Improvements in the Productivity of Energy Usage in the Mexican Petroleum Refining Industry

Thesis for Examination

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ABSTRACT

This research work has two objectives: first, to identify actions and projects to be considered in the refinery's energy saving programme to improve its energy usage productivity; second, to develop a methodology for the analysis and evaluation of alternatives of design for a new refinery.

The energy saving problem of a petroleum refinery is analyzed in order to provide a conceptual frame using concepts, methods and tools from system engineering. Energy saving is a very complex problem in which there are several hundreds of different possible opportunities to improve the energy usage productivity.

The problem approach is based on the analysis of the energy consumption and usage at several levels: national, sectorial, petroleum industry, refining subsection and for a specific refinery.

First of all, a list of energy saving opportunities for a specific refinery is gathered, identified and classified. Three main kinds of actions are considered: operation, maintenance and design projects. The research work puts more emphasis on the third group of measures: the projects to design a new refinery or to redesign an existing one.

An evaluation model for calculating several economic parameters to support the selection of the best design or redesign projects is proposed. This model allows the analyst to make valid comparisons of projects establishing their proper priority according to the availability of financial resources.

A methodological scheme for the analysis of design alternatives of a new refinery based on cost-effectiveness criteria is developed. In this part, two problems are studied: how to design a new refinery optimizing its energy consumption, and how to design a new refinery optimizing its cost-effectiveness ratio.

At present this kind of projects are carried out in a traditional way, developing the different parts of each project using criteria from each engineering branch. The main idea is not to split the whole design problem into small parts but to analyze the entire problem using approach and techniques from system engineering.

In this work three frameworks are proposed: 1) For redesigning a refinery to improve energy usage productivity, 2) For designing a new refinery to improve energy usage productivity and 3) For achieving an integrated refinery design through a cost-effectiveness analysis

The main objectives, achieved in the research work are: a complete analysis of energy consumption in Mexico, at different levels; a deep study about energy usage productivity in the Salina Cruz Refinery; an evaluation model to select the best projects to redesign an existing refinery or to design a new one; and finally a conceptual frame to solve the mentioned problem through concepts, methods and tools from system engineering.

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CHAPTER 1.
INTRODUCTION

1.1.0 AIM AND OBJECTIVES OF THIS RESEARCH WORK

1.1.1 AIM

Mexican refineries consume about 9% of the total oil process, while other refineries with the same characteristics of configuration operating in the North America Gulf Coast consume from 5 to 6 %.[1]

Regarding the energy intensity index, which is a parameter for making comparisons among similar refineries, Mexico had 191 in 1989, 174 in 1990, 158 in 1991 and 141 in 1993.[2] This means that Mexico has consumed between two times and one and a half time more in respect to similar refining installations in the same marketing area.[1]

The main aim of the research is to examine how to reduce the high energy consumption of the existing Mexican refineries, increasing the energy productivity index so that they become more competitive with other refineries and take actions to improve the future refinery designs to make the new Mexican refineries highly efficient in their energy usage and to have an optimized cost- effectiveness ratio.

1.1.2 OBJECTIVES

This research work is a very wide study of many aspects of the energy usage in the Mexican refineries and specifically in the Salina Cruz refinery. It has two main objectives:

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[1] Solomon. Studies about energy intensity index. Information by subscription. Reference 58

[2] This index is calculated by means of Solomon's methodology

a) To identify actions and projects which are going to be considered in the refinery's energy saving program for each time period.

b) To develop a methodology for the analysis of alternatives of design for a new refinery based on cost - effectiveness criteria. This part starts with a conceptual model which includes all the factors and variables that should be considered in the design of a new refinery.

Two problems are studied in the research:

How to design a new refinery optimizing its energy consumption.

How to design a new refinery optimizing its cost-effectiveness ratio

At present these decisions only satisfy a not very deep, not systemic and not integral technical and economic feasibility study aimed only partially to the actions carried out, without considering the overall problem.

Budget limitations make it more difficult to significantly advance in the implementation of energy saving actions because there are only resources to cover 20% of the total program.

Taking this situation into account, the first contribution of the research work is to build an evaluation model to calculate several economic parameters. By which it would be possible to measure the profitability of each investment, to analyze them and to select the actions or projects which are the best from the point of view of the economic benefits of the investment.

Once the economic parameters are analyzed, the model allows a valid comparison to establish action priorities according to the availability of financial resources in the correspondent budget program.

The proposed model applied at the Salina Cruz refinery and the results obtained, led to a definition of the energy saving program for this refinery. It can also be applied to other refineries if the economic data for the analysis of every action are available

The structure of a refinery consists of many subsystems, components and elements connected through many interrelations. The whole system performance depends on that of each part, each processing plant, each major equipment and each control system

Traditionally, when a project of a new refinery is considered by Pemex, many studies are made in the field of technical and economic issues, and many engineers of different branches work together seeking a good solution. However, there is not an established system approach nor a system methodology, nor even a cost-effectiveness criteria in the entire project.

For this reason, a significant effort is made in the research in order to build a conceptual framework to handle this problem trying to use concepts, methods and tools from system engineering. As the problem is very extensive, the research does not include the application to a practical case.

The indirect purpose of this research is to assess the role of energy conservation within the context of the petroleum industry in order to clearly see its contribution to the current energy situation and to evaluate the economic potential in improving the efficiency of the energy usage.

1.2.0 NEED FOR THIS RESEARCH WORK

1.2.1 RESEARCH WORK CONTRIBUTION AND JUSTIFICATION

There are five main areas of use in the petroleum industry: Refineries, transportation of refined products, gas plants, petrochemical plants and oil production.

The problems and characteristics of each area make it necessary to study them separately. Information availability is different in each case.

This research work is a very wide study of many aspects of the energy usage in the Mexican refineries and specifically in the Salina Cruz Refinery. It has two main contributions:

The first contribution is the selection of actions and projects to be considered in the Salina Cruz energy saving program. Now, these kind of decisions only satisfy a not very deep, not systemic and not integral technical and economic feasibility study, devoted to a part of the actions without considering the whole program.

So this contribution of the research work is an evaluation model for calculating several economic parameters. Through it, it is possible to measure how profitable each project of investment is and to select the actions which are the best, from the point of view of economic benefits of the investment.

The model allows to make a valid comparison of projects establishing their proper priority according to the availability of financial resources.

The proposed model can be applied to the Salina Cruz refinery or to other refineries if the economic data for the analysis of every action is available.

The second contribution is a methodological scheme for the analysis of alternatives of design of a new refinery based on cost - effectiveness criteria. In this part two problems are studied:

a) How to design a new refinery optimizing its energy consumption

b) How to design a new refinery optimizing its cost effectiveness ratio

Up to date, when a new refinery is designed by Pemex, there is neither a system approach nor a system methods, nor is cost-effectiveness criteria used in the whole project.

The definition of a conceptual frame to handle this problem using concepts, methods and tools from system engineering is shown as a part of the research work.

Then, the main justification for this research is that both Mexico, as an undeveloped country, and the petroleum industry, as the biggest and most important enterprise owned by the Mexican state, have difficulties in acquiring the financial resources needed for large scale projects. This is why, in the first stages of the system study horizon, it is necessary to define the basis for the best design of each installation, taking into account the specific technical and financial constraints.

At present, the Pemex's engineering project areas carry out large scale projects in a traditional way, developing the different parts of each project using criteria from each engineering branch: chemical, civil, electro - mechanical. Prior to the selection of the projects for investment, an economic study is carried out.

On the other hand, the modern view for project design is not to split the whole design problem into small parts, but to analyze the entire problem using the approach and the techniques taken from system engineering.

1.2.2 HYPOTHESIS STATEMENT ABOUT CAUSES AND CONDITIONS OF HAVING LOW ENERGY USAGE PRODUCTIVITY IN MEXICAN REFINERIES.

According to available data from refineries, it is known that the more efficient refineries consume 5-6% of the processed crude oil as fuel; Mexican refineries consume 9.5% in average.[1]

On the other hand, information about energy usage in Mexican refineries shows that the consumption, measured as energy intensity index, is a basis for a more valid comparison. This indicator, calculated by establishing a standard energy consumption level for each refinery process, is almost 75% higher than that observed in similar refineries of the North America Gulf Coast.[2]

After a preliminary analysis of the available information about energy usage three hypothesis have been stated:

HYPOTHESIS 1

The low energy usage productivity in Mexican refineries is due to the restriction of financial resources which were available from the 60's to the 90's. Given this limitation, managers reduced the capital for investment. So, very poor heat recovery systems were included in the refinery designs. After 30 years of these decisions, the structure of the refineries is inadequate to achieve good energy efficiency.

As the investment was diminished for a specified capacity of plant, it was necessary to simplify the process eliminating the additional equipment for recovery energy. This situation led to

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1 Energy Consumption in IEA countries. Reference 41 and Operation statistics data.

2 Solomon's Development of Comparative Refinery Performance Analysis Reference 58

higher operational costs, in comparison to the refineries that had enough money for investing in competitive designs.

HYPOTHESIS 2

The low energy usage productivity in Mexican refineries is due to a lack of a proper measurement of the fuels and gas used for different processes. This situation, combined with the fact that not many people at the refinery are aware of the importance of being efficient in energy usage, results in high consumption indexes.

The lack of a proper measurement was due to the acquisition in different stages of out dated instrumentation, control systems and measurement devices. Technological decisions were not supported by serious studies in this field because there were other factors that disguised a convenient analysis. One of the most important factor that contributed to this equivocal position was the union's position.

HYPOTHESIS 3

The low energy usage productivity in Mexican refineries is due to a mistaken prices policy for fuels and natural gas. This policy was applied for many years not only in the petroleum industry but throughout the nation. For a long period of time fuel prices were low in respect to other countries and this policy did not attract users to pay attention to the implementation of measures for conserving and saving energy.

1.3.0 BACKGROUND TO THIS RESEARCH WORK

1.3.1 DESCRIPTION OF THE MEXICAN PETROLEUM INDUSTRY

The Mexican petroleum industry has had for many years enough capacity to satisfy the internal demand for petroleum and petrochemical products and to export more and more significant quantities of oil.

According to energy planning, the production level in the last decade has grown slowly, as it has been necessary to satisfy internal as well as 1.5 MM BD [1] of crude oil to export.

Due to instability problems in the international petroleum market, the figure above has had variations when the oil price has either slumped or risen.

Besides, Mexico has other problems as it has been necessary to import growing quantities of several petroleum refinery products, like LP gas, lube oil basis, gasoline and several petrochemicals. This situation is a consequence of not having enough production capacity and of having taken wrong decisions about economic and ecological issues. Nevertheless the amounts of these imports are not very significant in relation to the domestic production.

In the decades of the 70's and 80's Mexico had a very severe economic crisis as a result of external and internal variables. Particularly low crude oil prices and government deficit increased the inflation ratio and provoked an economic depression.

In 1990 and 1991, most severe economic problems were solved; inflation rate was controlled, so GDP and primary energy production grew moderately [2].

There are several energy usage productivity indicators which allow us to conclude that the energy usage productivity of undeveloped countries is lower than that of the industrialized ones. Mexico is an example of this behavior.

The Mexican energy consumption pattern is characteristic of this kind of inefficient energy usage. Several indicators show Mexico has a high consumption of energy per capita as well as per dollar of GDP [3].

In spite of being an undeveloped country, Mexico has a high energy consumption per capita. In million kcal, this indicator was 9.4 in 1970, 16.1 in 1980 and 16.4 in 1990 [4]. On the other hand, Mexico's energy consumption by GDP unit is higher than the ones corresponding to -

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1_/ MM BD, Million Barrel Per Day

2_/ Mexican Energy Balances 1990 And 1991. References 8,9.

3_/ Mexican Energy Balances 1965-1985, 1992. References 4 And 10.

4_/ Mexican Energy Balances, 1990 And 1991, Economic Energy Parameters. Tables 70 and 27 pp 118 and 54 respectively. References 8 and 9.

France, Japan, Spain, Germany, Turkey, Italy, Iran and Brazil and is lower than the indicators for the United States and United Kingdom [1/] Also the energy intensity index, that is the national consumption in respect to GDP, has had many variations but in general the tendency is ascendant; this parameter was 240 in 1980 and 253 in 1990 [2/], expressed in Kcal/Pesos of 1980.

Petroleum energy makes 90% of the total primary energy that is consumed in the country in 1992 and this whole production is obtained in six main refineries with more than 300 processing plants.

The petroleum industry is the largest in the national economy and also the main contributor to public finances and one of the most important supports for government strategies.

The Mexican energy production industry consumed about 26.2% in 1970, 33.9% in 1980, 30.5% in 1990 and 29.8% in 1992 of the total energy produced inside the country [3/]. So, it is the largest consumer and, therefore, has the possibility of saving important amounts of money if it adopts an effective energy saving program.

Up to now, the efforts made to save energy in refining have been very ineffective because controls in the Mexican petroleum industry have not been as accurate and careful as required.

During the last ten years, Pemex has started energy saving programs in its six refineries which have began to show results. Nevertheless, there is still a lot to do. The problem has several facets: the technological, administrative and human ones are perhaps the most important. An in-depth study of these aspects is necessary in order to define solutions for each problem

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1_/ Energy Conservation in IEA Countries. References 41

2_/ Mexican Energy Balance 1990, Table 27, pp 54. Reference 8

3_/ Mexican Energy Balances 1965-1985,1992. Tables 52 and 23 pp 100 and 50 References 4 And 10.

1.3.2 ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY

Petroleum energy represents 89.9 % of the total energy produced in Mexico.[1] Of this, the petroleum and electricity sectors are the most important individual energy consumers. In 1990 both sectors consumed 30.8% of the total energy produced in the country and of this, two thirds are consumed by the petroleum industry.[1] This indicator shows the great magnitude of this industry.

There are many factors which explain the high demand of energy in the petroleum industry: All refining processes are intensive energy users and there are as well, many activities which require important amounts of energy. The extraction of crude oil, its transportation, the processing in refineries and petrochemical plants, the distribution of products, all of them demand a lot of energy.

One can come to an overview of the energy consumption in the petroleum industry by analyzing the hydrocarbon balance. There are several streams: Transformation losses, consumed gas, consumed fuel, unused energy and energy losses.

1.3.3 ENERGY CONSERVATION POLICY IN OIL INDUSTRY

The Mexican petroleum industry has been a state company for more than fifty five years, but it has only been in the last fifteen years that it has been interested in saving energy. For many years, the new projects were selected without considering any action for improving its energy usage efficiency. The main interest was to reduce the investment needed for new plants. And, in as far as operation and maintenance, there was no effective program to improve energy usage efficiency.

A department to conserve and save energy was included in the company organization in 1983. Two objectives were defined for it a) to optimize the consumed energy without affecting the production level, b) to contribute to the national energy saving program in all the economic sectors.

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[1] Mexican Energy Balance 1990. Reference 8 pp 11, 19

From the beginning of the first program the strategy focused on the operational areas in three stages:

1. To manage the energy resources more efficiently by means of operational adjustments and corrective maintenance.

2. To replace equipment and materials by more efficient ones through technological changes.

3. To modify processes in a frame of technological modernization of the installations.

Other supporting actions were:

- To evaluate the energy usage in the company to be able to set saving goals.
- To analyze program results data in order to adjust control variables.
- To inform people about objectives, programs, goals and obtained results.
- To make workers aware of their responsibility in energy usage.
- To provide training in energy saving.
- To study opportunities for saving energy.

The program was evaluated after six years of its implementation. It was concluded that 130000 barrels of crude oil per day were saved. However this figure was not very reliable, so it was necessary to support the program with an information system for the specific evaluation of the results. To support the program twenty courses were organized for supervisors, managers and engineers, in subjects related to energy conservation and saving.

From that time, many efforts have been made to avoid wasting energy and to discard inconvenient consumption patterns. It has been possible to change in only some of the operational practices causing wasted energy.

In last years most of the petroleum industry installations have had energy saving programs with specific goals and correspondent budgets to support the activities. Each refinery center has an energy manager who is the head of an energy saving committee.

However, the success of the energy saving program has been limited by many factors

- Imprecise and untimely information about energy consumption
- Not enough information for reliable energy balances
- Improper control and measurement systems
- Insufficient economic resources to save energy
- Too few people with energy saving responsibility

In the last three years many studies have been made in energy saving with the support of external consultant firms.

In spite of that, there has neither been a reduction of energy consumption nor an increase of energy efficiency parameters.

On the other hand, Mexican refineries have become more complex, so energy consumption has increased, and therefore, more in-depth studies have had to be made to understand the relation between production capacity, complexity, operation performance and energy consumption.

It was clear that many energy saving opportunities that were identified fifteen or ten years ago had not been implemented, so the energy usage parameters have remained almost unchanged.

The conclusion is that a great effort is needed to improve energy usage productivity parameters. Four fields are now identified as potentially interesting to achieve these objectives: operation, maintenance, redesigning existing refineries and designing new ones.

Conservation policy is now clear. The top level has specified in its general policies that saving energy has priority in respect to other investment projects because of its return on investment and its positive effect on pollution parameters. Unfortunately, Pemex has not been capable of starting the implementation of an effective program in this aspect.

1.3.4 ENERGY CONSERVATION POLICY IN MEXICO

Energy conservation should be an important component of the national energy policy. Since 1970 Mexico has proved how vital the national energy resources are in supporting the economy.

Consumers formed the habit of using energy without constraint, and the demand grew also as a consequence of several decades of economic development.

