CO₂ capture options for refineries* provides an understanding of how the economic evaluation was done in the present report.

2 CAPEX for refinery base cases

The capital expenditures for the refinery base cases are provided in Table 1. The calculation of Total Installed Cost (TIC) by Amec Foster Wheeler is included in Table 4.

Table 1. Capital expenditures for the four refinery base cases.

	Base Case 1	Base Case 2	Base Case 3	Base Case 4
Total installed cost (TIC)	1 626 000	4 014 000	4 768 000	6 555 000
Project contingencies	162 600	401 400	476 800	655 500
Total plant cost (TPC)	1 788 600	4 415 400	5 244 800	7 210 500
Spare parts	8 943	22 077	26 224	36 053
Inventory of fuel and chemicals	5 081	13 092	14 937	21 522
Start-up cost	43 132	99 048	117 136	157 790
Owner cost	125 202	309 078	367 136	504 735
Interest during construction	284 642	702 677	834 670	1 147 496
Total capital requirement	2 255 600	5 561 372	6 604 903	9 078 096

3 Annual operating costs for refinery base cases

Fixed and variable operating costs for the refinery base cases are provided in Table 2. Manpower requirement for calculating labour cost is determined by Amec Foster Wheeler (see Table 6-Table 9).

Table 2. Fixed, variable and total operating costs for the four refinery base cases.

	Base Case 1	Base Case 2	Base Case 3	Base Case 4
Labour cost	29 440	42 960	48 960	54 320
Annual maintenance	66 330	172 260	205 095	290 602
Other	8 943	22 077	26 224	36 053
Annual fixed operating cost	104 713	237 297	280 279	380 974
Natural gas consumption	37 647	58 937	29 598	59 716
Chemical and catalyst	51 480	140 195	169 950	240 900
Raw process water (make-up)	84	2 176	1 898	2 436
Waste disposal	0	0	0	0
Annual variable operating cost	89 211	201 308	201 447	303 052
Total annual operating cost	193 924	438 605	481 726	684 026

4 Refinery processing cost

The refinery processing cost in \$/bbl crude is presented in Table 3 and Figure 1. As for the costing of CO₂ capture, an annualization factor of 11.53 was used to calculate the annual capital cost for the refineries. The annualization factor is calculated based on an interest rate of 8% and an economic lifetime of 25 years. (Refer to the *Reference Document – Economic assumptions* for further details.)

Table 3. Refinery processing cost in \$/bbl for the four base cases.

	Base Case 1	Base Case 2	Base Case 3	Base Case 4
CAPEX	5.59	6.26	7.44	6.43
Fixed OPEX	2.99	3.08	3.64	3.11
Variable OPEX	2.55	2.61	2.62	2.47
Total	11.13	11.96	13.70	12.01

