Table of Contents:

Crown Prince International Scholarship Program Students Project

Action Learning Program 2008
The Action Learning is a two months program that involves teaming up Crown Prince International Scholarship Program students with delegates of major companies in Bahrain to work on a real challenge .

The Action Learning team balances between improving the behaviour and skills of its team members and at the same time aims at producing a result.

The Challenge:
“ Identify and Evaluate Carbon Credit Opportunities to Improve the Environmental Impact of the Bahrain Petroleum Company ”

Project Team:

Bapco Sponsor: Abdulkarim Al-Sayed
Bapco Chief Executive

Bapco Mgmt Representative: Hafedh Al-Qassab – Mgr Technical Services

Project Leader: Mishal Awadah

Team Members:
Zainab Abbas - CPISP (Sedbergh School, U.K.)
Hassan Al-Halwachi - CPISP (Sherborne School, U.K)
Mishal Awadah - CPISP (University of Pennsylvania, U.S.A.)
Ebrahim Al-Qassab - CPISP (Oundle School, U.K.)
Faisal Ahmed - Bapco (Special Projects Manager, Refining)
Abdulla Al-Ansari - Bapco (Environmental Engineer, Engineering)

Special thanks to over 50 Bapco employees who helped introduce the team to the refinery and contributed their ideas.

BACKGROUND

Since the late 1990s, energy conservation and environmental performance has become and integral part of Bapco management's business priorities.

The refining industry is now facing unique challenges which must be addressed, namely related to environmental issues like global warming (climate change), care for the environment, resource management and energy conservation to achieve sustainable development. All of these must be dealt with, in order to move forward, and to continue to grow and prosper. Bapco is eager to look at opportunities to address some of these concerns.

Bapco has in place an Environment, Health and Safety (EHS) Policy and also Environmental Policy Guidelines. These high level policies are aimed at improving the environmental impact of the company by reducing the consumption of resources, and reducing emissions to the environment, and in addition making Bapco a safer place to work.

Bapco is investing significant funds, but not just to improve revenue and profit, but all to continue our excellent progress in the fields of environment, health and safety. Bapco is spending in excess of 350 million dollars on environmental projects, related to air and water emissions from the refinery. This demonstrates the Bapco's commitment to the environment, and the people of Bahrain.

In 2002, Bapco formed Refinery Energy Teams aimed to enhance the company energy culture. It took management commitment, and employees buy-in of the energy conservation programme, to gain significant improvement in energy performance. Energy Intensity Index (EII) , a globally renowned energy benchmark, was reduced by 20 units in 4 years, i.e. from an EII of 135 in 2004 to 115 in 2007. With the current natural gas price of US$ 1.2 per million Btu, each point in EII reduction is equivalent to US$ 40,000 per month in energy savings. The annual average reduction of 5 units EII is worth about US$ 2.4 million energy savings per year.

In addition, the reduction in energy consumption reduces the environmental impact of the company.

To sustain the momentum of the energy conservation drive, an Energy Conservation Policy has recently been approved for company-wide implementation. The policy supports Bapco's commitment to the EHS Policy and Environmental Guidelines Policy. The Bapco theme for last year was "Energising the Nation", but at the core of this statement is the provision of low-cost energy to the major industries in the Kingdom of Bahrain, and protection of the wealth of the nation.

Typically environment and energy conservation projects are capital intensive. The introduction of Clean Development Mechanism (CDM), as one of the Kyoto Protocol innovative mechanisms which allows the industrialized nations to finance emission reduction projects in developing countries and then share emission reduction credit, in the region opens the path to evaluate opportunities and engage in Carbon Credit Trading or Emissions Trading, as an administrative approach to control pollution by providing economic incentives, for the financing of the capital investment of CDM qualified projects. The ultimate goal is to reduce greenhouse gas emissions for a cleaner environment. The cost benefit gained from improvements in energy efficiency alone typically can not justify the projects as the cost of fuel in Bahrain is comparatively low. However, the significant reduction in greenhouse gas emissions in the form of CER (Certified Emission Reduction) generated through Kyoto Protocol’s Clean Development Mechanism (CDM) could substantiate the project justification.

Bapco has started discussions with several carbon credit traders on potential CDM projects, and is reviewing options to hire Carbon Credit Consultants to handle the proceedings. The challenge presented to the CPISP Students is to identify and evaluate Carbon Credit Opportunities within the Bahrain Petroleum Company, to improve the environmental impact of the Company. Bapco is committed to continually search for and evaluate carbon credit opportunities, so as to continuously improve its environmental performance.