One of the most severe problems that the Mexican petroleum industry faces today is the low energy usage efficiency. Several factors contribute to this problem:

- Both Mexican industrial companies and energy production entities have been wasteful in energy consumption for many years. This problem has provoked a high demand for petroleum products in the domestic market, since petroleum is the major national energy source.
- Petroleum product prices were not realistic for many years.
- Most refinery operations have affected the air and water quality in the major Mexican cities, causing contamination in air and in waste water.
- The environmental condition has not been taken into account in order to save energy.
- Saving energy in refineries can be a very important variable to improve air quality. This can be done restricting refinery emissions and sulfur content specifications for fuels.
- Consumers and society as a whole have not been capable of using each barrel of oil more efficiently.

Energy conservation is an important strategy for developing countries. By using energy more efficiently these countries can reduce their unit costs of production, save foreign exchange by reducing energy imports and eliminate capital requirements for energy production.[1]

CONAE (Comisión Nacional para el Ahorro de Energía) estimates that 15 to 50 percent of the energy used in Mexico's most intensive industrial process could be saved, and the 10 to 20 percent could be saved in other sectors.

Savings in fuel and electricity will also save large amounts of capital, which will not need to be invested in additional energy production and distribution capacity.[1]

Other reasons to be considered in the promotion of an energy conservation programme are:

- Energy conservation can extend the availability of the national energy resources that are depletable and can reduce the environmental consequences of energy production and energy usage.

- Perhaps one of the most important advantages of the investment in energy conservation is that in most cases it provides a better return on investment than other projects to increase the installed capacity.

- IEA economies had a 20% reduction in energy intensity from 1973 to 1985. This goal was possible thanks to the many industries which had an important role in providing energy conservation services through their direct dialing with consumers.[2]

- As a supply company, Pemex could have an important role, as given national circumstances it has the leadership in this field.

- In Mexico, the Energy Department is involved in bringing about energy conservation. This responsibility depends on the legislative framework. Actually federal government has very little authority in the energy conservation program. Its influence on the state - owner enterprise is weak, due to the reduced organization available for this function. Because of this, coordinating a program across the whole country has been very hard.

- Energy conservation is a new field for the Mexican government. It has been considered in national plans only in the last eight years , and even now, there is not

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[1] Economic and Technological implications of Energy Conservation's Programs at the National and Enterprise Levels. Reference 22.

[2] Energy conservation in IEA countries. Reference 41

yet a formal program nor is there a formal agency to lobby conservation energy programs

- This is why it is very difficult to establish procedures for conservation measures, at both national and institutional levels.

- At present, the petroleum industry energy saving program is almost autonomous because the formal authority, that is, the ministry in charge of energy issues is much smaller than Pemex, the company to be controlled. The success in the energy conservation program depends on putting together many different actions and motivating a large number of industries which do not have energy conservation as their main interest.

- It is necessary to create and develop internal energy conservation services in the petroleum industry and to promote private services for complementing them. In order to identify energy conservation opportunities, experience has shown that governments can encourage these interests to come together and these programs, with only modest financial support, can play an important part in energy productivity improvement.

- A clear definition of a strong conservation policy headed by a senior officer who takes part of top management of the energy department, is needed in order to have strong political leadership and bureaucratic commitment.

1.4.0 RESEARCH STRATEGY ADOPTED

An outline for the research is proposed as follows:

- System approach to the Problem
- Description of the System and its Environment
- Analysis of energy Production, Demand and Consumption
- Total Energy Balance
- Energy balances in the refining industry
- Energy auditing
- Technology and its effect on energy consumption
- Refinery Operation and Maintenance
- Refinery System Design
- Energy Savings Programme for the specific studied refinery

    Operation and Maintenance
    Technology
    Process
    Design

- Redesigning an existing refinery
- Designing a new refinery

The most important support to redesign or design a refinery, when the main objective is improving the productivity of its energy usage is the availability of the results from a deep energy auditing study.

The logical sequence of activities to achieve the definition of the energy saving opportunities is: a) organize the information; b) analyze the information obtained from the specific energy audit; c) identify the energy saving opportunities and d) evaluate them to make a proper priorization of the possible actions to be included in the energy saving programme, this sequence is presented in diagram 1.4.a.

To design a new refinery three methodological supports are proposed within the research work

a) System concepts and a system methodology
b) A cost-effectiveness analysis
c) A system framework for an integrated design

The proposed general scheme to integrate these three methodological supports is shown in Diagram 1.4.b "General Scheme to design a refinery as a total system by means of a cost-effectiveness analysis". The general idea to bring into focus the methodological sequence to design a refinery is presented in diagram 1.4.c. According to this scheme the six phases to represent the refinery's life cycle are:

Phase 1. Development study
System concepts and general criteria

Phase 2 System preliminary design

Formulating and structuring the system
Integrating the whole design

Phase 3. System detail design

Phase 4. System realization - construction

Phase 5. System testing and operation

Phase 6. System replacement study

DIAGRAM 1.4.a

GENERAL OUTLINE TO SUPPORT A REFINERY DESIGN FROM AN ENERGY AUDITING

ENERGY AUDITING

- Analysis of energy consumption
- Whole energy balance
- Identification of the highest consumption areas
- Facilities energy balance
- Identification of the highest consumption equipment
- Tabulation of energy uses
- Comparison of energy consumptions

ENERGY SAVING OPPORTUNITIES

- Analysis of more advanced technology to identify potential opportunities
- Identification of areas which should improve their energy usage productivity
- Listing of energy saving opportunities

EVALUATION OF ENERGY SAVING

- Definition of hierarchy of the energy saving opportunities
- Analysis of partial system

DIAGRAM 1.4.b

GENERAL SCHEME TO DESIGN A REFINERY AS A TOTAL SYSTEM BY MEANS OF A COST - EFFECTIVENESS ANALYSIS

DEVELOPMENT STUDY

- Conceptual Design; System Definition,
- Formulating the system; Structuring the system

PRELIMINARY COST - EFFECTIVENESS ANALYSIS

- Technical Design
- Social and Environmental design

EVALUATION MODEL FOR COST - EFFECTIVENESS ANALYSIS

- Performance Design
- Reliability Design
- Support Design
- Integrated System Design

- Functional model
- Capability model
- Availability model
- Cost model
- System effectiveness model

MODEL IMPLEMENTATION

- System worth analysis
- Evaluation of system candidates
- System configuration and Partial system analysis

- Whole integrated system

PRELIMINARY DESIGN

- Selection of partial design
- Integrating the whole design

DETAILED DESIGN

- Partial Designs
- Integrating the whole design

DIAGRAM 1.4.c PHASES IN THE METHODOLOGICAL SCHEME TO DESIGN A REFINERY AS A TOTAL SYSTEM

PHASES

PHASE 1
DEVELOPMENT STUDY

- ANALYSIS FOR DESIRED PEFORMANCE
- SYSTEM CONCEPT

PHASE 2
SYSTEM PRELIMINARY DESIGN

- SYSTEM PRELIMINARY DESIGN
- SYSTEM DESIGN INTEGRATION

PHASE 3
SYSTEM DETAIL DESIGN

- SUBPROCESSES PLANT DESIGN
- MAIN EQUIPMENT DESIGN
- PROCESS INTEGRATION
- UTILITIES
- SYSTEM INTEGRATION

PHASE 4
SYSTEM REALIZATION - CONSTRUCTION

- EQUIPMENT DESIGN
- SYSTEM CONSTRUCTION
- SYSTEM DEVELOPMENT

PHASE 5
SYSTEM TESTING - OPERATION

- EQUIPMENT TEST
- PROCESS TEST
- ASSEMBLED SYSTEM TEST
- PROCESS AND QUALITY CONTROL
- SYSTEM INTEGRATION

PHASE 6
SYSTEM REPLACEMENT STUDY

- SYSTEM PERFORMANCE
- OPTIONAL SYSTEM PERFORMANCE
- SYSTEM REPLACEMENT

CHAPTER 2
ENERGY BALANCES

2.1.0 GLOBAL ENERGY BALANCE

A thorough analysis of energy balances at global level is required here, in order to have a reference for the Mexican energy balances. so, the behaviour of Mexico energy balances in terms of energy efficiency, can be compared with other more advanced countries.

Global energy consumption has increased from the beginning of this century, from 1940 to 1960 the rate was 4.1% and from 1960 to 1970, 6.0%. On the other hand, during these years, a higher dependence on petroleum, was brought about, so the relative part corresponding to oil was 39 1% in 1950, 67.1% in 1970 and 62.2% in 1980.[1] This last reduction was due to the results of several national energy saving programs launched by different government administrations.[2]

The energy industry has gone through several major stages in respect to level activity during the last 20 years. The frequent substantial changes in the cost of energy has been one of the major reasons for deep changes in this business. Another reason has been the gradual shift from an industrial economy to a more service oriented one.

Oil prices have greatly influenced the market behavior. In the 1973-1974 period the price of oil increased three times, and in that corresponding to 1974 - 1980 it increased yet three times more. After prices were increased in the 70's, a long period of low cost energy has taken place.[3]

Natural gas had a similar behavior. All forms of on energy became more expensive during 1973 - 1980. This huge increase it more attractive for users to find ways to conserve or save energy. Therefore, it became economically attractive to invest in reducing energy consumption and in equipment to establish multifuel capability, so large fuel users could select the least costly fuel. After that period, oil prices started going down.[3]

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1 The world Petroleum Industry. Reference 55

2 Energy Conservation in IEA Countries. Reference 41

3 Energy Economics. Growth, resources and policies. Reference 56

The new evolving economy is less energy intensive than the previous one. Conservation led to a drop in energy consumption per unit of economic activity, so energy consumption per unit of GDP has been falling continuously since 1970.[1]

It is easy to understand that low prices provoked unconsciousness about energy usage. Besides, inefficient technology and wasting consumption patterns determined a high energy consumption, so many countries based their development on cheap energy.

After the restriction in the energy supply occurred in 1973, many governments began taking into account the possibility of an ending of the oil era. Oil reserves were limited and many actions were taken to avoid the effects of energy scarcity. Then, most of the developed countries started programmes to save energy, the results of which we have seen in the last years.[1]

Since 1973, a change was observed in the energy oil demand trend, due in part to the energy conservation measures that were taken. According to a realistic evaluation, the results of these programmes were in 1973, 7% of saving, in 1980 11% and in 1990 20%.[1]

Considering the energy consumption related to Gross Domestic Product GDP, we can conclude that energy usage productivity has increased in the Organisation for Economic Co-Operation and Development OECD countries. In the period 1965-1973 the growing rates for GDP and energy consumption were 4.7% y 5.2%, respectively, while for the 1976-1980 period they were 3.9% and 3.3%.[2]

In **Annex 1**, some data on energy in the world are presented.

2.2.0 NATIONAL ENERGY BALANCE

In this part, information about the national energy structure from the point of view of supply and demand are presented. Data were obtained through a qualitative and quantitative analysis of the overall Mexican energy balance complemented with information of the producer sector.[2]

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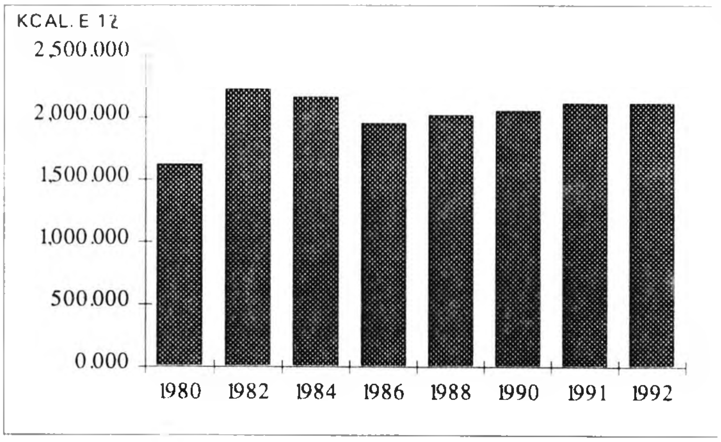
1 Energy Conservation in IEA Countries. Reference 41

2 1992 Mexican Balance of Energy. Table 19 reference 10, pp 46

The main variables analyzed were demand, consumption and supply, in order to make clear the balance between energy production, transformation and consumption.

The primary energy produced in the country in the last twelve years expressed in kcal e 12 or Petacalories is shown below.[1]

TABLE 2.2.a



PRIMARY ENERGY PRODUCTION

YEAR	PETACALORIES
1980	1,626.913
1982	2,227.494
1984	2,166.519
1986	1,954.016
1988	2,021.025
1990	2,056.888
1991	2,118.830
1992	2,120.479

These figures show that the total production has remained practically unchanged in magnitude in the last years, nevertheless, its variations show problems derived from the national economy and from the instability of the oil market. As a result, the total energy production increased only 10% from 1980 to 1990, but in respect to 1982 it diminished 5%.

The percenting primary energy structure in 1980, 1985 and 1990 was as follows:

[1] 1992 Mexican Balance of Energy. Table 19 Reference 10, pp 46

TABLE 2.2.b

MEXICAN PRIMARY ENERGY PRODUCTION

Pcal

	1980		1985		1990		1992	
	Pcal[1]	%	Pcal[1]	%	Pcal[2]	%	Pcal[3]	%
TOTAL	1626.9	100.0	2090.4	100.0	2058.4	100.0	2120.5	100.0
COAL	18.2	1.1	30.5	1.5	35.6	1.7	30.7	1.4
HYDROCARBONS		90.5		90.7		89.9		90.0
OIL	1081.5		1456.6		1401.3		1469.3	
CONDENSATE	0.2		46.6		57.3		67.4	
GAS	390.4		392.9		392.0		360.8	
ELECTRICITY		3.1		3.5		3.9		4.3
NUCLEAR					7.4		10.0	
HYDRO	47.8		69.8		60.2		14.7	
GEOENERGY	2.6		4.3		13.2		65.9	
BIOMASS	86.2	5.3	89.7	4.3	91.6	4.5	91.6	4.3

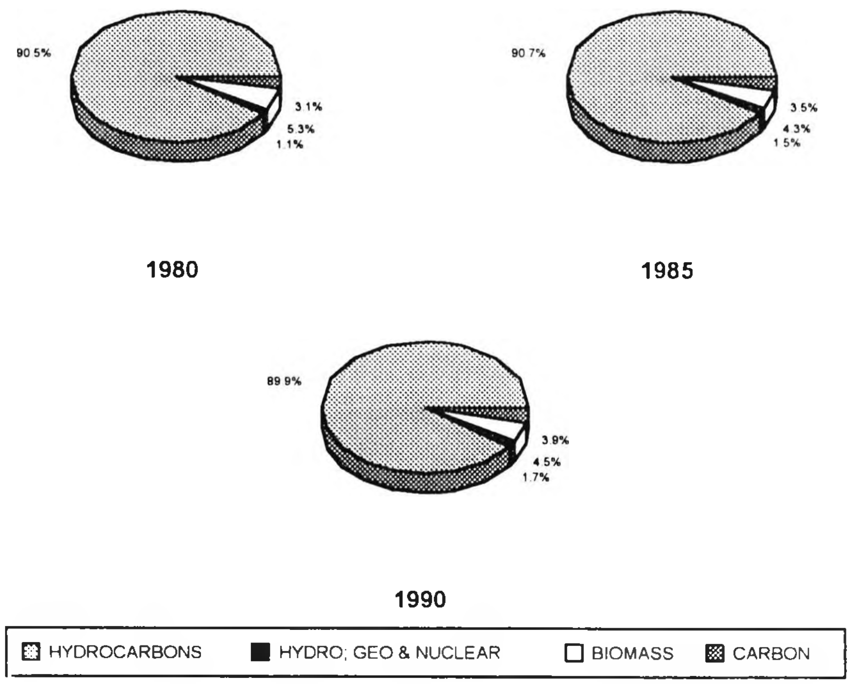
Pcal = Petacalories

[1] Mexican Energy Balance 1965 - 1985. Reference 4

[2] Mexican Energy Balance 1990. Reference 8

[3] Mexican Energy Balance 1992. Reference 10

MEXICAN PRIMARY ENERGY PRODUCTION
PETROLEUM ENERGY PRODUCTION RESPECT TO WHOLE ENERGY
%



Petroleum energy was 90.5%, 90.7% and 89.9% from the whole energy, in 1980, 1985 and 1990, respectively. That means that Mexico has had an energy structure based on oil.[1]

In 1991 and 1992, at the first step of the primary production, the reported wasted energy was 1.5% of the total produced energy. This figure is referred to gas burnt in the atmosphere and accidentally spilled oil. This part of the consumption is not studied here.[2]

2.2.1 ENERGY TRADE MARKET

In 1992, imports were 0.1 petacalories and exports were 756.3 petacalories. This last figure corresponded to a mixture of 67.5% of maya, 21% isthmus and 11.5% olmeca crude oil.[2]

The exported primary energy, for 1990, 1991 and 1992, were of 703.7, 756.4 and 756.3 petacalories. Oil represents 99.9% of Mexican energy exports and carbon represents 0.1% [2]

[1] Mexican Energy Balances 1965-1985 and 1990. References 4,8

[2] Mexican Energy Balance 1992. Table 2 pp 15. Reference 10

TABLE 2.2 c[1]
MEXICAN EXPORTS OF REFINED PRODUCTS, 1980 - 1991
(PETACALORIES)