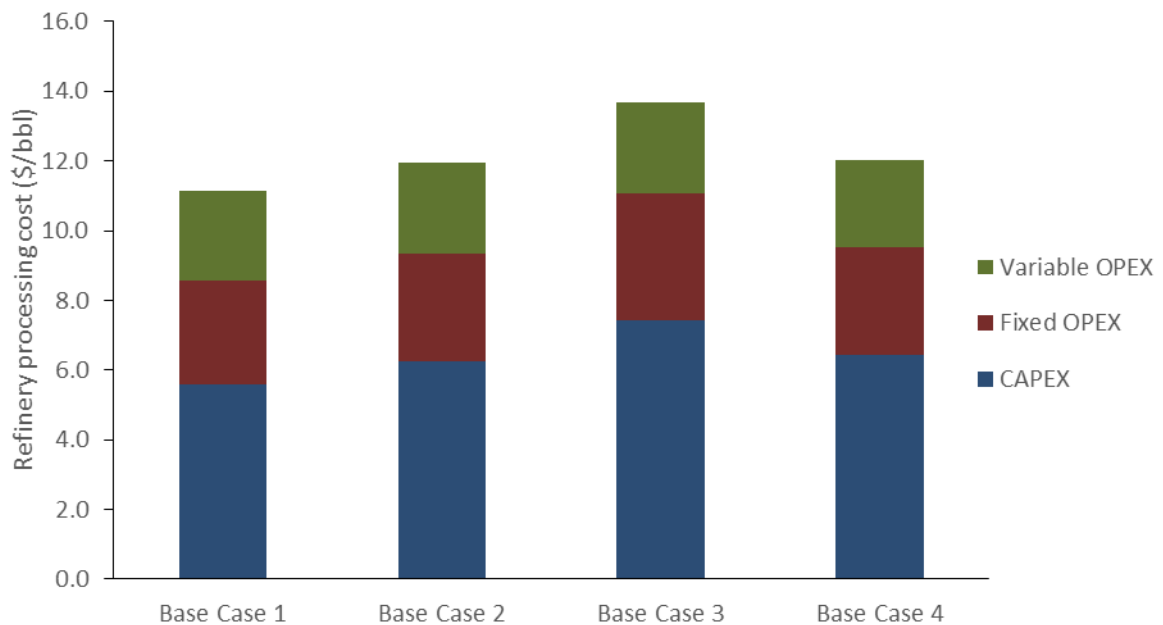


Figure 1. Refinery processing cost in \$/bbl for the four base cases.

A Estimated investment cost and manpower requirements for the refinery base cases

The contents of this Appendix have been provided by Amec Foster Wheeler, who has been a subcontractor to SINTEF Energy Research in the project resulting in this study aiming at understanding the costs of CO₂ capture in integrated oil refineries.

A.1 Estimated Investment Cost

Table 4 includes the cost estimate summary for the four Base Case refineries.

The cost estimated for the main units has been evaluated on a pro-rate capacity basis starting from the in-house database for similar units, populated with cost data from previous projects. A location factor has been then applied. The estimate is in current currency.

The table provides the details of the estimate, divided by areas, i.e., Process Units, Auxiliary Units, Power Units, Utilities and Offsite Units. In particular, the investment cost for Utilities and Offsite Units is evaluated as a percentage of the investment cost for the other units.

The estimate is excluding the following:

- The cost of land
- The cost covering process licensors fee such as technology fee, PDP preparation, royalties and the like
- The cost relevant to the local authorities permitting fee's
- The commissioning and start-up cost
- The cost associated to the utilities generation and consumption during the commissioning stage
- The cost of catalyst and chemicals and lubricants
- The local taxes of any kind
- Custom Duties
- All risk insurance
- Financial cost
- Capital and start-up spare
- Interest during construction
- Owner Cost
- EPC risk and profit

On top of the investment costs, some of the other capital costs could be estimated as follows:

- Spare Parts: Typically assumed equal to 0.5% of the TPC.
- Inventory of fuel and chemicals: Typically assumed to be 1 month of operating costs for chemicals, catalysts and raw process water, plus 25% of full load of natural gas consumption for 1 month
- Start-up expenses: Typically assumed equal to 2% of the TPC plus 3 months of labour cost
- Interest during construction: Typically assumed equal to 15.9% of the TPC.
- Owner cost: Typically assumed to be 7% of the TPC.

Table 4. Investment Cost Summary Table

Note: The total investment cost value that is not rounded off below was used for the TIC in Table 1 for slightly improved accuracy.