Carbon Credit Trading is an innovative mechanism for the Kingdom of Bahrain to benefit greatly from energy conservation practices, with the main impact and benefit, an improvement in the environment impact of Bapco on the Kingdom of Bahrain.

INFORMATION RELATED TO CARBON CREDIT TRADING

Carbon credits are a key component of national and international emissions trading schemes that have been implemented to mitigate global warming. They provide a way to reduce greenhouse effect emissions on an industrial scale by capping total annual emissions and letting the market assign a monetary value to any shortfall through trading. Credits can be exchanged between businesses or bought and sold in international markets at the prevailing market price. Credits can be used to finance carbon reduction schemes between trading partners and around the world.

There are also many companies that sell carbon credits to commercial and individual customers who are interested in lowering their carbon footprint on a voluntary basis. These carbon off-setters purchase the credits from an investment fund or a carbon development company that has aggregated the credits from individual projects. The quality of the credits is based in part on the validation process and sophistication of the fund or development company that acted as the sponsor to the carbon project. This is reflected in their price; voluntary units typically have less value than the units sold through the rigorously-validated Clean Development Mechanism.

The Kyoto Protocol and Clean Development Mechanism

The Kyoto Protocol is a protocol to the international Framework Convention on Climate Change with an aim of reducing greenhouse gases to prevent positive climate change.
The protocol was adopted on 11 December 1997 by the Conference of Parties which was held in Kyoto, Japan. Countries that ratify to this protocol commit to reducing their greenhouse gases emission or engaging in emission trading if they maintain or increase their emissions.

The protocol separates governments into two categories:

1. Annex 1 countries (developed countries): Those countries have accepted the obligations of greenhouse gases reduction and submit an annual greenhouse gas inventory.
2. Non-Annex 1 countries (developing countries): Those countries do not have an obligation to reduce their emissions but may participate in the Clean Development Mechanism. The Kingdom of Bahrain is one of these countries.

Annex 1 countries can invest in projects that reduce emissions in Non-Annex 1 countries as an alternative to more expensive emission reduction in their own countries. This can be done through the Clean Development Mechanism (CDM).
As Bahrain is a Non-Annex 1 country, it can establish projects to reduce its emission and sell its Certified Emission Reductions (CERs) to those developed countries.

Bahrain Petroleum Company is one of the top greenhouse gases emitters in the Kingdom. Hence, if we tackle it as an emission reduction area, CERs can be gained considering that it emits 3,749,165 Tons/Yr of Carbon Dioxide, which is one of the greenhouse gases.

PROJECT OBJECTIVE AND SCOPE

- Define the relevance of the Carbon Credit Trading scheme to Bapco and the Kingdom of Bahrain
  - Emission allowance
  - Kyoto Protocol flexible mechanisms
  - Emission market
  - Market price for all greenhouse gases (Market trend)
  - Environmental benefits
  - Emerging Market Opportunities
  - Bahrain & Climate Change
- Analysis of mechanism for creating real carbon credits
  - Additionality and its importance
  - Criticisms
  - CDM & project finance
- Calculate the carbon emission from the units that have potential for carbon credit.
- Identify Carbon Credit opportunities to improve the environmental impact of the Bahrain Petroleum Company
- Study the feasibility of the (emission reduction) projects for carbon credits trading
- Calculate the total natural gas reduction, and the carbon credit benefit, by implementing the projects
- Identify mechanisms to communicate the benefits and rationale for the projects to the Bapco workforce
- Identify options to publicize and promote the benefits of the carbon credit projects within the Kingdom of Bahrain
- Prepare a business case for implementing the identified carbon credit opportunities

BUSINESS RATIONALE

The business rationale for implementing this challenge for Bapco is as follows:

- Improved energy conservation, and improved use of the Kingdom of Bahrain's natural resources
- Improved environmental performance of Bapco
- Improved Bapco image
- Achieve quality performance in health, safety and environment, as part of the Corporate vision of 'striving for excellence'
- Social responsibility

DELIVERABLES

- Document proposed methodology and process
- Articulate information gathered on the Carbon Credit Scheme
- Summary of suggested strategies (potential projects) for Bapco to implement carbon credit opportunities
- Define a communication strategy
- Present findings to Bapco Chief Executive / Executive Management
- Present findings to H.H. Shaikh Salman bin Hamad Al-Khalifa, Crown Prince of the Kingdom of Bahrain and Deputy Supreme Commander

Top Six CO_2 Emitters in the Refinery

1. NO.2 Hydrogen plant in LSDP (1,006,313 tons/ yr)

This unit has been identified as the biggest carbon dioxide emitter in the whole refinery, with about 1 million tons per year. Carbon dioxide results from two processes:

1. The combustion of Khuff Gas in the furnace.
2. The reforming of Khuff Gas into hydrogen and carbon monoxide, which is then oxidised to carbon dioxide.