YEAR	TOTAL	carbon	CRUDE OIL	COKE	LP GAS	GASO-LINES	KERO-SENES	DIE-SEL	FUEL OIL	VIRGIN LOAD	N E P *	GAS	ELEC.
1980	512.303	-----	460.840	0.525	5.602	0.625	0.194	0.657	16.820	-----	0.160	26.880	-----
1981	677.473	0.002	613.328	0.001	0.979	0.460	0.205	4.591	30.383	-----	0.021	27.503	-----
1982	884.362	0.215	834.247	-----	0.453	1.070	0.244	1.392	20.679	-----	-----	26.062	-----
1983	924.774	-----	859.646	-----	1.680	10.244	1.618	13.120	15.073	2.457	0.110	20.756	0.070
1984	927.517	-----	855.669	-----	3.055	17.131	2.391	5.818	7.287	21.946	-----	14.143	0.077
1985	872.572	-----	802.139	0.631	6.957	12.150	2.729	8.048	14.270	25.444	-----	-----	0.204
1986	781.330	0.005	720.319	0.162	6.704	11.033	3.584	13.346	23.465	1.429	0.026	-----	1.257
1987	804.216	0.378	753.458	-----	5.844	9.530	6.795	5.868	19.504	0.993	0.090	-----	1.756
1988	795.160	0.458	732.281	0.431	11.558	11.031	9.626	4.041	24.017	-----	-----	-----	1.717
1989	757.139	0.236	714.244	0.121	10.977	2.435	5.372	7.622	14.470	-----	-----	-----	1.662
1990	756.105	0.038	703.694	0.026	18.118	4.016	7.515	16.561	4.464	-----	-----	-----	1.673
1991	804.859	0.005	756.423	0.199	13.851	7.376	8.426	12.848	4.531	-----	0.305	-----	1.736
1992	816.623	-----	756.402	-----	7.184	10.681	7.688	19.987	12.848	-----	0.078	-----	1.755
PERCENTUAL VARIATION													
81/80	32.2	-----	33.1	-99.8	-82.5	-26.4	5.7	598.8	80.6	-----	-86.9	2.3	-----
86/85	-10.5	-----	-10.2	-74.3	-3.6	-9.2	31.3	65.8	64.4	-94.4	-----	-----	516.2
91/90	6.3	-86.8	7.5	665.4	-23.6	83.7	12.1	-35.8	1.5	-----	-----	-----	3.8

* N.E.P. = NO ENERGETIC PRODUCTS

On the other hand, imports of primary energy have not been significant compared to exportation. It is interesting however to see how imports have changed recently. LP gas had been traditionally imported for complementing national production. But since 1989, gasoline and fuel began being imported, as a consequence of a new commercial policy in the petroleum industry, in which two new factors were considered: environmental actions and economic objectives. The following can be observed:

TABLE 2.2.d
MEXICAN IMPORTS OF REFINED PRODUCTS[2]
(PETACALORIES)

YEAR	LP GAS	GASOLINE	KERO	DIESEL	FUEL	GAS
1980	6.507	0.292	0.682	1.342	--	--
1990 [2]	8.110	17.267	--	--	30.159	4.021
1991 [2]	8.040	35.405	--	--	27.266	15.526
1992 [2]	11.170	42.296	--	--	30.888	24.175

1 "Mexican Energy Balance 1992," Table 20, pp 47, Reference 10.

2 "Mexican Energy Balances 1990, 1991, 1992". References 8, 9 ,10.

2.2.2 DOMESTIC MARKET

The domestic gross offer is defined as the total production, plus inventory variations, plus imports, minus wasted energy minus exports. The following table 2.2.e has the comparison of this figure between 1990, 1991 and 1992.

TABLE 2.2.e. DOMESTIC GROSS OFFER [1]

	PETACALORIES		
	1990	**1991**	**1992**
TOTAL DOMESTIC GROSS OFFER	1316.0	1326.2	1324.9
PRODUCTION	2056.9	2118.9	2120.5
EXPORTS	703.7	756.4	756.4
IMPORTS	1.4	0.2	0.1
INVENTORY VARIATION	4.3	3.6	5.0
WASTED ENERGY	34.3	40.1	44.4

In 1990, 1991 and 1992 the total energy offer was 1316.0, 1326.2 and 1324.9 petacalories, the difference in respect to production was assigned to the external market.

2.2.3 ENERGY TRANSFORMATION

Most of the primary energy is transformed in the country. In 1991, 1204.1 petacalories were sent to energy transformation centers; 58.8 % was processed in refineries. Production from refineries, gas plants and fractionation plants was of 1073 petacalories, 2% higher than in 1990.[2]

In 1992, from the processed energy, 58.5% was oil for refining, 31.0% went to natural gas processing plants, 1.3% to coke plants and 9.2% to hydroelectric, geothermic, and

[1] Mexican Energy Balances 1990, 1991, 1992. References 8,9,10.

[2] Mexican Energy Balance 1991. Table 5 pp 17. Reference 9

carboelectric plants.[1] In this year 1198.5 petacalories were sent to transformation centers, 0.5% less than in 1991.[1]

In 1991, Mexico had 7 refineries, but in that same year, one of them near Mexico City was closed to eliminate pollution. In the last three years from 1990 to 1992, the feed to refineries were 692.6, 707.6, and 701.4 petacalories.[2]

The refinery system had a distillation capacity of 1373 MBD in 1992.[3] In the same years, refined products in terms of percentage of the total production were: 23.2% gas, 22.5% fuel oil, 21.7 % gasoline and naphtha, 15.0% diesel, 8.7% gas LP and 8.9% other products.[4]

In 1991 and 1992, transformation of energy provoked energy losses in these plants, equivalent to 16.3 and 15.9 petacalories respectively. So, the energy conversion factor was 98.5% in both cases.[4]

2.2.4 NATIONAL ENERGY CONSUMPTION

Energy production in Mexico increased five times in twenty years, between 1965 and 1985. This rapid growth represented a rate of 8.4% per year. Three different periods can be observed: from 1965 to 1973, the rate was 4.5% per year; in the second, from 1973 to 1982 the rate was 15.8% and in the third, from 1982 to 1986, the annual rate was 2.0%.[5] From 1987 up to date there have been variations but the average annual rate has been more or less 1%.[6] The variation of the production annual rates in that period is explained by the behavior of the international petroleum market.

Between 1965 and 1985, the wasted energy increased 1.5% per year and was 8.2% in average.[1] As energy recovery equipment was being installed in the Mexican petroleum

1 / Mexican Energy Balance 1992. Table 5. pp 17. Reference 10

2 / Mexican Energy Balance 1991, 1992. pp 17. References 9 and 10

3 / Mexican Energy Balance 1992. pp 16. Reference 10

4 / Mexican Energy Balance 1992. pp 18. Reference 10

5 / Mexican Energy Balances 1965-1985. Reference 4

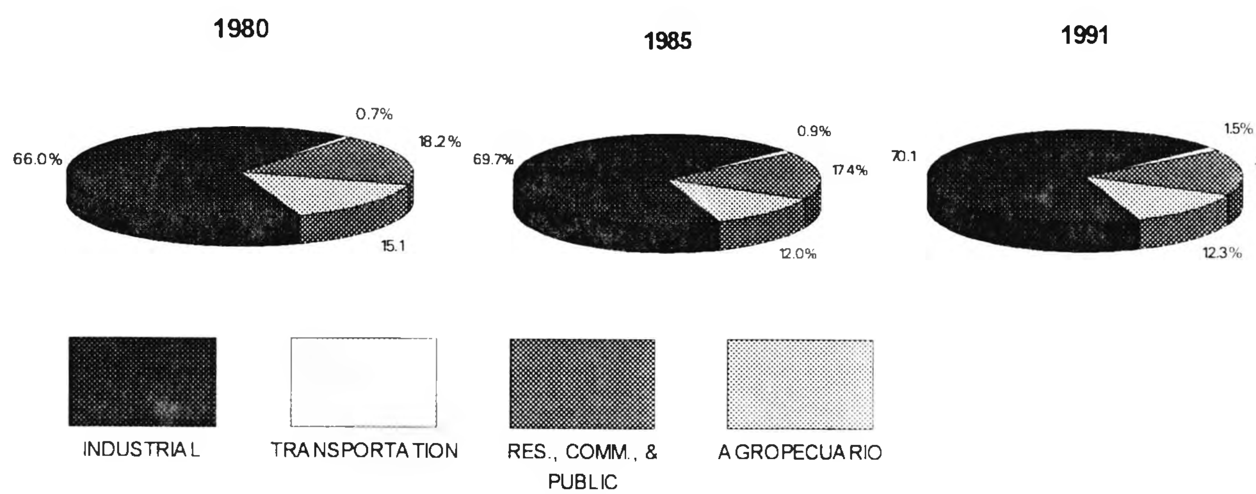
6 / Mexican Energy Balances 1987, 1988, 1989, 1990, 1991, 1992. References 5 - 10

industry, wasted energy was going down. Nevertheless, the complexity of refineries has became higher, so the consumed energy is also higher.

During 1991, national energy consumption was 1359.4 petacalories, 2.5% higher than the figure correspondent to 1990. The sector which produce energy consumed 405.6 petacalories, 29.8% of the total energy used. 70.2% of the energy was destined for final consumption in other sectors of economic activity.[2]

The final consumption is shared by the different subsectors as follows [1] [2]

FIGURE 2.2.f



In 1992, the national energy consumption was 1381.3, petacalories 1.6% higher than the figure correspondent to 1991. The final consumption percentage remained at the same level.[3]

1 / Mexican Energy Balance 1965-1985. Reference 4
2 / Mexican Energy Balance 1991. Reference 9
3 / Mexican Energy Balance 1992. Reference 10

2.3.0 ENERGY BALANCE IN THE SECTOR WHICH PRODUCES ENERGY

2.3.1 ENERGY CONSUMPTION IN TRANSFORMATION CENTERS

Most domestic oil energy offer in Mexico has as its destiny to be processed in energy transformation centers. In 1992 only 104.4 petacalories, 7.9% of primary energy, went directly to a final consumption. From this amount, 11% was natural gas. The difference was biomass. The self consumption of primary energy in the sector which produces energy was of 8.3 petacalories, and from this amount, 1.6 petacalories were losses in transportation, distribution and storage.[1]

Most primary energy is sent to transformation centers to produce secondary energy. In 1990, there were 7 refineries with a total capacity of 1679 MBD.[2] [3] The installed capacity for generating electricity was 25299 mw, 50% in thermoelectric plants, 30.9 % in hydroelectric plants, 4.7% carboelectric, 2.8% geoelectric and 2.7% nucleoelectric ones. Besides, there were four coking plants.

In 1992 with six refineries, the sames figures were total capacity of refining 1373 MBD, total capacity for generating electricity 27068 MW, 61% in thermoelectric plants, 29.3% in hydroelectric plants, 4.4% carboelectric, 2.7% geothermic and 2.5% in nucleoelectric ones.[4] The energy balance in these transformation centers is presented in table 2.3.a:

1 / Mexican Energy Balance 1992. Reference 10

2 / Mexican Energy Balance 1990. Reference 8:

3 / Million barrel per day. (MBD)

4 / Mexican Energy Balance 1992, pp. Reference 10

TABLE 2.3.a

ENERGY BALANCE IN ENERGY TRANSFORMATION CENTERS [1] [2]

	1990			1992		
	PETACA LORIES	%	ANNUAL RATE 1990/1989 %	PETACA LORIES	%	ANNUAL RATE 1992/1991 %
TOTAL	1201.6	100	2.1	1198.5	100.0	-0.5
REFINERIES	692.6	57.6	1.3	701.4	58.5	-0.9
GAS PLANTS	393.1	32.7	2.4	372.1	31.0	-2.5
ELECTRICITY CENTERS	98.9	8.2	5.3	110.0	9.2	10.9
COKERS	17.0	1.5	5.9	15.1	1.3	-3.6

It is difficult to understand how energy flows in the energy producer sector because there are many streams, transformation changes and feedbacks. For an easier appreciation of the main streams, table 2.3.b, based on the total petroleum energy balance, shows the different consumptions at national level.

In the last three years, national consumption was analyzed to determine how the consumption of the energy sector producer has changed. It was observed that the corresponding figures went up and down, but kept the same percented sharing.

In 1992, the energy sector consumption that included the consumption itself and transformation, distribution and storage losses was 29.8% of the total national consumption. This energy sector consumed 411.2 Pcal; 60.3% were transformation losses or satistical differences and 39.7% was the consumption of the energy sector by itself [2].

---

[1] Mexican Energy Balance 1990. Reference 8

[2] Mexican Energy Balance 1992. Reference 10

TABLE 2.3.b
ANALYSIS OF NATIONAL ENERGY CONSUMPTION
1990- 1992

CONSUMPTION	1990[1] Pcal	1991[2] Pcal	1992 [2] Pcal	% 1990	% 1991	% 1992
NATIONAL	1327.5	1359.4	1381.3	100.0.0	100.0	100.0
SECTOR WHICH PRODUCES ENERGY	409.2	405.6	411.2	30.8	29.8	29.8
SELFCONSUMPTION	160.4	162.0	163.2	12.1	11.9	11.8
TRANSFORMATION	231.7	219.0	219.9	17.4	16.1	15.9
LOSSES	14.3	20.6	20.8	1.1	1.5	1.5
STATISTICAL DIFF.	2.7	4.0	7.2	0.2	0.3	0.6
FINAL CONSUMPTION	918.3	953.8	970.1	69.2	70.2	70.2
NO ENERGETIC	98.7	98.0	105.1	7.5	7.2	7.6
ENERGETIC	819.5	855.8	865.0	61.7	63.0	62.6

Energy transformation is the conversion of primary energy to secondary energy. It takes place in cooking plants, refineries, gas plants and electric centers.

Transformation losses are explained by thermodynamic limitations derived from out dated technologies. They are calculated by determination of the difference between energy to transformation and obtained secondary energy.

The total energy transformation had the balance in 1990, 1991 and 1992 as table 2.3.b shows.[3]

Self consumption, transformation losses and other losses, have remained at the same level, in percentage, in the last years.

The differences between the obtained secondary energy and the utilized primary energy show the losses by transformation.

Following it is presented table 2.3.c, to resume the main 1992 figures about energy transformation.

---

[1] Mexican Energy Balance 1990. Reference 8

[2] Mexican Energy Balance 1991. Reference 9

[3] Mexican Energy Balance 1992, Table 15 pp 39. Reference 10.

Table 2.3.c

TOTAL ENERGY TRANSFORMATION[1]

1992

	Primary Energy	Secondary Energy	Total
Total Transformation	-1198.5	978.6	-219.9
Coking plants	-15.1	13.6	-1.5
Refineries	-701.4	685.9	-15.5
Gas plants	-372.1	371.7	-0.4
Electric centers	-110.0	92.5	-202.5
Energy sector consumption	-83	154.9	-163.2
Statistical differences	-7.5	0.3	-7.2
Losses	-6.1	-14.6	-20.7

Table 2.3.c shows that the total losses by transformation is 219.9 petacalories. From them, 15.5 corresponded to refineries and 202.5 to electric centers. So, 163.2 Pcal is the energy sector consumption and 20.7 Pcal the losses because of transportation, distribution and storage.