ReCAP Project 1-BD-0839A											
INVESTMENT COST ESTIMATE											
PROCESS UNITS											
UNIT	Unit of measure	BASE CASE 1		BASE CASE 2		BASE CASE 3		BASE CASE 4			
		Design Capacity	CAPEX [MM USD]	Design Capacity	CAPEX [MM USD]	Design Capacity	CAPEX [MM USD]	Design Capacity	CAPEX [MM USD]		
0100A	CDU	Crude Distillation Unit (1)	BPSD	100,000	124	100,000	124	100,000	124	175,000	184
0100B	CDU	Crude Distillation Unit (1)	BPSD	-	-	120,000	141	120,000	141	175,000	184
0250	LSW	LPG Sweetening	BPSD	4,000	12	14,000	23	14,000	23	19,000	27
0280A	KSW	Kerosene Sweetening	BPSD	5,000	4	5,000	4	5,000	4	12,000	6
0280B	KSW	Kerosene Sweetening	BPSD	-	-	10,000	5	10,000	5	12,000	6
0300A	NHT	Naphtha Hydrotreater	BPSD	23,000	46	23,000	46	23,000	46	40,000	62
0350A	NSU	Naphtha Splitter Unit	BPSD	23,000	71	23,000	71	23,000	71	40,000	104
0300B	NHT	Naphtha Hydrotreater	BPSD	-	-	27,000	56	27,000	56	40,000	62
0350B	NSU	Naphtha Splitter Unit	BPSD	-	-	27,000	79	27,000	79	40,000	104
0400	ISO	Isomerization	BPSD	8,000	20	15,000	27	15,000	27	23,000	34
0500A	CRF	Catalytic Reforming (2)	BPSD	15,000	154	15,000	154	15,000	154	30,000	251
0500B	CRF	Catalytic Reforming (2)	BPSD	-	-	18,000	175	18,000	175	30,000	251
0600A	KHT	Kero HDS	BPSD	14,000	51	14,000	51	14,000	51	15,000	53
0600B	KHT	Kero HDS	BPSD	-	-	5,000	30	12,000	47	15,000	53
0700A	HDS	Gasoil HDS	BPSD	26,000	117	26,000	117	26,000	117	42,500	165
0700B	HDS	Gasoil HDS	BPSD	-	-	34,000	141	39,000	155	42,500	165
0800	VHT	Vacuum Gasoil Hydrotreater	BPSD	6,000	69	35,000	236	50,000	302	36,000	240
0900	HCK	Vacuum Gasoil Hydrocracker	BPSD	-	-	-	-	-	-	60,000	496
1000	FCC	Fluid Catalytic Cracking (3)	BPSD	-	-	50,000	350	60,000	405	60,000	405
1050	PTU	FCC Gasoline Post-Treatment Unit	BPSD	-	-	20,000	77	24,000	85	24,000	85
1100A	VDU	Vacuum Distillation Unit	BPSD	35,000	71	35,000	71	35,000	71	65,000	109
1100B	VDU	Vacuum Distillation Unit	BPSD	-	-	45,000	84	51,000	92	65,000	109
1200A	SMR	Steam Reformer	Nm ³ /h Hydrogen	-	-	22,500	42	35,000	58	65,000	89
1200B	SMR	Steam Reformer	Nm ³ /h Hydrogen	-	-	-	-	-	-	65,000	89
1300	SDA	Solvent Deasphalting	BPSD	-	-	-	-	-	-	30,000	85
1400	DCU	Delayed Coking (4)	BPSD	-	-	-	-	35,000	308	50,000	395
1500	VBU	Visbreaking Unit	BPSD	13,000	54	28,000	92	-	-	-	-
Total Process Units					794		2,198		2,598		3,811
AUXILIARY UNITS											
2000A	ARU	Amine Washing and Regeneration	t/d Sulphur	55	22	55	22	55	22	375	81
2000B	ARU	Amine Washing and Regeneration	t/d Sulphur	-	-	165	47	395	84	375	81
2100A	SWS	Sour Water Stripper	m ³ /h	30	22	30	22	30	22	190	85
2100B	SWS	Sour Water Stripper	m ³ /h	-	-	90	47	200	88	190	85
2200A	SRU	Sulphur Recovery & Tail Gas Treatment	t/d Sulphur	55	34	55	34	55	34	3 x 250	208
2200B	SRU	Sulphur Recovery & Tail Gas Treatment	t/d Sulphur	-	-	2 x 82.5	73	2 x 197.5	132	-	-
2300A	WWT	Waste Water Treatment / API Separator	m ³ /h	100	64	100	64	100	64	500	207
2300B	WWT	Waste Water Treatment / API Separator	m ³ /h	-	-	150	84	200	104	-	-
SubTotal Auxiliary Units					142		393		550		747
POWER UNITS											
2500	POW	Power Plant	kW	40,000	80	80,000	176	78,000	140	175,000	298
UTILITY UNITS											
3000	SWI	Sea Water Intake									
3100	CWS	Cooling Water System									
3200	SRW	Service & Potable Water Systems									
3300	DEW	Deminerlized Water System									
3350	BFW	Boiler Feed Water System									
3400	STS	Steam System									
3450	CON	Condensate Recovery System									
3500	FFW	Fire Water and Fire Fighting System									
3600	AIR	Plant and Instrument Air System									
3700	FGS	Fuel Gas System									
3750	FOS	Fuel Oil System									
3800	NGU	Nitrogen System									
3900	CHE	Chemical Systems									
SubTotal Utility Units					254		554		658		728
OFF-SITES UNITS											
4000	FLA	Flare System									
4100	TAN	Tankage and Pumping System									
4200	INT	Interconnecting System									
4300	COH	Coke Handling System									
4400	SEW	Sewer Systems									
4500	TLA	Trucks Loading Area									
4600	JPF	Jetty and Port facilities									
	BUI	Buildings, DCS, S/S									
SubTotal Off-Sites Units					356		692		822		971
TOTAL					1,626		4,014		4,768		6,555
				say	1,600		3,900		4,700		6,500