The purge gas that results from reforming is recycled and combusted to make use of the energy released due to the combustion of hydrogen, methane and carbon monoxide. The stack temperature is fairly low (300˚F), as well as the pressure (<5 psi)

2. Power and Utilities (526,040 tons/yr)

Electricity is supplied to the refinery by the power and utilities section. The three gas turbines: 13, 14 and 15 are the main producers of electricity. These gas turbines are old; the first two were built in 1972 and GT 15 in 1979. Their efficiency stands at 18%, which is inefficient compared to today's requirement.

3. 4A CDU (266,159 tons/yr)

Both heaters of this unit emit hot flue gases (about 1000° F) with low pressures (<5 psi) which are also rich in CO_2, although they are fairly efficient. This is mainly because of the high duties of the heaters.

4. FCCU Regenerator (208,319 tons/yr)

During fluid catalytic cracking, coke is formed and deposited on the surface of the catalyst (silica and alumina mixture). This affects the activity of the catalyst and hence the rate of the reaction. Therefore, the used catalyst is transferred to the regenerator where the coke is burnt. The burning process generates carbon dioxide. The energy released in this exothermic reaction supplies the energy needed for FCC (endothermic) by heating up the catalyst.

The temperature of the flue gas is very high (1400˚F) and the pressure is very low (5.5 psi).

5. 6 VDU (161,998 tons/yr)

The heater of this unit emits a hot flue gas (950˚F) with low pressure (<5 psi) that is rich is CO_2.

6. Benfield Unit in LSFO (141,380 tons/yr)

This unit emits almost a pure CO_2 stream with a low temperature (175° F) and low pressure (<5 psi). CO_2 and H_2O are separated from the other gases in this unit as one of the hydrogen purification steps.

	Unit	Quantity Tons/Yr	Contribution to total CO_2 emission/%
1	No. 2 Hydrogen Reformer	1,006,313	27
2	Power & Utilities	526,040	14
3	4A Crude Distillation Unit	266,159	7
4	FCCU Regenerator	208,319	6
5	6 Vacuum Distillation Unit	161,998	4
6	Benfield Unit (LSFO)	141,380	3

THE PROJECT

Aims

1. To Increase the efficiency of the gas turbines in P&U.

2. To utilize the heat from hot flue gases to generate steam.

3. To capture the carbon dioxide from rich flue gases, purify it and pump it for other uses.

Phases

Phase 1: Increasing efficiency
Phase 2: Waste heat recovery
Phase 3: CO_2 capture

Phase 1-Increasing efficiency:

Considered units:

- 13, 14 & 15 Gas turbines.

Phase 1's recommendation is to first replace the three gas turbines with new ones that are 35% efficient, and then upgrade their configuration to the combined cycle set up which will further improve on their efficiency (can reach up to 51%).

Rough Calculations

Equipment / Modification	Amount	Cost of equipment / $million	Cost / $million
New gas turbines	3	20	60
Total			60

Calculations for the return on phase 1 are attached in Appendix 1.

Capital cost	$60 million
Fuel savings	$4.5 million/yr
CER return	$4.0million/yr
Total return	$8.5 million/yr
Simple payback	7 yrs

CO_2 reduction (20%)	Cost-return benefit (20%)	Feasibility (20%)	Reliability & Additionality (40%)	Weighted Mean
2.5	4.0	9.5	9.0	6.8

Phase 2 – Waste Heat Recovery

The aim of this phase is to utilize the heat carried by some hot flue gases around the refinery by installing waste heat boilers. The units considered are:

- 4A Crude Distillation Unit (CDU) – 22F1A/1B/2 & 24F-1
- Fluid Catalytic Cracking Unit (FCCU) Regenerator - V-601[REGEN]
- 6 Vacuum Distillation Unit (VDU) - 32F-1
- K-3650 Platformer Gas Turbine

The reason for selecting the first three units is to facilitate for the next phase (CO_2 capture) since the flue gases are not only hot but they are also rich in CO_2. This is because the flue gases need to be cooled down before entering the carbon capture complex. Our recommendation is to design the waste heat boilers so that the cooled gas has a temperature of 300° F in order to make it possible to continue cooling using sea water in phase 3.