In 1992, the secondary energy production was 1188.5 petacalories; its main components in petacalories were: residual gas, gasoline, fuel oil, diesel, naphtha and electricity.[2]

The conclusion of analyzing the total consumption in 1980-1992 period, is that final consumption has increased its shared part from the total energy consumed. In 1980 it was 66%, in 1985 it increased to 69.7%, in 1990 it diminished slightly to 69.2%, and in 1991 and 1992 remained at 70.2%. Self consumptions were 15.1%, 12.0% 12.3%, 11.9 and 11.8% respectively, for the same years, while energy losses in transformation processes were of 18.2%, 17.4% 17.4%, 16.1% and 15.9% respectively.[3]

The figures shown in diagrams from 2.3.d.i to 2.3.d.g were arrived by quantifying each phase of the hydrocarbon process. It starts from the primary energy production of crude oil, gas and condensates

---

[1] Mexican Energy Balance 1992. pp 39. Reference 10

[2] Mexican Energy Balance 1992. pp 71. Reference 10

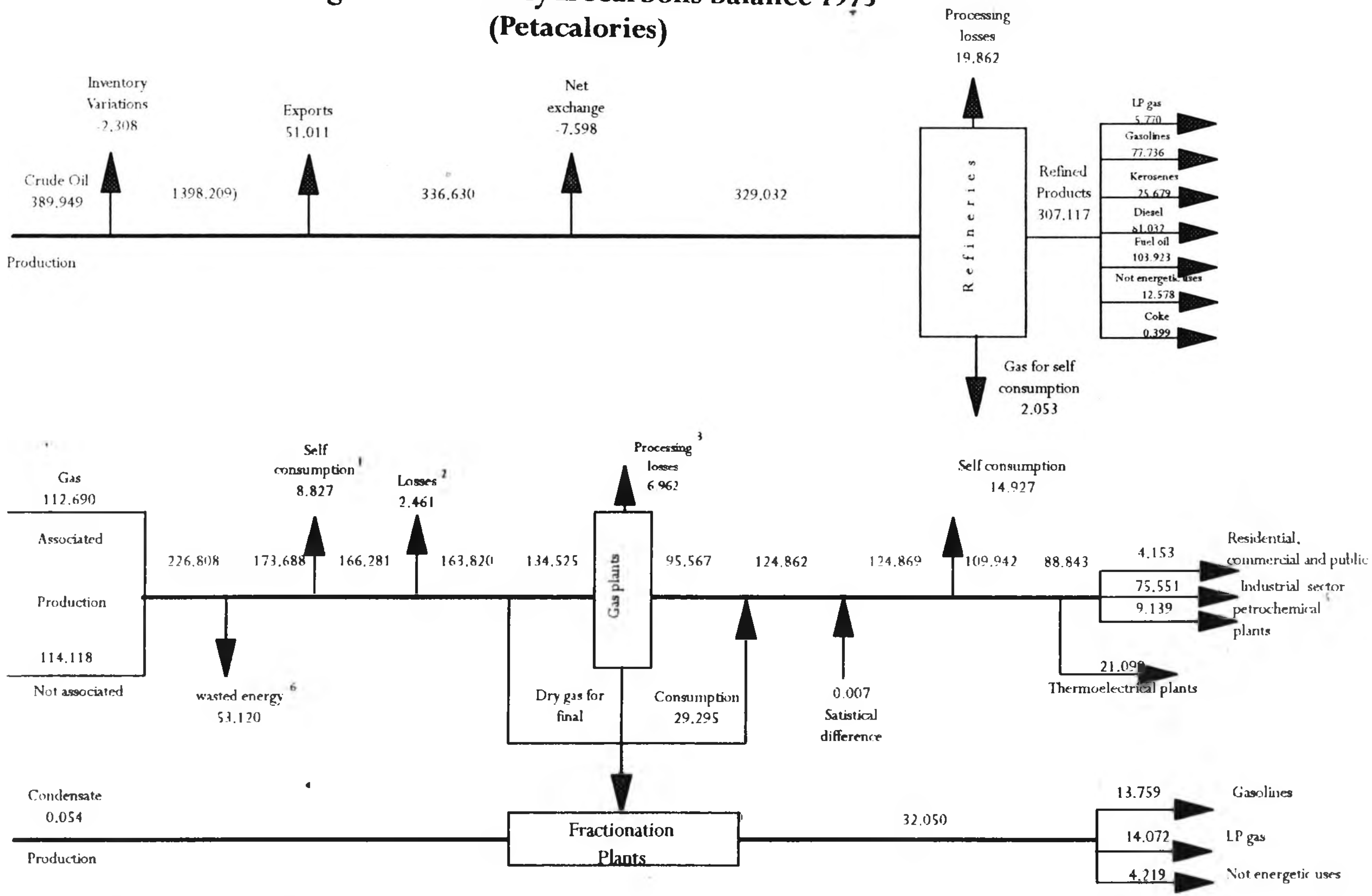
[3] Mexican Energy Balance 1965-1985. Reference 4

Each diagram corresponds to a specific year between 1985 to 1992. Crude oil process begins with its production and continues with exportation, wasted primary energy and energy to transformation in refineries. Finally the final consumption is defined for each of the refined products; L.P. Gas , gasolines, kerosines diesel, fuel oil, not energetic uses, virgin stock and coke. For the purpose of this research, the hydrocarbon process defines the transformation losses that is the variable that is needed to be optimized.

Gas process is analyzed in similar way as crude oil. This analysis includes self consumption, looses and process transformation in gas plants. Final consumption is determined by user sector. Condensates are included in balances, considering the process in fractionation plants. Final consumption of gasolines, L. P. gas and non energetic uses are also specified. all balances are expressed in petacalories

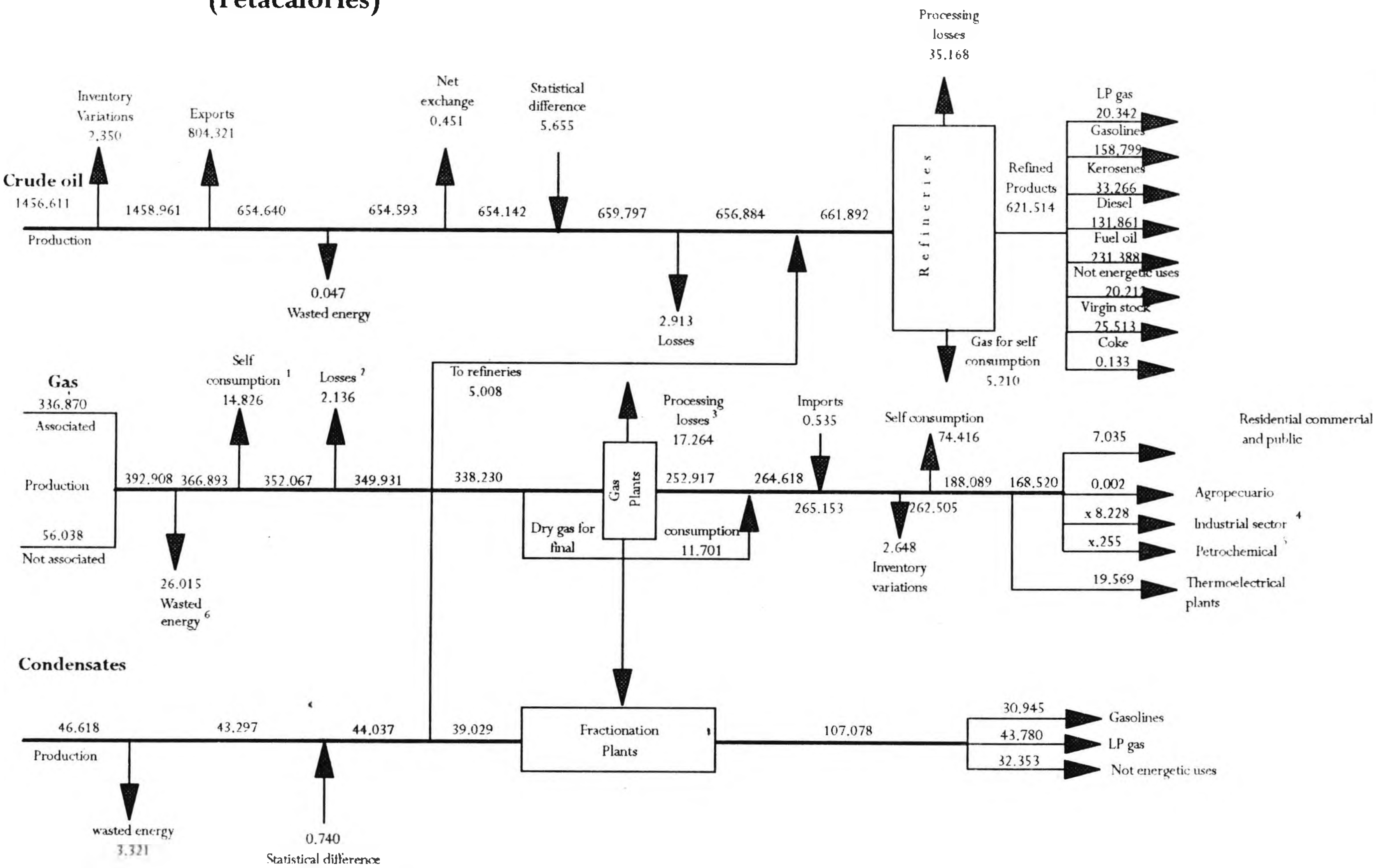
The mentioned diagrams show the amount of energy used by the sector in relation to the produced energy. In this analysis, the amounts of primary energy exported were deducted, in order to observe the behaviour of the domestic consumption.

Diagram 2.3.d.1 Hydrocarbons balance 1975 7_/ (Petacalories)



1 Includes associated gas and not associated gas
2 Refers not to associated gas looses
3 Includes Fractionation Plants looses
4 Includes energy consumption for petrochemicals
5 Refers to consumption only as raw material
6 Includes wasted energy from associated gas (14.736) and not associated gas (6.799) sent to the atmosphere
7_/ Mexican Energy Balance 1975. Reference 4

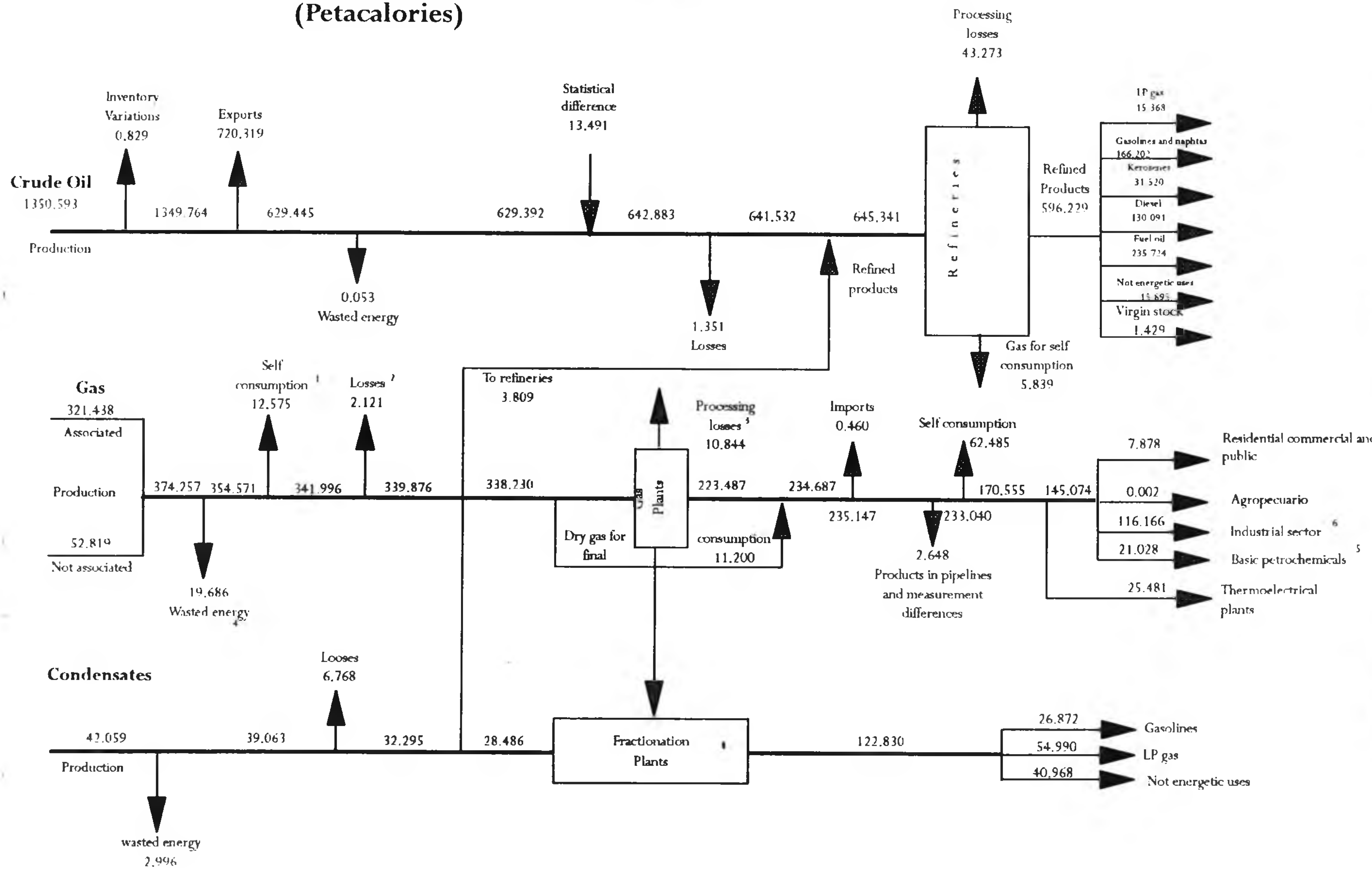
Diagram 2.3.d.2 Hydrocarbons balance 1985[8]
(Petacalories)



1 Includes associated gas and not associated gas for self consumption
2 Refers not to associated gas looses
3 Includes fractionation gas looses
5 Refers to consumption only as raw material
6 Includes wasted energy from associated gas (25.436) and not associated gas (0.579) sent to the atmosphere.
7 Satistical production for condensates from natural gas
8_/ Mexican Energy Balance 1985. Reference 4

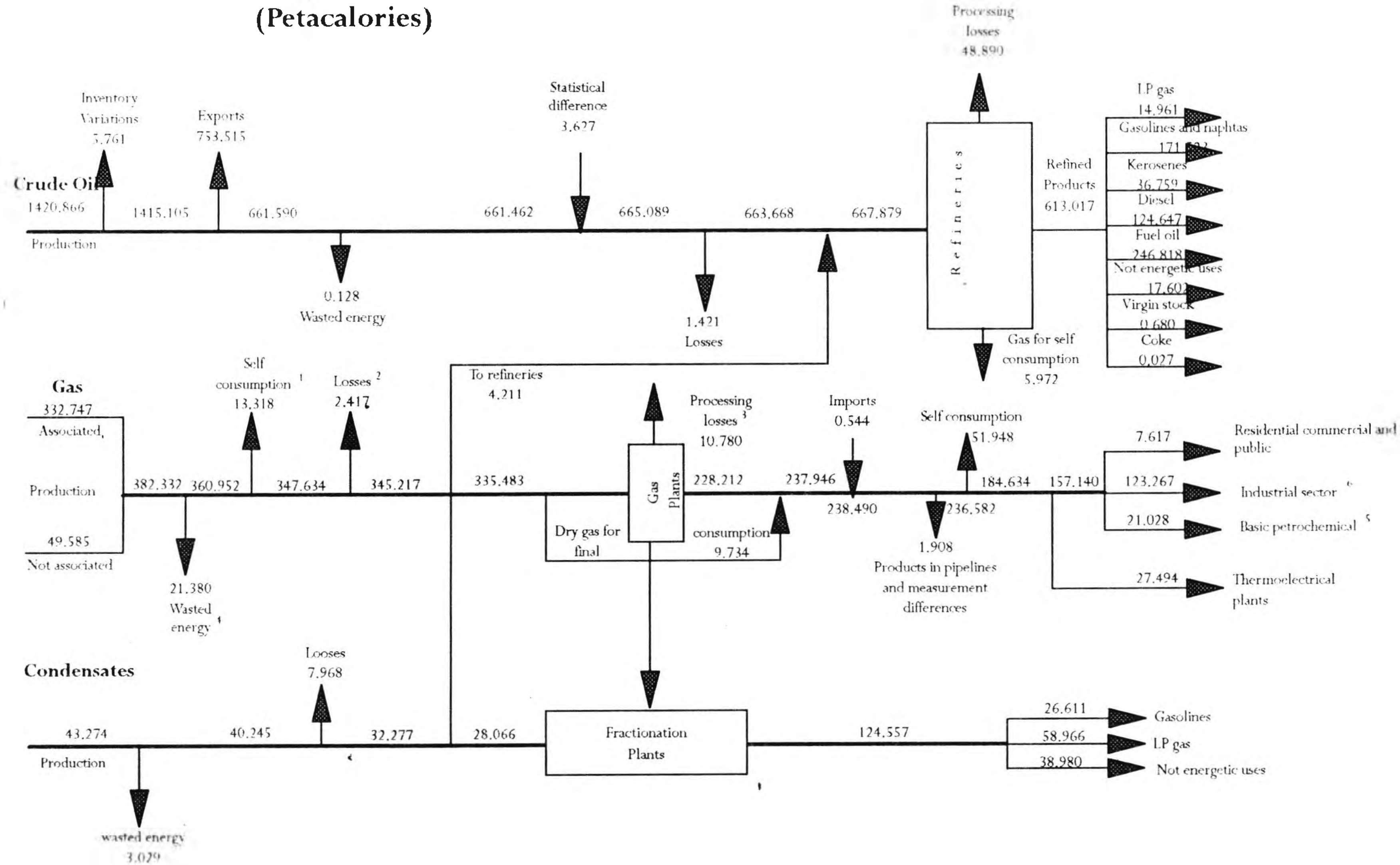
Diagram 2.3.d.3 Hydrocarbons balance 1986 [7_/]

(Petacalories)