Notes
 (1) CDU includes Saturated Gas Plant (SGP), unit 0200, composed of Naphtha Stabilizer, Deethanizer, C3/C4 Splitter
 (2) CCR includes Pressure Swing Adsorption (PSA), unit 1700.
 (3) FCC includes C3/C3= Splitter and LPG Sweetening.
 (4) DCU includes LPG Sweetening.

Table 6: Base Case 1) Estimated manpower requirement

ReCAP Project 1-BD-0839A									
<u>REFINERY STAFF - BASE CASE 1</u>									
OPERATION MANPOWER (shift breakfactor = 5.5)									
		Shift Leader	Boardman	Field Operator	Loading Master	Jetties	Senior Shift Supervisor	Total Shift Personnel	Total Personnel
OPERATING AREA 1		1	1	3	0	0	0	5	27.5
0100	Crude Distillation Unit								
0200	Saturated Gas Plant								
0250	LPG Sweetening								
0280	Kerosene Sweetening								
1100	Vacuum Distillation Unit								
1500	Visbreaking Unit								
OPERATING AREA 2		1	1	3	0	0	0	5	27.5
0300	Naphtha Hydrotreater								
0350	Naphtha Splitter Unit								
0400	Isomerization								
0500	Catalytic Reforming								
OPERATING AREA 3		1	1	4	0	0	0	6	33.0
0600	Kero HDS								
0700	Gasoil HDS								
0800	Vacuum Gasoil Hydrotreater								
2000	Amine Washing and Regeneration								
2100	Sour Water Stripper								
2200	Sulphur Recovery & Tail gas Treatment								
OPERATING AREA 7		2	2	4	0	0	0	8	44.0
3000	Utility Units								
OPERATING AREA 8		1	1	2	1	3	0	8	44.0
4000	Off-sites Units								
Senior Shift Supervisor							2	2	11.0
DAY PERSONNEL		Superintendent	Assistant Superintendent	Manager Operation					
		4	6	3					
TOTAL OPERATING PERSONNEL								200	
MAINTENANCE MANPOWER									
TOTAL MAINTENANCE PERSONNEL								80	
SUPPORT FUNCTIONS / MANAGEMENT MANPOWER									
Refinery Manager		2							
Logistics		10							
Administration		15							
Management Log / Admin		4							
Purchasing		4							
Stores		6							
Personnel		3							
Info Systems		5							
Laboratory		24							
Process Engineering		15							
TOTAL SUPPORT / MGMT PERSONNEL								88	
TOTAL REFINERY STAFF								368	