The reason for choosing the K-3650 Platformer Gas Turbine as well is in order to have enough steam to shut down two boilers in P&U (HP7&8), thus reducing CO_2 emissions. The steam generated from phase 1 is added to that from phase 2 to enable this. Although there are opportunities for generating more steam in LSDP, this was intentionally avoided because the complex already contributes a large amount to the grid, which makes increasing the dependence on that complex an insensible action to take because an emergency shutdown would deprive the refinery from a significant amount of steam.

It is worth noting that installing waste heat boilers would require changing the configuration of heaters to induced draft.

Rough Calculations

Equipment / Modification	Amount	Cost of equipment / $million	Cost / $million
Waste heat boilers	5	5	25
Combined cycle	3	5	5
Induced draft	5	2	10
Total			50

Capital cost	$40 million
Fuel savings (based on $1.2 per MMBtu)	$2.6 million/yr
CER return (based on $29 per CER)	$3.9 million/yr
Total return	$6.5 million/yr
Simple payback	7 yrs

Ranking

CO_2 reduction (20%)	Cost-return benefit (20%)	Feasibility (20%)	Reliability & Additionality (40%)	Weighted mean
2.5	4.0	9.5	9.0	6.3

Phase 3A – Installing Carbon Capture Complex (CCC)

Considered units:

- No.2 Hydrogen Reformer – S7601
- LSFO Benfield unit – F-6401

The aim of this stage is to capture the CO_2 emitted from the No.2 Hydrogen Reformer in LSDP and the Benfield unit in LSFO. This would require building a new Benfield unit.

The temperature of the Hydrogen Reformer flue gas is 300˚ F. Because the absorber in the new Benfield unit would require a lower temperature (150˚ F), the flue gas needs to be cooled by a seawater cooler. Also, the flue gas has a low pressure (<5 psi), which means that a compressor will be needed after the cooler to send the gas to the CCC. In the absorber of the new Benfield unit, CO_2 and H_2O will be separated from the flue gas by an amine solvent. Then the solvent will be circulated to a regenerator where it is heated to release the wet gas, which is then routed to a dehydrator. After dehydration the pure dry gas (about 98% pure) is liquefied under high pressure (800 psi) and stored in special refrigerated tanks (ISO tanks), or transferred directly for use in other applications.

The flue gas from LSFO consists of CO_2 and H_2O only and is relatively cool (175˚ F). Therefore, it can be compressed directly and sent to the dehydrator in CCC.
The final compression in this phase will be provided by 2X50 compressors.

Rough Calculations

Equipment / Modification	Amount	Cost of equipment / $million	Cost / $million
Compressors	3	10	30
Small compressor/ blower	1	15	15
Seawater coolers	1	5	5
Benfield unit	1	20	20
CO_2 storage tanks	undetermined	30	30
Piping	X 2.5		
Total			250

(Piping was considered here because of the large size of the project)

Capital cost	$250 million
CO_2 sales (based on $160 per ton)	$184 million/yr
CER return (based on $29 per CER)	$27 million/yr
Total return	$211 million/yr
Simple payback	2 yrs

Ranking

CO_2 reduction (20%)	Cost-return benefit (20%)	Feasibility (20%)	Reliability & Additionality (40%)	Weighted mean
10	9.0	6.0	3.5	6.4

Phase 3B - Expanding the Carbon Capture Complex (CCC)

Considered Units

- 4A Crude Distillation Unit (CDU) – 22F1A/1B/2 & 24F-1
- Fluid Catalytic Cracking Unit (FCCU) Regenerator - V-601[REGEN]
- 6 Vacuum Distillation Unit (VDU)- 32F-1

Because the flue gases from those heaters are rich in CO_2 and relatively cool (due to the waste heat boilers installed in phase 2), Capturing CO_2 from them seems a viable option. This will be done by cooling the gases further to 150˚ F, using seawater coolers, and sending them after compression to the CCC. (Flue gases from the two 4ACDU heaters will be routed to the same compressor).
Because of the increased gas flow to the CCC, the amount of purified CO_2 coming out is increased as well. This would require a new compressor after the dehydrator to convert the operation into 3x50 to increase reliability.