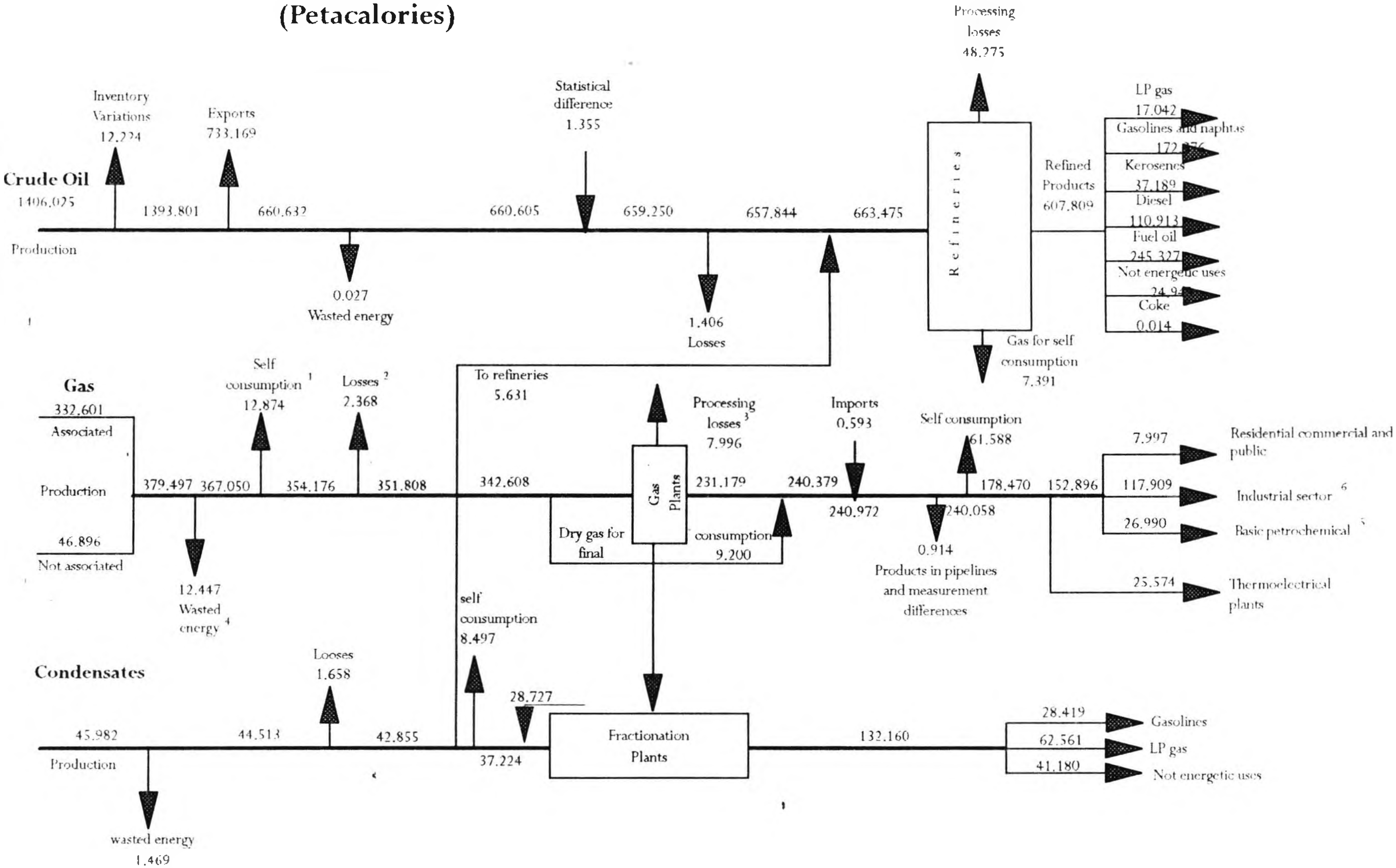
1 Includes Associated gas (11.180) and not associated gas (1.395) for self consumption
2 Refers not to associated gas looses and CO2 sent to the atmosphere
3 Includes fractionation plants looses
5 Refers to consumption only as raw material
6 Includes energy consumption for basic petrochemicals
7_/ Mexican Energy Balance 1986.Reference 57.

Diagram 2.3.d.4 Hydrocarbons balance 1987_/ (Petacalories)



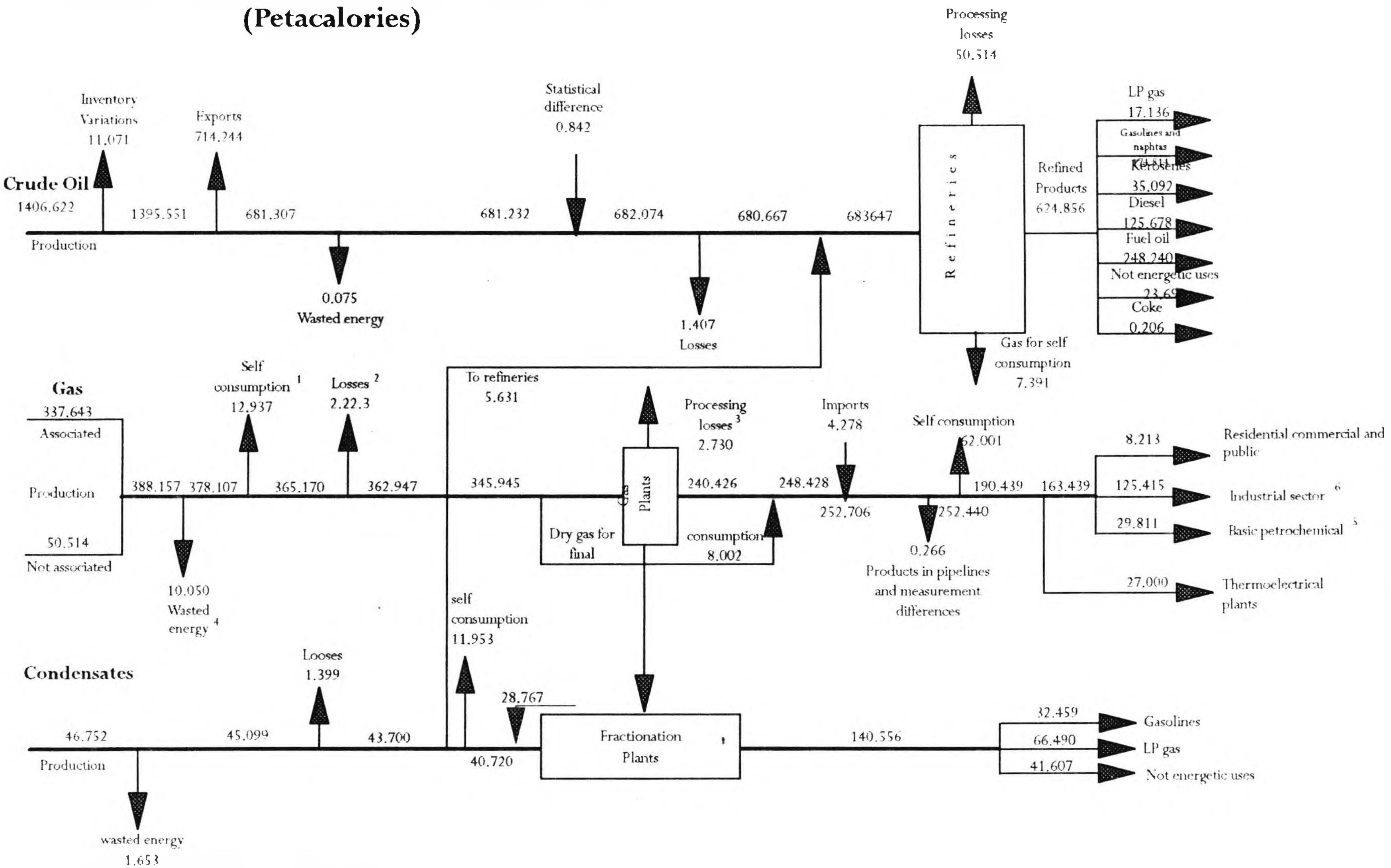
1 Includes associated gas (11.587) and not associated gas (1.731) for self consumption
2 Refers not to associated gas looses and CO2 sent to the atmosphere
3 Includes fractionation plants looses
4 Includes wasted energy from associated gas (20.884) and not associated gas (0.496)
5 Refers to consumption only as raw material
6 Includes energy consumption for basic petrochemicals
7_/ Mexican Energy Balance 1987, reference 5.

Diagram 2.3.d.5 Hydrocarbons balance 1988[7]
(Petacalories)



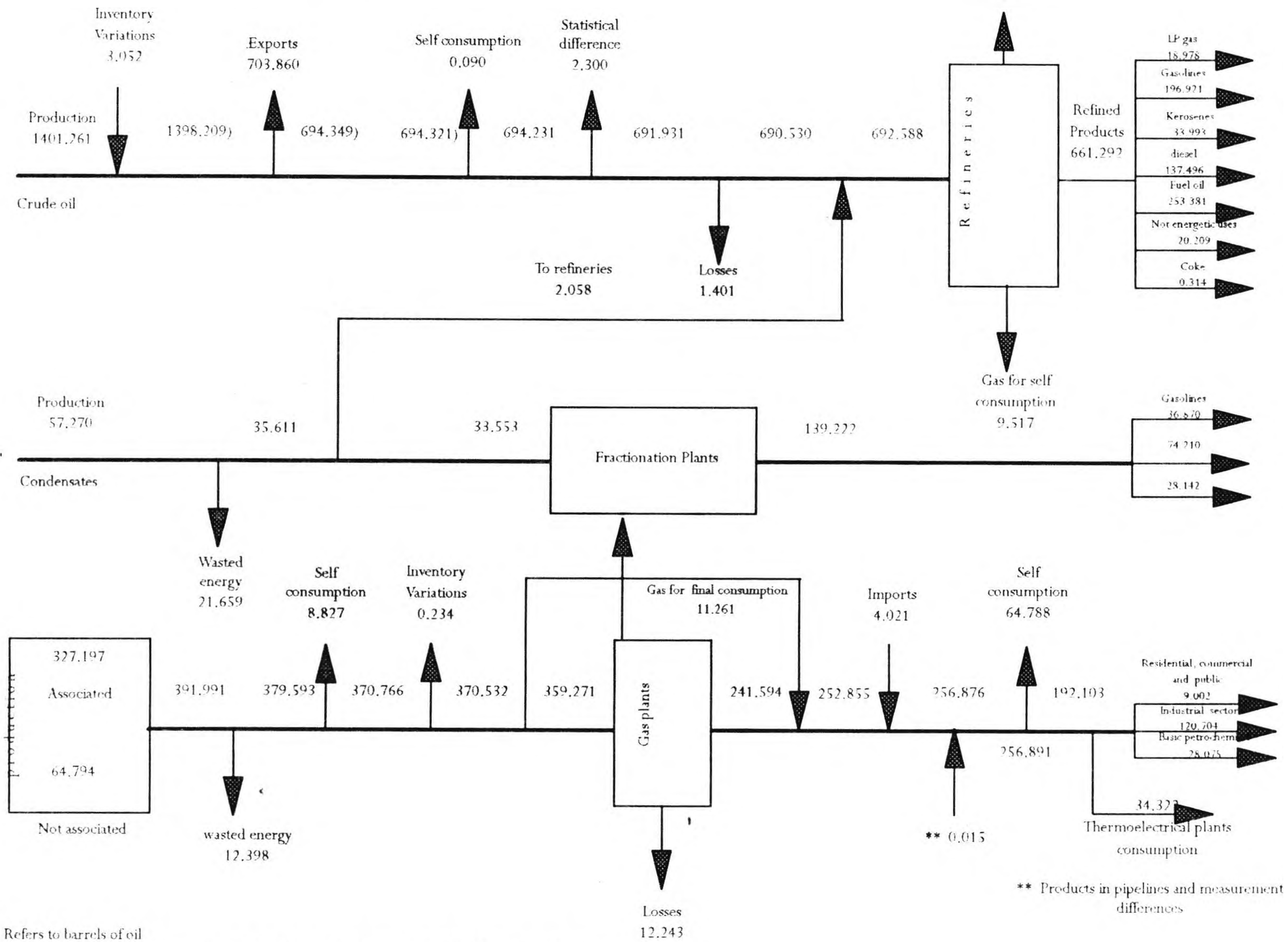
1 Includes associated gas (11.497) and not associated gas (1.377) for self consumption
2 Refers not to associated gas looses sent to the atmosphere
3 Includes fractionation plants looses
4 Includes wasted energy from associated gas (11.978) and not associated gas (0.469)
5 Refers to consumption only as raw material
6 Includes energy consumption for basic petrochemicals
7_/ Mexican Energy Balance 1988. Reference 6.

Diagram 2.3.d.6. Hydrocarbons balance 1989 7_/ (Petacalories)



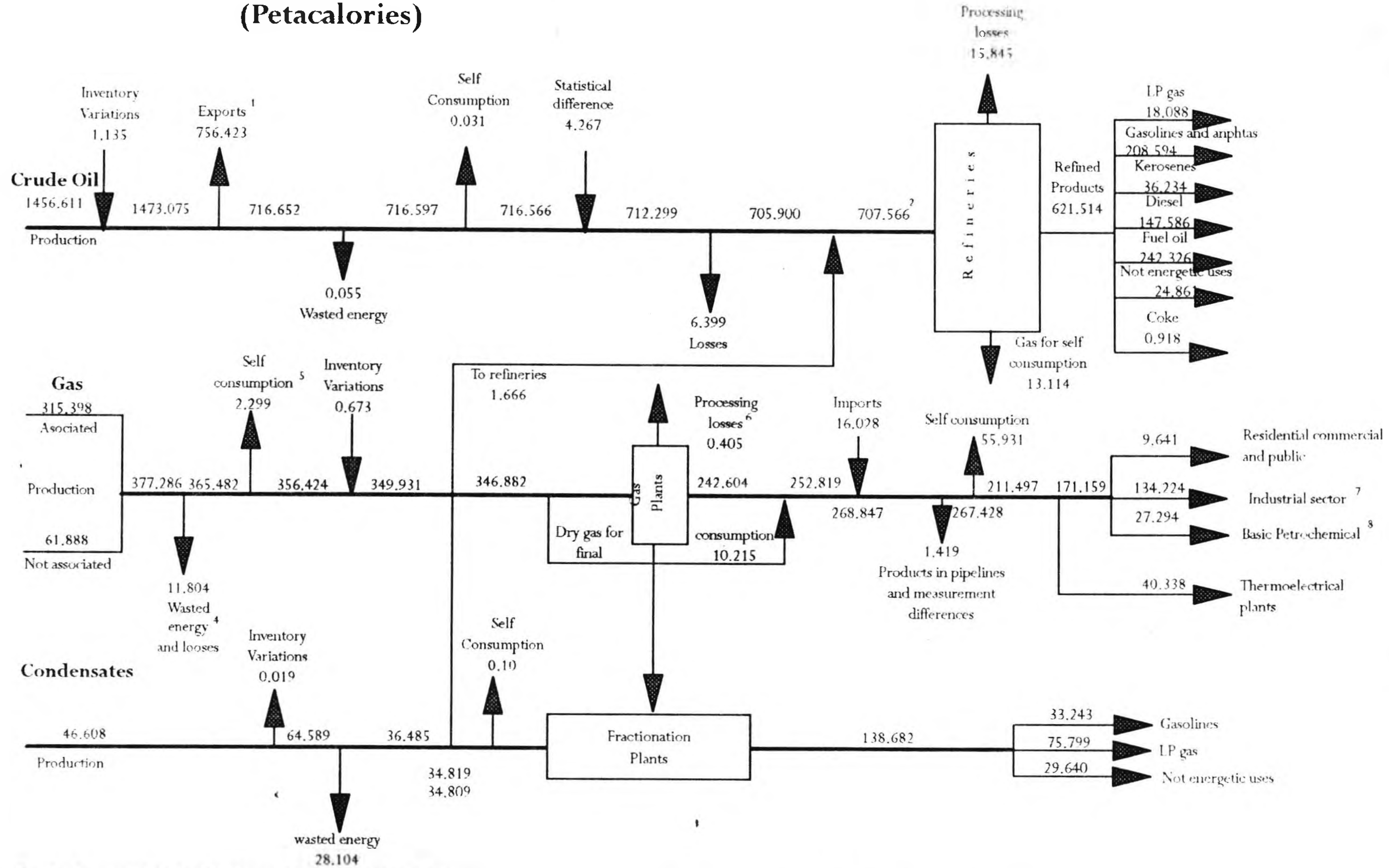
1 Includes associated gas (11.422) and not associated gas (1.515) for self consumption
2 Refers not to associated gas looses sent to the atmosphere
3 Includes fractionation plants looses
4 Includes wasted energy from associated gas (9.545) and not associated gas (0.505)
5 Refers to consumption only as raw material
6 Includes energy consumption for basic petrochemicals
7_/ Mexican Energy Balance 1988, Reference 7

Diagram 2.3.d.7. Hydrocarbons balance 1990
(Petacalories)