Table 7: Base Case 2) Estimated manpower requirement

ReCAP Project 1-BD-0839A REFINERY STAFF - BASE CASE 2								
OPERATION MANPOWER (shift breakfactor = 5.5)								
	Shift Leader	Boardman	Field Operator	Loading Master	Jetties	Senior Shift Supervisor	Total Shift Personnel	Total Personnel
OPERATING AREA 1A/ 1B								
0100	Crude Distillation Unit	1	2	6	0	0	9	49.5
0200	Saturated Gas Plant							
0250	LPG Sweetening							
0280	Kerosene Sweetening							
1100	Vacuum Distillation Unit							
1500	Visbreaking Unit							
OPERATING AREA 2A/ 2B								
0300	Naphtha Hydrotreater	1	2	6	0	0	9	49.5
0350	Naphtha Splitter Unit							
0400	Isomerization							
0500	Catalytic Reforming							
OPERATING AREA 3A/ 3B								
0600	Kero HDS	2	2	9	0	0	13	71.5
0700	Gasoil HDS							
0800	Vacuum Gasoil Hydrotreater							
1200	Steam Reformer							
2000	Amine Washing and Regeneration							
2100	Sour Water Stripper							
2200	Sulphur Recovery & Tail gas Treatment							
2000	Amine Washing and Regeneration							
2200	Sulphur Recovery & Tail gas Treatment							
OPERATING AREA 4								
1000	Fluid Catalytic Cracking	1	1	3	0	0	5	27.5
1050	FCC Gasoline Post-Treatment Unit							
OPERATING AREA 7								
3000	Utility Units	2	2	5	0	0	9	49.5
OPERATING AREA 8								
4000	Off-sites Units	1	1	2	1	3	8	44.0
	Senior Shift Supervisor					4	4	22.0
DAY PERSONNEL								
	Superintendent	6	8	5				19.0
	Assistant Superintendent							
	Manager Operation							
TOTAL OPERATING PERSONNEL								333
MAINTENANCE MANPOWER								
TOTAL MAINTENANCE PERSONNEL								100
SUPPORT FUNCTIONS / MANAGEMENT MANPOWER								
	Refinery Manager	3						
	Logistics	12						
	Administration	18						
	Management Log / Admin	6						
	Purchasing	6						
	Stores	8						
	Personnel	3						
	Info Systems	5						
	Laboratory	24						
	Process Engineering	19						
TOTAL SUPPORT / MGMT PERSONNEL								104
TOTAL REFINERY STAFF								537