Rough Calculations

Equipment / Modification	Amount	Cost of equipment / $million	Cost / $million
Compressors	4	10	40
Seawater coolers	3	5	15
Piping	X 3		
Total			165

(Piping was considered here because of the large size of the project)

Capital cost	$165 million
CO_2 sales (based on $160 per ton)	$95 million/yr
CER return (based on $29 per CER)	$15 million/yr
Total return	$110 million/yr
Simple payback	2 yrs

Ranking

CO_2 reduction (20%)	Cost-return benefit (20%)	Feasibility (20%)	Reliability & Additionality (40%)	Weighted mean
6.5	8.0	4.5	4.5	5.6

Note: The energy costs were not taken into account in any of the phases.

Options for Exploitation of Carbon Dioxide

In order to gain carbon credits from capturing carbon dioxide we need to show that the gas we capture is not re-emitted into the atmosphere. These are the options that we have explored:

1. Pumping the gas to GPIC

GPIC uses carbon dioxide as a feedstock for the production of methanol and urea. Therefore, this option seems to be the simplest and quickest way of gaining CERs.

2. Liquefying and exporting CO_2

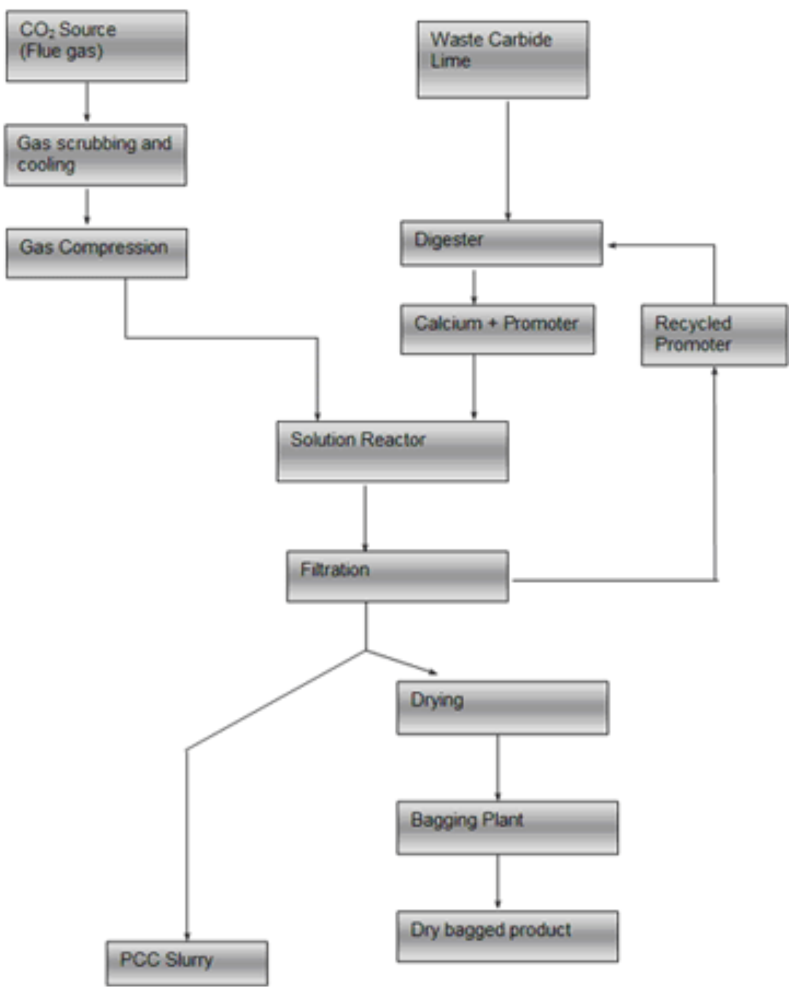
Liquefied CO_2 has a large market with a price of around $160 per ton (middle-east and North Africa). It forms under a pressure of 800 psi.

3. Building a PCC (Precipitated Calcium Carbonate) Plant

PCC is a versatile material which is in large demand. It can be manufactured by bubbling carbon dioxide into a calcium hydroxide solution (lime water).The carbonate could be sold to some customers, including:

- Printing paper manufacturers: PCC is used as filler and a coating to give brightness.
- Paints manufacturers: PCC is used to give brightness.
- Limestone aggregate manufacturers (used in construction and road building)
- Pharmaceutical companies (Aspirin)

It can also be added to drilling fluids as a weighting material



4. IG Applications
Because CO_2 is a fairly inert compound it could be used for blanketing purposes within the refinery. This would save the money spent on buying nitrogen for these purposes. However, this option still needs further investigation as CO_2 might poison the material it blankets.