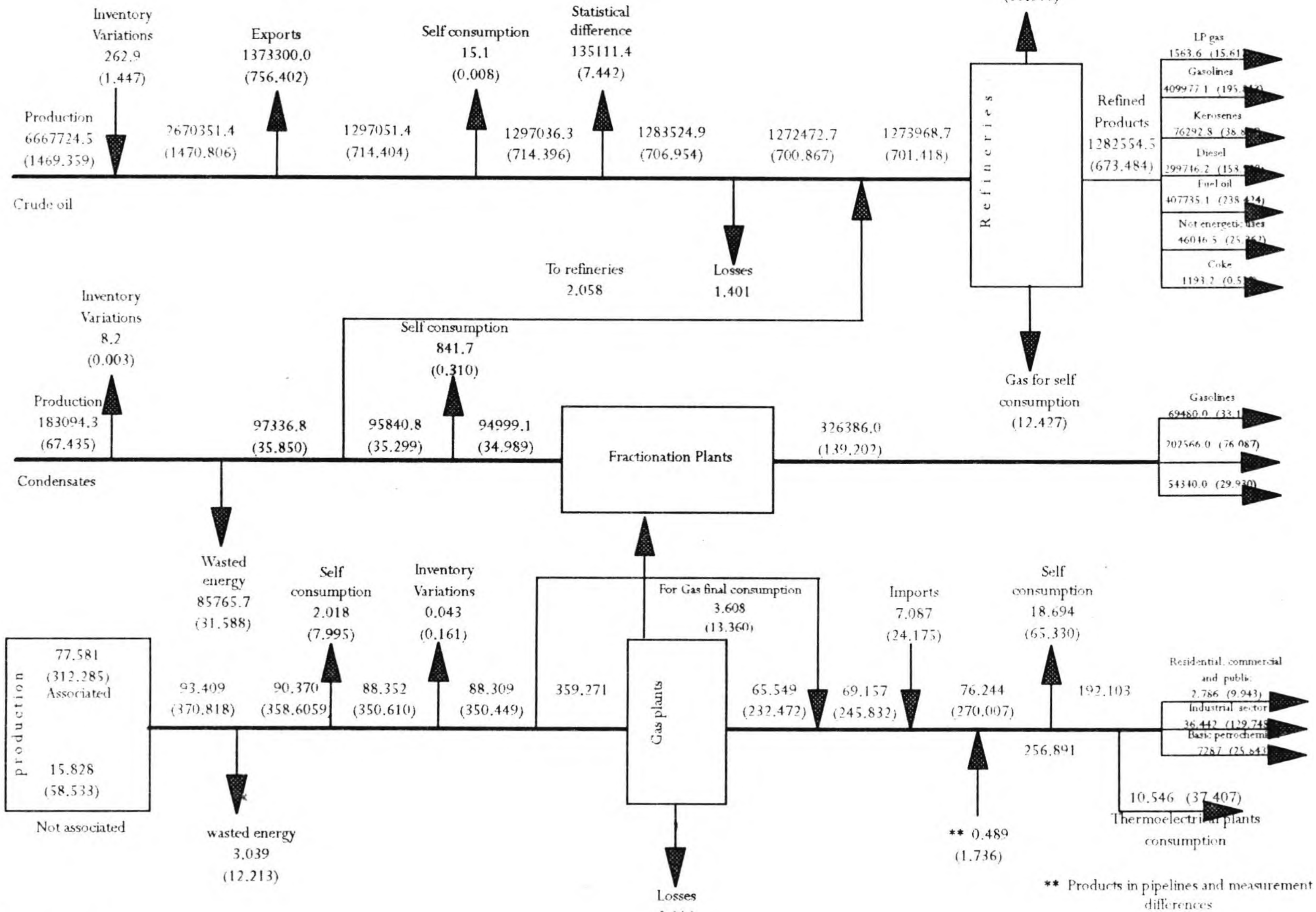
1
2 Refers to barrels of oil
3 Includes wasted energy of associated gas (11,987) and not associated gas (0.226) sent to the atmosphere
4 includes self consumption of associated gas (6.5461) and not associated gas (1.434)
5 Includes fractionation plants looses
6 Includes energetic consumption of basic Petrochemical
7 Refers to consumption only as raw material
8_/ Mexican Energy Balance

Diagram 2.3.d.8. Hydrocarbons balance 1991 (Petacalories)



1 The calorific power of Crude Oil for exportation is 1,514,242 Kcal/Bbl
2 The calorific power of Crude Oil to refineries is 1,499,552 Kcal/Bbl
4 Includes wasted in associated gas (11.518) and not asociated gas (0.229) sent to the atmosphere, and (0.057) looses from associated gas.
5 Includes associated gas (7.123) and not associated gas (6.935) for self consumption.
6 Includes fractionation plants looses. Looses were calculated from the calorific of the remaining gas.
8_/ Mexican Energy Balance 1987. Reference 4
7 Includes energy consumption for PEMEX petrochemicals
8 Refers to consumption only as raw material

Diagram 2.5.d.9. Hydrocarbons balance 1992 8_/ (Petacalories)



1
2 Refers to barrels of oil
3 Includes wasted energy of associated gas (11,987) and not associated gas (0.226) sent to the atmosphere
4 Includes self consumption of associated gas (6.5461) and not associated gas (1.434)
5 Includes fractionation plants looses
6 Includes energetic consumption of basic Petrochemical
7 Refers to consumption only as raw material
8_/ Mexican Energy Balance

In table 2.3.e the consumption of sector of energetics is compared to national consumption. It is clear that the relation between these two variables has remained within the same range; from 34.0% to 29.8%. That means that total energy consumption in the sector has diminished perhaps due to technological advances and energy saving efforts in last period.[1_/]

TABLE 2.3.e.
NATIONAL ENERGY CONSUMPTION, 1980-1992 [1_/]
(PETACALORIES)

YEAR	NATIONAL CONSUM.	SECTOR WHICH PRODUCES ENERGY TOTAL	S.C.[2_/]	T.L.[3_/]	D.L.[4_/]	S.D.[5_/]	FINAL CONSUM.
1980	1074.613	365.555	106.692	195.988	7.055	55.820	709.058
1981	1147.539	365.665	113.410	210.706	7.077	34.472	781.874
1982	1232.782	427.015	125.831	240.807	37.296	23.081	805.767
1983	1165.547	366.823	116.765	239.199	14.920	-4.061	798.724
1984	1184.279	371.995	139.279	227.052	10.721	-5.057	812.284
1985	1210.137	366.946	143.912	210.899	11.219	0.916	843.191
1986	1184.931	370.265	146.618	217.199	16.308	-9.860	814.666
1987	1233.153	380.867	132.993	229.295	18.113	0.466	852.286
1988	1250.172	397.959	145.034	233.723	12.116	7.086	852.213
1989	1324.407	432.657	151.816	262.923	17.742	0.176	891.750
1990	1325.930	405.599	158.762	231.689	14.328	0.820	920.331
1991	1361.319	407.277	163.903	218.697	20.556	4.121	954.042
1992	1381.267	411.161	163.238	219.707	20.776	7.240	970.106
PERCENTUAL VARIATION							
81/80	6.8	-----	6.3	7.5	0.3	-38.2	10.3
85/84	2.2	-1.4	3.3	-7.1	4.6	-118.1	3.8
90/89	0.1	-6.3	4.6	-11.9	-19.2	365.9	3.2
91/90	2.7	0.4	3.2	-5.6	43.5	402.6	3.7
92/91	1.6	1.4	0.7	0.4	1.1	79.0	1.7

1_/ Mexican Energy Balance 1992. Reference 10

2_/ S.C. = SELF CONSUMPTION

3_/ T.L. = TRANSFORMATION LOSSES

4_/ D.L. = DISTRIBUTION LOSSES

5_/ S.D. = STATISTICAL DIFFERENCE

2.3.2 HYDROCARBON BALANCE

The total hydrocarbon balance at national level contains the origins and destinations of the energy derived from petroleum. In this balance, the various final consumptions are identified, as well as the various items of consumption within the sector of energetics itself.

The use of energy in the petroleum and electrical sectors has represented the most important component of the total national consumption, if they are taken as individual consumptions. In relation to total national consumption, their consumptions have been in average 27% in the period of 1965 to 1975. In 1980, it represented 33.9 % and in 1985 30.2 %. In 1990 the same indicator was 30.8%. Of these figures approximately two thirds of the total corresponded to the petroleum industry.[1]

So, the energy consumed in the remaining sector of energetics, amounts to approximately 30% of the total energy consumed, and is an indicator of the great magnitude of energetics used in the sector.

Consumption of intermediate products for production of basic petrochemicals, which form part of the petroleum sector, has been increasing in relation to the total. During the last 10 years the development of production of petrochemical products has had the fastest growing rate in the industrial sector and has required larger volumes of fuels and raw materials.[1]

Therefore, a detailed analysis of destinations and conditions of the use of energy in this industry is very important. This information should constitute the foundation from which to develop policies for using energetics, to consider saving and conservation of energy as a primary objective.

The complexity of the petroleum industry causes the existence of a considerable number of factors that determine the use of energy, and makes it possible to have many options and possibilities to decrease its consumption, given that all its processes are intensive in using energy.

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[1] Mexican Energy Balances. 1965-1985 1987,1988,1989,1990,1991 and 1992. References from 4 to 10.

Because of the magnitude and diversity of its operation, which starts with the extraction of crude, its storing and transportation, and continues with the process in refineries and petrochemical plants and the distribution of refined products for their final sale, large volumes of energy are required For this reason, Petroleos Mexicanos is the largest energy consumer in the country and therefore, its program for saving energy is very important.

To adequately support this program, a detailed analysis of its requirements is needed, together with the specific energy consumption by production phase, plant and product unit, with which identification and estimation of the potential saving is possible.

Information basis required to analyze this problem and to manage the corresponding program requires a specific effort to integrate detailed information, and to build the various indicators that will permit a comparison of coefficients, both of economics and energy uses, associated to the process.

We shall now continue with an overview of the energy consumption in the petroleum and electrical sectors as a part of the balance of hydrocarbons. The balance for the years 1965, 1975, 1985, 1987, 1988, 1989, 1990, 1991 and 1992 are shown in diagrams 2.3 d from 1 to 9. The source of this information are the energy balances of Mexico and some additional information that has been gathered from related studies in this field.[1/]

In order to appreciate the weight that consumption of energy has in this sector as related to the national consumption, the main items have been identified as follows:

- Transformation losses
- Gas consumed in the sector itself
- Unused energy
- Losses

These items correspond to the various transformation processes of crude oil and gas in the refineries and gas plants.

[1/] Mexican Energy Balances 1965 - 1985, 1987, 1988, 1989, 1990, 1991 and 1992. References 4 to 10

2.4.0 ENERGY CONSUMPTION IN THE PETROLEUM INDUSTRY

The petroleum industry uses a great amount of energy taken from the products of the same industry, mainly fuel oil and natural gas. It also requires a large amount of electricity

One of the largest requirement of products derived from petroleum is in the same petroleum industry. The use of these products is as fuel for supplying calorific energy to the refining and petrochemical processes, steam generation, electricity generation, and transportation of crude, gas and products

Petrochemical activity uses also large quantities of hydrocarbons, both as raw material and fuel. The total consumption in refining and petrochemical industry depends on the configuration and depend on the specific process in each plant, its size and yields.

Energy is used in the production processes, as well as being required to cover losses, unused energy and waste. The usage productivity is related to the efficiency of the transformation processes. Lack of installations, losses through evaporation and handling of products in the distribution to the users areas are some of the several factors to be considered to understand the energy usage.

Annex 2 Shows national energy balance diagrams and national energy balance consumption in energetics sector.

From the national energy hydrocarbon balance, it is clear that the energy consumption in the petroleum industry correspond to the following concepts, according to table 2.4.a.

It can be observed that losses have been maintained more or less at 3.5% with respect to domestic offer of oil products.

TABLE 2.4.a

SELF CONSUMPTION AND LOSSES IN THE MEXICAN PETROLEUM INDUSTRY[1]

CRUDE OIL	1991 MM BCE	1992 MM BCE
DOMESTIC OFFER	1.309	1.297
SELF CONSUMPTION	0.000	0.000
SATISTICAL DIF	0.008	0.013
LOSSES	0.012	0.011
TRANSFORMATION LOSSES	0.028	0.028
CONDENSATES		
DOMESTIC OFFER	0.176	0.183
SELF CONSUMPTION	0.000	0.001
GAS		
DOMESTIC OFFER	0.000	0.000
SELF CONSUMPTION	0.000	0.000
+LOSSES+		
TOTAL LOSSES AND SELF CONSUMPTION	3.2%	3.6%

In **Annex 4** some statistical data about Mexican petroleum industry are presented.

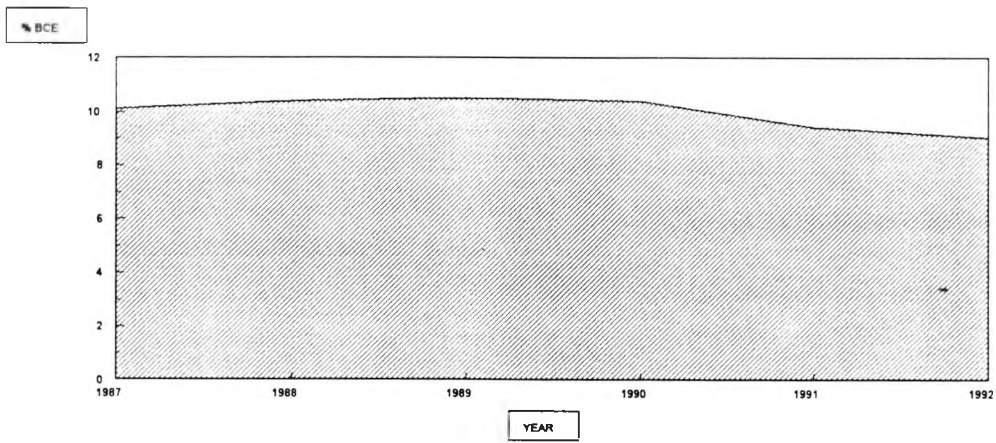
2.5.0 ENERGY CONSUMPTION IN THE REFINING SUBSECTION

As part of the research work, the energy balance in the refining sector has been determined. The balance for each refinery was obtained and its productivity analyzed

[1] Mexican Energy Balance 1992. Reference 10

Energy costs are 46% of the operation costs.[1] That is why many actions for saving energy have been carried out. Unfortunately, these actions have been implemented without an integral point of view, without the support of a reliable evaluation system to measure the results and without a clear idea about economic aspects.

Since 1965, there have been several attempts to audit processing plants and utilities areas to determine the position of Pemex-Refinación in energy consumption. Some technologies were introduced gradually and efforts to improve the energy productivity through operational actions led Mexican refineries to diminish its energy consumption. If the consumption is expressed in bce, per 100 barrels of processed oil, the figures for the last five years are:[2]



YEAR	%
1987	10 1
1988	10 4
1989	10 5
1990	10 4
1991	9 4
1992	9 0

Evaluation of the consumption through the above figures has had the inconvenience of requiring a very precise material balance of which there is none available in Pemex, because the integration is manual and there is no an advanced control system, yet.

Nonetheless, the energy balance in the refining sector has been determined, and the balance for each refinery obtained. Information was gathered for five years and tendency for the historical series was analyzed.

Efforts to implement energy saving programs in Mexican refineries began fifteen years ago. However, there have been poor results up to now, because the actions carried out were not

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1 / Solomon is studies on Mexican Refineries

2 / Operation Data and internally calculated parameters.

integrated from the point of view of the whole refinery system; there was not a quantitative evaluation of the energy saved based on reliable measurement of energy consumption; nor was there an adequate amount of money allotted for the needed investment. In the last two years a positive change begins to be observed, improving several energy efficiencly parameters.

The first technical efforts for identifying actions for saving energy were several energy audits in the refineries, which led to a specific energy profile for each refinery. These profiles showed that the energy consumption was higher than the one determined by the engineering firm which made the design and the construction of each plant.[1_/]

Other evaluation of the energy consumption indexes has defined that the energy consumption expressed as the percentage of equivalent crude oil consumed in refineries has diminished from 10% in 1987 to 9.0% in 1992.

This energy usage efficiency indicator has been calculated for the following refineries: Madero, Tula, Atzcapotzalco, Cadereyta, Minatitlan, Salamanca and Salina Cruz. The indicators have been compared to each other.[1_/]

The reached conclusion is that energy productivity has shown a behaviour which apparently is not derived solely from technical variables. The following indicators were calculated from the available data: 6.0% in 1985, 6.0% in 1986 6.2% in 1987, 6.9% in 1988[1_/] and 6.7% in 1989.

During this period, the refining sector has had a moderate growth. The consumption of natural gas has grown at the expense of a decrease in the use of fuel oil.

For the analyzed period, the overall behaviour is the result of participation of the various refineries: Atzcapotzalco, registered a slight decrease. Cadereyta, Minatitlan and Salamanca remaineded stationary in their consumption while Madero showed a variable high-low-high, productivity.

The energy productivity index for each refinery showed marked differences in their more frequent values: Atzcapotzalco 5.8% - 6.5%; Cadereyta 5.2% - 5.5%; Madero 8.0% - 12.0%;

1_/ Indexes calculated from operation data.

Minatitlan 5.0% - 6.0%; Salamanca 7.0% - 6.5%; Salina Cruz 3.5% - 4.5%; and Tula - 4.8% - 5.8%. All these figures are in percentage of equivalent consumed oil crude. [1]

These variations depend on the general tendency of the energy productivity of each refinery, from the available information system for gathering data for the balance, as well as on the effects of higher or lower operating conditions. The differences between the indexes of the refineries, compared with others, are due in part to the complexity.

The composition of the processes of refineries is shown in **Annex 5** related to the estimate of their complexity indexes.

It was observed that when one refinery is older than others, and was technically backward or more complex, it showed a lower energy productivity, while new refineries, with a simplified process and better integration showed more efficiency because they had lower energy consumption in relation to their installed crude oil capacity.