Table 8: Base Case 3) Estimated manpower requirement



ReCAP Project 1-BD-0839A REFINERY STAFF - BASE CASE 3									
									
OPERATION MANPOWER (shift breakfactor = 5.5)									
		Shift Leader	Boardman	Field Operator	Loading Master	Jetties	Senior Shift Supervisor	Total Shift Personnel	Total Personnel
OPERATING AREA 1A/ 1B		1	2	6	0	0	0	9	49.5
0100	Crude Distillation Unit								
0200	Saturated Gas Plant								
0250	LPG Sweetening								
0280	Kerosene Sweetening								
1100	Vacuum Distillation Unit								
OPERATING AREA 2A/ 2B		1	2	6	0	0	0	9	49.5
0300	Naphtha Hydrotreater								
0350	Naphtha Splitter Unit								
0400	Isomerization								
0500	Catalytic Reforming								
OPERATING AREA 3A/ 3B		2	3	9	0	0	0	14	77.0
0600	Kero HDS								
0700	Gasoil HDS								
0800	Vacuum Gasoil Hydrotreater								
1200	Steam Reformer								
2000	Amine Washing and Regeneration								
2100	Sour Water Stripper								
2200	Sulphur Recovery & Tail gas Treatment								
2000	Amine Washing and Regeneration								
2200	Sulphur Recovery & Tail gas Treatment								
OPERATING AREA 4		1	1	3	0	0	0	5	27.5
1000	Fluid Catalytic Cracking								
1050	FCC Gasoline Post-Treatment Unit								
OPERATING AREA 5		1	1	4	0	0	0	6	33.0
1400	Delayed Coking								
OPERATING AREA 7		2	2	7	0	0	0	11	60.5
3000	Utility Units								
OPERATING AREA 8		1	1	3	1	4	0	10	55.0
4000	Off-sites Units								
Senior Shift Supervisor							4	4	22.0
DAY PERSONNEL		Superintendent	Assistant Superintendent	Manager Operation					
		8	10	6					
TOTAL OPERATING PERSONNEL								398	
MAINTENANCE MANPOWER									
TOTAL MAINTENANCE PERSONNEL								110	
SUPPORT FUNCTIONS / MANAGEMENT MANPOWER									
Refinery Manager		3							
Logistics		12							
Administration		18							
Management Log / Admin		6							
Purchasing		6							
Stores		8							
Personnel		3							
Info Systems		5							
Laboratory		24							
Process Engineering		19							
TOTAL SUPPORT / MGMT PERSONNEL								104	
TOTAL REFINERY STAFF								612	

Table 9: Base Case 4) Estimated manpower requirement

ReCAP Project 1-BD-0839A REFINERY STAFF - BASE CASE 4									
									
OPERATION MANPOWER (shift breakfactor = 5.5)									
		Shift Leader	Boardman	Field Operator	Loading Master	Jetties	Senior Shift Supervisor	Total Shift Personnel	Total Personnel
OPERATING AREA 1A/ 1B		1	2	6	0	0	0	9	49.5
0100	Crude Distillation Unit								
0200	Saturated Gas Plant								
0250	LPG Sweetening								
0280	Kerosene Sweetening								
1100	Vacuum Distillation Unit								
OPERATING AREA 2A/ 2B		1	2	6	0	0	0	9	49.5
0300	Naphtha Hydrotreater								
0350	Naphtha Splitter Unit								
0400	Isomerization								
0500	Catalytic Reforming								
OPERATING AREA 3A/ 3B		2	4	10	0	0	0	16	88.0
0600	Kero HDS								
0700	Gasoil HDS								
0800	Vacuum Gasoil Hydrotreater								
1200	Steam Reformer								
2000	Amine Washing and Regeneration								
2100	Sour Water Stripper								
2200	Sulphur Recovery & Tail gas Treatment								
2000	Amine Washing and Regeneration								
2200	Sulphur Recovery & Tail gas Treatment								
OPERATING AREA 4		1	1	3	0	0	0	5	27.5
0900	Vacuum Gasoil Hydrocracker								
OPERATING AREA 5		1	1	3	0	0	0	5	27.5
1000	Fluid Catalytic Cracking								
1050	FCC Gasoline Post-Treatment Unit								
OPERATING AREA 6		1	1	4	0	0	0	6	33.0
1300	Solvent Deasphalting								
1400	Delayed Coking								
OPERATING AREA 7		2	3	7	0	0	0	12	66.0
3000	Utility Units								
OPERATING AREA 8		1	1	3	1	4	0	10	55.0
4000	Off-sites Units								
Senior Shift Supervisor							4	4	22.0
DAY PERSONNEL		Superintendent	Assistant Superintendent	Manager Operation					24.0
		8	10	6					
TOTAL OPERATING PERSONNEL									442
MAINTENANCE MANPOWER									
TOTAL MAINTENANCE PERSONNEL									120
SUPPORT FUNCTIONS / MANAGEMENT MANPOWER									
Refinery Manager				4					
Logistics				14					
Administration				18					
Management Log / Admin				7					
Purchasing				8					
Stores				10					
Personnel				3					
Info Systems				5					
Laboratory				26					
Process Engineering				22					
TOTAL SUPPORT / MGMT PERSONNEL									117
TOTAL REFINERY STAFF									679



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