CDM CAMPAIGN

Aim of the Campaign

The aim of the campaign is to raise awareness about the Clean Development Mechanism (CDM) and the importance of CO_2 reduction among the Bapco workforce and beyond to reach a national level.

The Challenges Faced

The first challenge of delivering such a campaign is the concept of the Clean Development Mechanism itself. Its concept may be difficult to grasp by all the employees at Bapco. The origin of the CDMs, how they are applied and their financial and environmental benefits are complex stages which require a simplified and attractive presentation.

Another challenge is that employees at Bapco speak different languages, have different working hours and places and are in different age groups. This challenge requires the campaign to be delivered in different methods to reach them all.

1. A small percentage of employees do not have access to Bapco's Intranet Portal or a workplace E-mail address.
2. The distribution of the workforce according to location is as follows :

Location	Counts
Refinery	1915
Awali	666
Jebel	241
Sitra Tanks	206
Wharf	A87

Campaign Design Approach

Step 1
Identify the Specific Message the Campaign is Aiming to Deliver:
((To raise awareness about the Clean Development Mechanism (CDM) and the importance of CO_2 reduction))

Step 2
Meeting with Public Relations Department: The aim of meeting to have the knowledge about the current campaigns Bapco is running , and the methods used which are more likely to get the message across .

Step 3
Draw Potential Campaign Plan

Step 4
Assess the Feasibility of the Campaign in Bapco

Campaign Plan and Design

Phase 1

- Contact department managers
- Initiate a page on Bapco's Intranet Portal

Comments on Phase 1:
To start off the campaign, contacting managers of Bapco is essential to get the initial message across to each part of Bapco.
A page on the portal will serve the same purpose but on a direct basis for employees with the intranet access.

Phase 2

- Sending letters to employees and distribute brochures , posters and mugs
- Plant in helmet for each employee to plant at home
- Paint vehicles with logo & slogan

Comments on Phase 2:
Contents of the brochures and posters will be a challenge in a sense of simplifying the concept of CDM.

Phase 3

- Community garden in Bapco
- Bicycle marathon
- Initiate Clean Development Mechanism (CDM) Week

Comment on Phase 3:
CDM Week will be conducted in the same manner as the Environmental, Health and Safety Week (EHS Week).

Phase 4

- Cooperate with other CDM appliers in the gulf and out, such as Al-Shaheen in Qatar to deliver a cooperative CDM campaign
- Start a radio station within Bapco operated by a part-time operator
- Introduce Bapco and CDM in Environmental Studies curriculum in schools.

Comments on Phase 4:
In this phase, the campaign will expand beyond Bapco, and will take an international level. By cooperating with other international companies, financial support will be provided for a larger scale media campaigns.

Appendix 1:
Calculation for fuel savings if gas turbines are replaced:

Bapco's Power and Utilities section uses three gas turbines: GT 13, GT 14 and GT15. GTs 13 and 14 date back to 1972, whereas GT 15 was built in 1979. The efficiency of each of the gas turbines is 18%. This means that only 18% of duty (natural gas) converts to useful energy (electricity in this case). This is summarized in the table below:

	Duty in gas turbines (MMBTU/hr)	Effective duty (MMBTU/hr)

# GT 13	138.2	24.876
# GT 14	189.9	34.182
# GT 15	199.8	35.964
Total	527.9	95.022

The effective duty column represents the amount of natural gas that fully converts to electricity. It is calculated by multiplying the duty in the gas turbines by 0.18. Figures for gas turbines duties were taken from Bapco's spreadsheets.
If the current turbines were to be replaced by new ones that are 35% efficient, less natural gas would be needed to produce the same amount of electricity. To calculate the duty required in these new gas turbines, the total effective duty in the table above has to be divided by 0.35. And then, by subtracting the duty required in the new gas turbines from the total duty in the incumbent ones, the amount of saved fuel can be found. This is done in the table below:

Duty required for new GTs (MMBTU/hr)	Fuel saved (MMBTU/hr)	Savings $/Yr
271.4914286	256.4085714	4,492,278.17*

*The price per MMBTU was taken to be $2.00

The amount of savings, as shown above, is around $4.5 million per year.
To calculate the amount of CER benefit (CER = certified emission reduction), the reduction in carbon dioxide emission has to be calculated. This is done by applying the methodology in Emission Calculations part A:

Fuel saved (MMBTU/hr)	CO_2 reduction (Tons/Yr)	CER benefit $/ Yr
256.4085714	139,089.86	4,033,606.05*

*The current price of a CER is $29.00

The benefit is then around $4 million per year.
Therefore the total benefit = 4,492,278.17 + 4,033,606.05 = 8,525,884.22
So the total benefit is around $8.5 million per year.