2.6.0 ENERGY EFFICIENCY INDEXES IN REFINERIES

In this part several calculations of energy consumption indexes are shown:

a) 1985 Energy consumption indexes for Mexican Refineries

b) 1988 Energy consumption index

[1] Indexes calculated from operation data

TABLE 2.6.a

1985 ENERGY CONSUMPTION INDEXES FOR MEXICAN REFINERIES
(Percentage of equivalent crude oil)
%

	ATZCA-POTZALCO	CADEREY-TA	CD.MA-DERO	MINA-TITLAN	SALA-MANCA	SALINA CRUZ	TULA	TOTAL
1985								
JANUARY	7.4	4.7	10.0	4.2	8.6	4.8	6.0	6.6
FEBRUARY	6.5	5.5	9.3	4.3	8.0	3.8	5.1	6.1
MARCH	6.2	5.0	9.0	4.6	7.7	3.0	4.4	5.9
APRIL	6.9	4.5	9.1	5.1	7.8	3.2	4.5	6.1
MAY	6.7	4.5	8.3	5.2	8.2	5.8	5.2	6.3
JUNE	6.0	4.3	8.6	4.2	9.3	4.6	4.9	6.2
JULY	6.1	4.2	8.0	3.6	9.0	4.0	4.9	5.7
AUGUST	6.0	4.5	8.3	4.2	9.2	4.0	5.7	6.1
SEPTEMBER	6.3	4.8	8.7	4.3	8.1	4.0	5.4	6.0
OCTOBER	6.2	4.9	7.6	4.7	9.3	4.3	5.4	6.0
NOVEMBER	5.5	4.4	5.2	5.0	7.5	4.6	11.0	6.2
DECEMBER	5.6	4.4	9.2	4.4	7.4	4.8	5.2	5.9

Table 2.6.b

1988 ENERGY CONSUMPTION INDEXES FOR MEXICAN REFINERIES

(Percentage of equivalent consumed oil crude)

%

	ATZCA-POTZALCO	CADEREY-TA	CD.MA-DERO	MINA-TITLAN	SALA-MANCA	SALINA CRUZ	TULA	TOTAL
1988								
JANUARY	7.4	7.6	9.3	5.4	10.9	5.2	5.5	7.4
FEBRUARY	7.1	5.8	10.2	5.2	11.4	4.9	4.5	7.05
MARCH	6.8	4.9	10.1	4.9	12.7	4.7	4.4	6.7
APRIL	7.1	5.1	10.5	4.7	10.7	5.1	4.6	6.7
MAY	8.3	5.1	5	4.8	10.9	5.8	5.4	7.3
JUNE	7.2	4.4	11.9	5.8	11.6	5.7	4.9	7.05
JULY	7.2	4.7	10.4	5.5	13.5	0	5.2	7.5
AUGUST	7.7	5.4	7.9	5.9	11.7	0	4.8	7.2
SEPTEMBER	7.1	5.7	8.3	6.2	15.3	4.7	5.2	7.1
OCTOBER	0	4.6	8.1	5.5	11.5	4.7	5.8	7.3
NOVEMBER								
DECEMBER								

3.0.0 ENERGY USAGE IN THE SALINA CRUZ REFINERY

The aim in this chapter is to show how energy is used in the Salina Cruz Refinery. This energy consumption is anlyzed by plant and as a whole.

In 1987 and 1988 an in depth study for determining the energy profile of the Salina Cruz Refinery was carried out.1_/ The study led to the detailed energy balance of the refinery. A resume of the characteristics of each plant from the point of view of energy consumption is presented in section 3.1.0. The study compared the design and operation data for each plant, identifying the consumption of five different classes of energy:

Fuel
Gas
60 Kg/Cm^2 Steam
19 Kg/Cm^2 Steam
3.5 Kg/Cm^2 Steam
Electricity

3.1.0 CAPACITY AND ENERGY CONSUMPTION PER PROCESSING PLANT

DISTILLATION UNIT

	DESIGN	OPERATION
CAPACITY B/D	165000	160461
ENERGY MM BTU/D		
INLET	19043	20710
OUTLET	1890	1767
NET CONSUMPTION	17144	18944

VACUUM DISTILLATION UNIT

	DESIGN	OPERATION
CAPACITY B/D	75000	63055
ENERGY MM BTU/D		
INLET	4568	4492
OUTLET	375	419
NET CONSUMPTION	4193	4073

1_/ " Informe Sobre Consumo Energetico de la Refineria de Salina Cruz 1988". Published by IMP. Reference 50

HYDRODESULPHURIZING NAPHTHA UNIT

	DESIGN	OPERATION
CAPACITY B/D	25000	25000
ENERGY MM BTU/D		
INLET	2690	2949
OUTLET	271	375
NET CONSUMPTION	2419	2674

NAPHTHA REFORMING UNIT

	DESIGN	OPERATION
CAPACITY B/D	20000	19787
ENERGY MM BTU/D		
INLET	6456	5875
OUTLET	1666	1140
NET CONSUMPTION	4790	4735

HYDROCARBON TREATING UNIT

	DESIGN	OPERATION
CAPACITY B/D	10	4
ENERGY MM BTU/D		
INLET	442	953
OUTLET	0	0
NET CONSUMPTION	442	953

INTERMEDIATE DISTILLATED PRODUCTS HYDRODESULFURIZING UNIT

	DESIGN	OPERATION
CAPACITY B/D	25000	19810
ENERGY MM BTU/D		
INLET	2313	3663
OUTLET	276	237
NET CONSUMPTION	2037	3090

CATALYTIC CRACKING UNIT

	DESIGN	OPERATION
CAPACITY B/D	40000	57469
ENERGY MM BTU/D		
INLET	11941	11465
OUTLET	1653	1263
NET CONSUMPTION	10267	10202

SULPHUR RECOVERY UNIT

	DESIGN	OPERATION
CAPACITY B/D	80	31
ENERGY MM BTU/D		
INLET	840	1534
OUTLET	258	496
NET CONSUMPTION	590	1038

CB 1 BOILER

	DESIGN	OPERATION
CAPACITY B/D	3312	3070
ENERGY MM BTU/D		
INLET	12434	14471
OUTLET	9854	9131
NET CONSUMPTION	2581	5341

CB 2 BOILER

	DESIGN	OPERATION
CAPACITY B/D	3312	3205
ENERGY MM BTU/D		
INLET	12984	14065
OUTLET	10289	9473
NET CONSUMPTION	2695	4592

CO BOILER

	DESIGN	OPERATION
CAPACITY B/D	3305	2375
ENERGY MM BTU/D		
INLET	8417	8125
OUTLET	7577	7023
NET CONSUMPTION	841	1102

FACILITIES

	DESIGN	OPERATION
CAPACITY B/D	--	--
ENERGY MM BTU/D		
INLET	3469	3469
OUTLET	493	493
NET CONSUMPTION	2976	2976

EFFLUENTS TREATMENT

	DESIGN	OPERATION
CAPACITY B/D		
ENERGY MM BTU/D		
INLET	177	112
OUTLET	0	0
NET CONSUMPTION	177	112

PRODUCT MOVEMENT

	DESIGN	OPERATION
CAPACITY B/D	--	--
ENERGY MM BTU/D		
INLET	1344	1344
OUTLET	573	573
NET CONSUMPTION	771	771

COOLING TOWERS

	DESIGN	OPERATION
CAPACITY B/D	240000	209500
ENERGY MM BTU/D		
INLET	3777	1361
OUTLET	2276	404
NET CONSUMPTION	1499	957

TG 1 AND TG 2 TURBOGENERATORS

	DESIGN	OPERATION
CAPACITY B/D	954744	505307
ENERGY MM BTU/D		
INLET	12165	20034
OUTLET	8769	14409
NET CONSUMPTION	3396	5625

3.2.0 INTRODUCTION TO ENERGY USAGE IN THE SALINA CRUZ REFINERY

Energy consumption data in Mexican refineries has had three stages: From 1970-1985, when the figures had very low reliability because PEMEX did not have a proper measuring of energy consumption; from 1985-1990, when an effort for having better statistics on energy usage began, but when data had a lot of mistakes because there was no proper method for reporting the mass balance of the refineries because the instrumentation was incomplete and out dated; the third stage from 1990 to date, when managers have become more interested in the evaluation of energy saving programs through reliable information on total, partial and specific consumptions.

Unfortunately, the control system and the instrumentation of most areas in Mexican refineries still have a lot of problems. However, now there is more interest in energy consumption data in order that this information serves as a support for leading the energy saving program.

For this research work, all the available energy usage data was analyzed, and many problems of consistency were detected. As there was no better information, it was analyzed and used for the purposes of the study, taking into account the limitations as when making final conclusions about energy productivity usage.

According to statistics in the second period, the Salina Cruz Refinery had an energy efficiency in 1985 as shows in the following table:

Table 3.2.a

1985 ENERGY CONSUMPTION INDEXES 1_/

ENERGY CONSUMPTION INDEX
% BCD OF CHARGE 2_/

REFINERY	JAN	JUN	SEP	DEC
ATZCAPOTZALCO	7.4	7.2	7.0	5.6
CADEREYTA	7.6	4.4	5.7	4.4
CD. MADERO	9.3	11.9	8.3	9.2
MINATITLAN	5.4	5.8	6.2	4.4
SALAMANCA	10.9	11.6	15.3	7.4
SALINA CRUZ	5.2	5.7	4.7	4.8
TULA	5.5	4.9	5.2	5.2
TOTAL REFINERIES	7.4	7.0	7.1	5.9

According to the latest energy consumption statistics, supported by the energy balances for each refinery, the behavior of them, in 1991-1993 are as follows in Table 3.2.b.

1_/ Estimated indexes from operation records

2_/ % BCD of charge is the percentage of charge consumed as self consumption in the refinery

Table 3.2.b

1991-1993 ENERGY CONSUMPTION INDEXES 1/

ENERGY CONSUMPTION INDEX
% BCD OF CHARGE 2_/

REFINERY	1991	1992	1993 3_/
ATZCAPOTZALCO	---		-----
CADEREYTA	7.8	7.6	7.6
CD. MADERO	12.3	12.6	12.4
MINATITLAN	6.7	6.3	5.7
SALAMANCA	14.9	14.1	14.2
SALINA CRUZ	8.2	7.6	7.4
TULA	7.9	7.4	7.6
TOTAL REFINERIES	9.4	8.9	8.2

The relative difference between refineries can be explained by configuration, operational practices and design factors and not only necessarily as an indicator of energy usage efficiency. That is why other indexes were calculated. Energy intensity indexes were also determined to try to take into account the standard consumption of every processing plant and are presented in following chapters.

Table 3.2.c shows several energy consumption indexes obtained for the last four years by different methods

1_/ Figures based on internal refinery records

2_/ % BCD is the percentage of energy consumption respect to the charge to the refinery

3_/ " Prontuario estadistico 1993 ". Reference 9.1

Table 3.2.c SALINA CRUZ REFINERY
ENERGY CONSUMPTION INDEX BY DIFFERENT METHODS AND SOURCES

1988-1993

	1988 3_/	1989	1990	1991	1992	1993
STANDARD ENERGY 1_/ SOLOMON MM BTU/D	47 320	46 859	59 770	69 800e	89 740	89 742
ACTUAL ENERGY 1_/ SOLOMON MM BTU/D	69 018	89 704	104 266	12 7031 e	122 944	126 426
ACTUAL CONSUMPTION 2_/ in 1988 % BCE	5.1	8.0	8.4	8.2	7.6	7.4
Energy intensity index 1_/ EII	146	191	174	146	144 e	141 e
UTILIZED CAPACITY %		65.6	78.4		-	74.4
COMPLEXITY INDEX 4_/	7.00		4.32			-
WHOLE REFINERIES 5_/ % BCE	10.4	10.5	10.4	9.4	8.9	8.9

Design Data 1988 56 028 MMBTU/D; 6.5% BCE 3_/

BCE Barrels Of Equivalent Crude Oil

MM Million

E Estimated

1_/ Consumed energy calculated according to Solomon's method. Reference 58

2_/ Statistical data from operation records

3_/ Original data from operation records. Reference 50

4_/ Complexity index calculated through Solomon's mehtodology

5_/ Data from operation records according to a recent statistical scene

An in-depth study of energy auditing was made in the Salina Cruz Refinery in 1988. This study defined the first energy profile for the refinery. The study focused on determining the energy consumption difference in each processing plant, boiler or turbogenerator, according to design data and real operation.

This information made it possible to define hierarchical consumption, in order to concentrate more attention on the processing plants which consume more energy.

3.3.0 ENERGY SUPPLY RESOURCES

The energy profile for the Salina Cruz Refinery was very useful for determining which were the main consumers and how energy was used and supplied, during the studied period.

The Mexican refining process uses gas and fuel in 40% and 60%, respectively. Gas is supplied in two forms: As refinery gas from the refineries themselves and as natural gas from the production area.

The Salina Cruz Refinery has a different composition in the supplied energy, because natural gas and electricity from outside are not consumed. Thus, the supplied energy can be classified as follows:

Table 3.3 a 1988 AND 1993 ENERGY CONSUMPTION IN SALINA CRUZ REFINERY BARRELS OF EQUIVALENT CRUDE OIL (BCE)

	1988 1_/		1993 2_/	
	BCE	%	BCE	%
NATURAL GAS	0	0		
REFINERY GAS	7439	31.1	-8444.6	36.7
FUEL OIL	16451	68.9	14997	65.2
ELECTRICITY	0	0	-462	-2.0
TOTAL BCDE	23890	100.0	22982	100.0
PROCESSED OIL	292692		309537	
% BCDE/PROCESSED		8.2	7.4	

1_/ " Informe sobre el consumo energetico de la Refineria de Salina Cruz 1988 " Published by IMP. Reference 50.

2_/ Data from operation records

According to the energy profile 1988 of the Salina Cruz Refinery the net consumption of each plant is shown in the following table:

Table 3.3.b
1988 ENERGY CONSUMPTION IN THE SALINA CRUZ REFINERY 1_/
MM BTU/D

	GAS	FUEL	CAPACITY B/D	NET CONS.
ATM. DISTILLATION	7012	8986	160461	18944
VACUUM DISTILLATION	1779	1463	63055	4073
HYDRO NAPHTHA	989	885	25000	2674
NAPHTHA REFORMING	2407	2263	19787	4735
HYDROCARBON TREAT.	--	--	4	953
HYDRO INT. DIST.	1663	415	19810	3090
CATALYTIC CRACKING	4722	448	57469	10202
SULPHUR RECOVERY	12	780	31	1038
BOILER CB1	3873	9476	3070	5341
BOILER CB2	4640	8499	3205	4592
BOILER CO	989	6096	2375	1102
BOILER	1547		433	898
FACILITIES				2976
EFFLUENT TREAT.				112
PRODUCT MOV.				771
COOLING TOWER			209500	957
TURBOGENERATORS	11099	24071		5625
TOTAL	29633	39311		68083

After analyzing the table it is clear that processing plants are as important as power plants, because their consumption is similar. On the other hand, the above figures show which plants are the most important consumers of energy, in order to emphasize their attention once the program is defined.

1_/ "Informe sobre el consumo energético de la Refinería de Salina Cruz 1988" Reference 50

3.3.1 STEAM

Steam and electricity generation are the main products of the refinery's power station. There are five boilers and four turbines in operation. Another turbine is going to be included very soon.

High pressure steam is generated by these boilers. Besides there is an economizer at the CO boiler but it is by passed. There are plans to replace it by a new one. All boilers are fired with 85% fuel and 15% refinery gas. 1_/

So, the existing power station has four fired steam generators of 200 Ton/ hr equipped with dual burners. Besides there is one CO boiler of 180 Ton/hr capacity which contributes to steam generation. All boilers have common feed water headers. 2_/

Boilers produced in 1990 557 Ton/hr of 60 bar steam. From this amount, 439 Ton/hr went to turbines, 331 Ton /hr were obtained of 19 bar steam and 100 Ton/hr of condensing part. 3_/

During the same year, turbines were in discontinuous operation. The average operation in 1990 was as follows: Steam generation 593 Ton/hr, steam to turbine 429 ton/hr, steam extraction 396 Ton/hr, condensing part 103 Ton/hr and load to 60/19 bar reduction station 80 Ton/hr 3_/

According to energy efficiency recommendations, boilers should be operated within a range of 165 to 170 Ton/yr steam output. 2_/ The comparison between generation and maximum capacity of boilers was:

1_/ "Informe sobre el consumo energético de la Refinería de Salina Cruz. 1988". Reference 50.

2_/ Design Data

3_/ Data from operation records.

Table 3.3.c GENERATION, CAPACITY AND LOAD IN BOILERS 1_/

	1990 GENERATION TON/HR	MAX CAPACITY TON/HR	LOAD %	1991 GENERATION TON/HR	LOAD %
CB1	97	150	65	113	75
CB2	121	200	61	114	57
CB3	114	200	57	83	41
CB4	107	200	54	130	65
CO	121	180	67	126	70

The average load in 1990 and 1992 was 59% and 62%, respectively. 1_/

3.3.2 ELECTRICITY

Electric power is produced in the refinery by four turbogenerators TG1, TG2, TG3 and TG6 with nominal rating of 32, 32, 40 and 40 MVA, respectively. Three of them are steam turbines and the last one is a gas turbine. 3_/ This gas turbine is at present fueled with turbosine. According to present demand, the gas turbine power was not needed in the refinery until 1993. Meanwhile, the 8.2 MW electric power could be supplied by the three current steam turbines. 1_/

The relative cost of electricity generation when the turbine is fueled with turbosine or gas refinery is 0.12 or 0.02 Dls / Kw. 2_/

Now, the turbine generation is of 11 MW compared with the design capacity that is of 29.8 MW. Thus, the turbine should be rehabilitated to generate full power. 1_/ 3_/

1_/ Data from operation records

2_/ Estimated costs

3_/ Design data

Table 3.3 d. TECHNICAL DATA ABOUT TURBINES 1_/

	MAX CAPACITY MW	OPERATION 1990 MW	DATA 1991 MW
TG1	25	18.2	17.3
TG2	25	16.4	18.3
TG3	25	3.1	3.7
TG4 FUTURE	32	0.0	0.0
TG6	30	3.5	8.2

Once the gas turbine is rehabilitated and converted to refinery gas, one 55 Ton/hr waste heat boiler should be implemented to recover the heat contained in the exhaust gas flow

The system supplies steam to 2 turbo-sets for generation of internal electric power, turbine-driven drivers and the processing units of the refinery. The nominal ratings of existing and future turbogenerators are: TG1 and TG2 32 MVA; TG3, TG4 and TG6 40 MVA. 2_/

The power demand is on an average of between 44 and 49.5 MW. There are two voltage levels 13.8 KV at the main distribution frame in the central power plant, and 480 V at refinery substations. 1_/ 2_/

Substations are located at various refinery sections where electric power consumption is high.