Appendix 2:
Calculation of steam generated from waste heat boilers:

Waste heat boilers generate steam by extracting heat from the flue gases that come out of the stacks. Generating superheated steam from flue gases requires these gases to be at a temperature around 350 °C. After generating steam, the temperature of the flue gases will be brought down to around 150 °C. The energy extracted from the flue gases can be calculated using the equation:

E = mcΔT where:
m: the mass of the flue gases in kg/hr
c: specific heat capacity of flue gases, this is equal to 1.094 KJ/kg °C
ΔT: the difference between inlet and outlet temperatures of the flue gases
To calculate the amount of steam generated from the energy extracted from the flue gases, we divide the energy value obtained by the steam enthalpy value, which is taken to be 2680 KJ/kg.

Calculation for phase 2: Installing waste heat boilers:
Units considered for waste heat boilers installation:
-4A CDU heaters (22F1A/1B/2, 24F-1)
-6 VDU heater (F-7001)
-FCCU Regenerator
-13, 14 and 15 gas turbines
-K-3650 turbine in platformer
The table below applies the methodology described earlier to calculate the amount of steam generated out of the aforementioned units:

Stack No.	Duty per stack (MMBTU/ hr)	Flue gas (Lb/ hr)	Stack temp °F	Stack temp °C	Flue gas (kg/ hr)	Energy (KJ/hr)
24F-1	122.80	169,240	1,141	616	76,765.97	39,144,931.31
# 13 GT	138.20	666,522	698	370	302,329.29	72,764,614.45
# 14 GT	189.90	915,582	698	370	415,301.01	99,954,647.00
# 15 GT	199.80	963,501	698	370	437,036.70	105,185,993.55
F-7001	295.30	304,609	662	350	138,168.32	30,231,228.05
22F1A/ 1B/2	356.60	384,834	970	521	174,557.77	70,869,677.29
K-3650	64.00	308,585	752	400	139,971.80	38,282,287.74
V-601[REGEN]	-	152,066	1,292	700	68,975.98	41,502,845.60
					Total	**497,936,225.00**
					Steam generated (kg/hr)	**185,797.0989**
					Steam generated (lb/hr)	**409,612.4869**

Using the calculating method described above, the table shows that installing waste heat boilers on these six stacks will produce a total of 410 thousand lbs/hr. This will enable the shutdown of two hp boilers (7 and 8) which use natural gas. Thereby CO_2 emissions will go down and fuel will be saved:

Boilers	Duty (MMBTU/ hr)	CO_2 reduction (Tons/Yr)	Savings** $/Yr	CER benefit* $/ Yr
# 8 HP boiler	150.9	82,489.22	2,643,768.00	2,392,187.38
# 7 HP boiler	95.1	51,984.90	1,666,152.00	1,507,562.02
Total	246	134,474.12	4,309,920.00	3,899,749.39

Thus the total benefit is: 4,309,920.00 + 3,899,749.39 = 8,209,669.39
And so the return is around $8.2 million/Yr.

* The current price of a CER is $29.00
** The price per MMBTU was taken to be $2.00

- Values for steam enthalpy and specific heat capacity of flue gases were taken from a study done by Faisal Shaheen on Rifaa power station in 1986.

Appendix 3
Emissions Calculations

A. Calculating CO_2 emissions from stack duties
We have used this method for calculating CO_2 emissions from nearly all stacks (apart from No.2 hydrogen reformer and FCCU regenerator). This is the explanation of the method using F-702 as an example.

Data available
Stack duty, fuel type, fuel composition & LHVs of components.

Method
1. We assumed that we have 100 lb moles of fuel, and put the number of moles of each compound (column B)
2. We wrote down the number of C atoms in one molecule of each compound (column C)
3. Assuming that all the carbon in the fuel is converted to CO_2, we multiplied columns B and C to calculate the number of moles of CO_2 that each component generates, and added them up to find the total number of moles of CO_2 generated (column D).
4. Now we have the total moles of CO_2 emitted per hour if the fuel was fed in a rate of 100 moles per Hr. Therefore, we need to find the actual rate of fuel feeding to calculate the figure we want.
5. Since we only have the rate in MMBtu per Hr (12.6) we converted this into moles per Hr by the following:
    a. We listed the Btu content per SCF of each component (column E) and multiplied by 379.48 to convert it to Btu per mol (column F). Then we multiplied this by the number of moles present in 100 moles of fuel shown in column B to find the amount of energy generated from each component (column G). Then we added them up to find the total energy (below column G).
    b. So, a feed rate of 66 MMBtu per Hr occurs when 100 lb moles per Hr of fuel are fed, therefore a feed rate of 12.6 Btu per Hr occurs when 14.9 moles per Hr are fed.
6. Now that we have the rate of feeding in lb moles per Hr we can calculate the answer in lb mol per hour: 100 lb moles of fuel per Hr yields 225.6 lb mol per Hr of CO_2, therefore 14.9 moles per Hr of fuel yields 43.2 lb mol per Hr of CO_2.
7. This can be converted to lb per Hr by multiplying by the molecular weight of CO_2 (44 lb per mol) to give 1899 lb per Hr, which equals 7547 tons /yr.

B. Calculating CO_2 emission from FCCU regenerator

To do this we had to take the data directly from the control room.

Data collected
Shown on the table in the next page.
Method of calculation:

1. The percentage of nitrogen in the dry flue gas was calculated by subtracting the percentages of all other gases from 100.

2. The total dry air flow into the regenerator was calculated by summing up the figures in the green boxes. The figure was multiplied by a constant (97/(100x379)) to convert the units into mol/Hr. This gives 8443 mol/Hr

3. Using the fact that the nitrogen going into the regenerator goes out unaffected, the total dry flue gas rate can be calculated from the following balance:

   $n\ N_2\ (in) = n\ N_2\ (out)$

   $x\ N_2\ (in)\ .\ n\ Air\ (in) = xN_2\ (out)\ .\ n\ Air\ (out)$

   $$n\ Air\ (out) = \frac{xN_2\ (in)\ .n\ Air\ (in)}{xN_2\ (out)}$$

   $$= \frac{79.1 \times 8443}{83.3} = 8013\ mol/Hr$$

4. Now the CO_2 flow rate can be calculated by multiplying this figure by the mole fraction (percentage) of CO_2 in the flue gas from the data collected, which gives 1192 mol/Hr. This figure can be converted to lb/Hr by multiplying by 44 lb/mol.

C. Calculating CO_2 emission from No.2 Hydrogen Plant

For that we were supplied with the following data by TSD.
Data used:

- Composition and feed rate of purge gas (6652 mol/Hr)
- Composition of Khuff gas
- That 60% of the duty comes from purge gas and 40% from Khuff gas

Method of Calculation:

1. We assumed that we have 100 lb moles of purge gas, and noted the number of moles of each compound (column B)
2. We wrote down the number of C atoms in one molecule of each compound (column C)
3. Assuming that all the carbon in the fuel is converted to CO_2, we multiplied columns B and C to calculate the number of moles of CO_2 that each component generates and added them up.
4. 100 mol/Hr of purge gas yields 68.1 mol/Hr CO_2.So, 6652 mol/Hr purge gas yields 4530 mol/Hr CO_2, which equals 199321 lb/Hr. (B20-22) (#)
5. Since a feed rate of 100 mol/Hr is an equivalent of 8.9 MMBtu/Hr, a feed rate of 6652 mol/Hr is an equivalent of 592 MMBtu/Hr. (G15-16)
6. Since this feed rate provides 60% of the duty, then the duty required is 987.8 MMBtu/Hr. So the duty provided by Khuff gas is 40% of that (395.1 MMBtu/Hr).(B24-25)
7. From a previous calculation, 100 mol/Hr of Khuff gas gives 29.4 MMBtu/Hr. Therefore a duty of 395.1 MMBtu/Hr is provided by 1345 mol/Hr of Khuff gas. (B27)
8. Similarly, from a previous calculation, 100 mol/Hr Khuff gas gives 4011 mol/Hr CO_2. So, 1345 mol/Hr Khuff gas gives 53937 mol/Hr of CO_2. (B28-29)
9. Adding this number to that calculated in (#) gives a total emission of 253258 lb/Hr.