STEAM BALANCE ON AVERAGE FIGURES FOR 1990 1_/

60 BAR TON/HR	557	GENERATION
60 BAR "	439	TO TURBINE
19 BAR "	331	STEAM EXTRACTION
"	100	CONDENSING PART
LOAD 60/19 BAR	80	REDUCING STATION

1_/ Technical data from operation records

2_/ Design data

The recent revamping of the refinery was planned in two steps:

1) Implementation of units 700-2 and 800-2 in the middle of 1991

2) Implementation of the visbreaker and FCC II, in 1993

3) Sulphur recovering plants, in 1993

The amount of steam from the power station will be reduced by steam generation in several 19 bar waste steam boilers.

In 1991, the steam demand was expected to be in the range of 1_/

- 55.4 Ton/hr at 60 bar steam pressure
- 550.7 Ton/hr at 19 bar
- 164.5 Ton / hr at 3.5 bar

In 1993, the steam demand was expected to be in the range of: 2_/

- 89.7 Ton /hr at 60 bar
- 647.7 Ton / hr at 19 bar
- 200.4 Ton / hr at 3.5 bar

The maximum steam capacity generation is of 930 Ton /hr of 60 bar steam. Once the waste heat boiler in the new FCC section is installed, the steaming capacity will be of 970 Ton /hr.

In order to save energy, when the revamp is carried out, the recommended measures are: 3_/

---

1 / Technical data from operation records

2 / Estimated Technical data

3 / These measures were defined by means of a specific study about the power station. This study takes into account the revamp of the refinery

a) To increase boiler efficiency so that 30% more steam can be produced.

b) To diminish the amount of steam, reducing its pressure from 60 bar to 19 bar.

c) To take advantage of the revamp of the refinery to supply the steam needed from the same boilers, once these are efficiency improved.

d) The main measure is to set a proper balance between steam generation and power generation to diminish operation costs. As the refinery revamp depends on the incorporation of new plants, the economic solution is related to these events and to addition of waste heat boilers.

The economic advantage of the proposed measures can be evaluated from the following figures:

Table 3.3.e 60 BAR STEAM PRODUCTION AND USES 1_/

60 BAR STEAM PRODUCTION

	TON / HR		
	BOILERS	CO BOILER	TOTAL
1991. EARLY	452.2	126.0	578.2
1991. END	566.6	141.6	708.2
93-94 (Estimated)	608.5	152.1	760.6

60 BAR STEAM USES

	TON / HR				
	TURBO-GENERATORS	REDUC-TION	PROCE-SSING PLANTS	UTILI-TIES	TO-TAL
1991 EARLY	427	89.9	55.4	23.5	595.5
1991.END	600	23.6	55.4	29.2	708.2
93-94 (Estimated)	600	80.5	49.7	30.4	760.4

1_/ Technical data from operation records and estimation for 1993. The estimation is based in planned changes to improve efficiency to boilers.

Steam and power balance are closely related, so the best solutions should be analyzed from the point of view of both services, taking into account their dynamic modification. Several statements should be considered: 1_/

1) Through operational adjustments the five boilers should improve their efficiency

2) This improvement will allow an increase of the steam production capacity

3) Once the steam production is increased, one of the boilers can be kept in maintenance and provide hot stand by capacity.

4) FCC and visbreaking units were included in processing plants in 1993, so the increased demand can be satisfied with the present installed capacity.

5) All above conditions are necessary to diminish the operating costs, improving energy usage efficiency to save energy

1 / This measures were obtained from several studies about the Power-Station of the Refinery

Table 3.3 f EVOLUTION AND ALTERNATIVES OF STEAM AND POWER BALANCE 1_/

		1	2	1	2	3
	MIDDLE 1991	END 1991	END 1991	1993-1994	1993-1994	1993-1994
STEAM GENERATION						
60 BAR 5 BOILERS						
TON/HR		660	708	788	800	720
%	77	71	75	80	84	87
WASTE HEAT	62					
BOILER						55
FCC II				40	40	40
STEAM TO TURBINE						
TON/HR		570	600	570	600	600
60/19 BAR REDUCTION	409	1	11	89	80	0
LOAD OF AUX.	80.4					
CONDENSER		100	96	93	73	0
AVERAGE POWER	52					
DEMAND		48.8	48.8	52.2	52.2	58.
GENERATION	47.5	48.8	48.8	52.2	52.2	71.
CFE SUPPLY	47.5					14
STEAM TURBINE LOAD	52	65	65	69	69	69
GT (MW)		8.2	8.2	8.2		20
ST (MW)	8.2	40.6	48.8	44.0	52.2	52
FUEL DEMAND TON/YR	39.3					
BOILERS		327	347	327	382	289
GT	279	33		33		
COSTS	33	69.0	59.0	75.3	64.91	43.0
FUEL SAVINGS	60.8		33		33	108
MM DLS			7.91		7.9	

1 / This table is obtained from several technical analysis of steam and power balance

3.4.0 ENERGY AUDITING IN THE SALINA CRUZ REFINERY

Energy auditing is the systematic study of energy flows to determine the way of using energy and to identify measures to improve energy usage in any productive activity, so, energy auditing can be defined as the means to identify opportunities to improve the efficiency and productivity of the energy used in equipments, industrial areas or specific processes.

An energy auditing provides the following results: 1_/

a) To determine if the energy consumption in a specific process is within the boundaries of the standards.

b) To study deviations in energy consumption respect to design data or international standars

c) To recommend technically and economically feasible corrective actions.

In order to carry out energy audit its objectives and scope must be clearly defined.

Energy auditing is a tool to promote the rational use of energy and supply a practical means of implementing measurements for saving it 2_/

a) Producing more while consuming the same amount of energy

b) Producing the same volume while using less energy

c) Evaluating the possible substitution of one energy for another with more economical or technical advantages.

Auditing makes it possible to know how energy flows: amounts, levels of transformation and where main consumptions are located; all of which serve to identify where the opportunities for energy saving are.

3.4.1 ENERGY AUDITING OBJECTIVES

The main objetives of an energy auditing are:3_/

1) To define conservation and saving goals.
2) To set saving norms.

1_/ Reay A D. "Uso eficiente de nergia en la industria" Reference 47

3_/ Santos R. "Auditoria Energética"., Reference 46

3) To identify and analyse possibilities for energy saving
4) To design and build an energy consumption and flow information system.
5) To define energy consumption indicators.

Energy auditing of Mexican refineries has been carried out in recent years, improving little by little the technical task and studies.

A set of measurements was determined based on the general concepts and objectives, the results obtained from application of this energy auditing and energy management was analysed as a part of this research work.

The available information gathered from the energy auditing carried out on the Mexican refineries was organized and it will be the basis for a further study.

In order to define solutions for the specific system under study, a more valuable information was needed, so the Salina Cruz Refinery energy saving problem was analysed. This information served as a more complete reference matter to approach the general problem. Diagram 1.4.a shows the main ideas considered.

The refinery process auditing was focused to the following points:

1. Processing plant general data.
   - 1.1 Processing plant name
   - 1.2 Processing plant location
   - 1.3 Highest responsible authority name
   - 1.4 Plant description and process diagram
   - 1.5 Energy usages and block diagram
   - 1.6 Process data and materials flow diagram

2. Energy supply resources.
   - 2.1 Fuels
   - 2.2 Vapor
   - 2.3 Electricity
   - 2.4 Residual heat

3. Analysis of energy balances.
   - 3.1 Heat balance in each processing plant
   - 3.2 Heat balance in each main equipment
   - 3.3 Energy consumptions

3.4 Energy flows
3.5 Energy consumption according to design bases
3.6 Energy productivity

4 Consumption analysis

4.1 Energy consumption by charge

5. Energy usage conclusions

5.1 Identification of highest consumption by areas
5.2 Identifications of potential opportunities

6. Analysis of facilities

6.1 Fuels
6.2 Electricity
6.3 Vapor and condensates
6.4 Compressed air
6.5 Cooling water
6.6 Air conditioned

The general outline to bring into focus the methodological sequence to redesign a refinery as a total energy system is presented in diagram 3.4.a. The six phases to design or redesign a refinery are 1_/

Phase 1.	Development study
Phase 2.	System preliminary design
	Formulating
	Structuring
Phase 3.	System detail design
	Subprocess plant design
	Utilities design
	Main equipment design
	System integration
Phase 4	System realization - construction
Phase 5	System testing and operation
Phase 6	System replacement study

DIAGRAM 3.4.a

GENERAL OUTLINE TO DESIGN AND REDESIGN A REFINERY AS A TOTAL SYSTEM FROM AN ENERGY AUDITING 1_/

ENERGY AUDITING

- ANALYSIS OF ENERGY CONSUMPTION
- WHOLE ENERGY BALANCE
- IDENTIFICATION OF HIGHEST CONSUMPTION AREAS
- FACILITIES ENERGY BALANCE
- IDENTIFICATION OF HIGHEST CONSUMPTION EQUIPMENT
- TABULATION OF ENERGY USES
- COMPARISON OF ENERGY CONSUMPTIONS

ENERGY SAVING OPPORTUNITIES

- ANALYSIS OF MORE ADVANCED TECHNOLOGY TO IDENTIFY POTENTIAL OPPORTUNITIES
- IDENTIFICATION OF AREAS WHICH SHOULD IMPROVE THEIR ENERGY USAGE PRODUCTIVITY
- LISTING OF ENERGY SAVING OPPORTUNITIES

EVALUATION OF ENERGY SAVING

- DEFINITION OF HIERARCHY OF THE ENERGY SAVING OPPORTUNITIES
- ANALYSIS OF PARTIAL SYSTEMS

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1 / This diagram is based on the content of several references :
Reference 49 "Programa Maestro de Ahorro de Energia"
Reference 46 "Energy Auditing"
Reference 48 "Guia para el aprovechamiento de calor de desperdicio"

3.4.2 ENERGY MANAGEMENT

In order to save energy it is necessary to analyse and to manage the factors which determine energy consumption. The entire study of this problem belongs to the energy management field.

The main objectives of this discipline are:

1) Planning and setting actions to save energy in a defined area.
2) Organizing and coordinating human resources to achieve the energy saving program objectives.
3) Promoting human resources training to support the energy saving program.
4) Carrying out economical, technical and administrative analysis and studies to identify saving energy measurements .
5) Maintaining relationship among the different enterprise areas to support the saving program.

Diversification of energy sources is very difficult for undeveloped countries, as large investments are required and there are not enough financial resources to support it.

3.4.3 MOST IMPORTANT CONCLUSIONS FROM ENERGY AUDITING IN MEXICAN REFINERIES

Energy auditing defines how energy is used and lost, in comparison to design basis and according to operational consumptions. It is also possible to conclude how to recover energy from atmosphere burned gas combustion gases, condensates, steam, warm water and processing steams.

In accordance with the national and industrial balances, the petroleum industry consumes energy equivalent to 277 841 of oil barrels. 70 % of this amount is consumed by refineries and petrochemical centers. When the auditing was made, the existing then seven Mexican refineries processed 1 408 000 barrel per day and their consumption was 134 000

Boilers and direct fired heaters consume the most energy but their technology is out dated at least by 10 or 15 years. This means that once modernized they will have a high energy saving potential

From energy auditing it is known that there is a considerable energy saving potential at the Salina Cruz Refinery. Nonetheless, limitations of financial resources have prevented the enterprise from investing in the necessary modifications of processing plants.

Most efforts has been made in improving maintenance and operational adjustments. Nevertheless, the results have not been very successful due to the lack of control and measurement instruments.

Due to this problem there is not an accurate energy balance nor a detailed control of the energy saving achievements.

Now the six refineries have relatively the same set of typical processing plants: Distillation Unit, Vacuum Distillation Unit, Naphtha Hydrotreating and Reforming Units, Catalytic Cracking Unit and Viscosity Reduction of Heavy Bottoms Unit.

As heaters and boilers are the main equipment to transfer thermic energy to charge, they have the biggest potential for saving energy.

From energy auditing, it seems convenient that actions for saving energy be classified according to the following phases.

Phase 1
Operational adjustments (short term program)

Phase 2
Corrective maintenance (short term program)

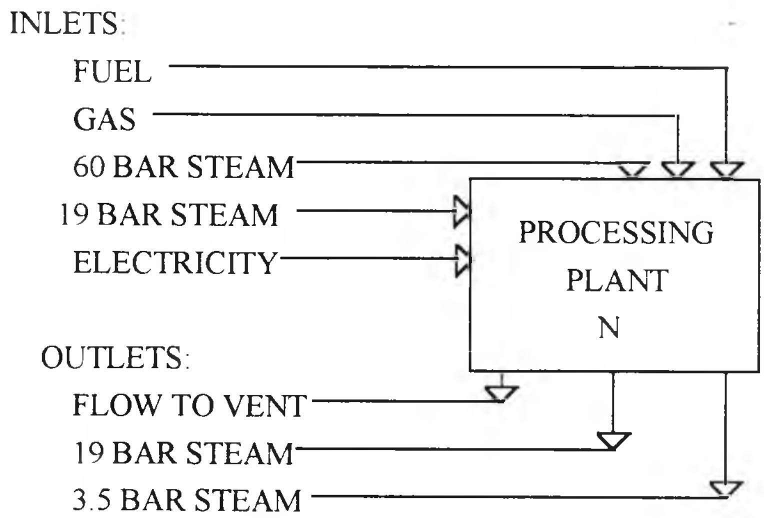
Phase 3
Redesign the refinery to improve the energy usage efficiency (mid term)

Phase 4
Improved design for achieving a better cost-effectiveness relation in new refineries. (long term)

In all phases it is necessary to define a hierarchical order for the energy saving opportunities according to the adopted value criteria. In all cases it seems convenient to build an evaluation model to simplify the analysis.

3.4.4 ENERGY AUDITING IN THE SALINA CRUZ REFINERY

Processing plants consume gas, fuel, electricity and three different kinds of steam. The energy profile defines how energy flows are in each processing plant and shows the specific consumptions of each kind of energy. So that it be homogeneous, the energy balance is expressed in MM BTU/D. The structure for balances represents every energy flow, distinguishing whether they are inlets or outlets, in order to calculate accurately the net consumption.



The detailed energy balances for each processing plant are showed in annex 6.

A resume of the results is presented in table 3.4.a. the net consumptions in the processing plants expressed in MM BTU/D according to the study carried out in 1988, were:

Table 3.4.a.

PROCESSING PLANTS CONSUMPTION IN MM BTU/D:1_/

ATM. DISTILLATION	18944
VACUUM DISTILLATION	4073
HYDRO NAPHTHA	2674
NAPHTA REFORMING	4735
HYDROCARBON TREAT	953
CATALYTIC CRACKING	10202
SULPHUR RECOVERY	1038
TOTAL	45709

According to these consumptions, most attention should be paid on Atmospheric Distillation, Catalytic Cracking, Vacuum Distillation and Naphtha Reforming.

The Salina Cruz Refinery has had several revamps in the last years, so the energy consumed has increased. In table 3.3.b a resume of the existing and future plants in the refinery is presented:

1_/ "Informe sobre consumo energètico de la Refineria de Salina Cruz 1988" . Reference 50

Table 3.4.b

REVAMP OF THE SALINA CRUZ REFINERY 1_/

PLANT	1989	1990	1991	1992	1993	1994
ATM. DISTILLATION 1	O	O	O	O	O	O
ATM. DISTILLATION 2	*O	O	O	O	O	O
VACUUM DISTILLATION 1	O	O	O	O	O	O
VACUUM DISTILLATION 2	*O	O	O	O	O	O
FCC 1	O	O	O	O	O	O
FCC 2		C	C	C	*O	O
SULPHUR RECOVERY 1	O	O	O	O	O	O
SULPHUR RECOVERY 2	C					
NAPHTHA REFORMER 1	O	O	O	O	O	O
NAPHTHA REFORMER 2		C	*O	O	O	O
HYDRO DISTILLATED PROD.1	O	O	O	O	O	O
HYDRO DISTILLATED PROD.2	O	O	O	O	O	O
HYDRO DIST. 1B			*O	O	O	O
HYDRO DIST. 2B			*O	O	O	O
HYDRO NAPHTHA 1	O	O	O	O	O	O
HYDRO NAPHTHA 2		C	*O	O	O	O
TREAT AND FRACT. 1	O	O	O	O	O	O
TREAT. AND FRACT. 2		C	*O	O	O	O
C3 FRACTIONATION	*O	O	O	O	O	O
VISBREAKING		C	C	C	*O	O
EFFLUENTS	O	O	O	O	O	O
MEROX	O	O	O	O	O	O
STABILIZER	O	O	O	O	O	O

O PLANT IN OPERATION

*O PLANT WHICH STARTS OPERATION

C PLANT IN CONSTRUCTION

1_/ This table was formulated with data from " Memoria de labores de PEMEX 1989-1994" . References 11 to 14

Table 3.4.c

ENERGY CONSUMPTION INDEXES IN SALINA CRUZ REFINERY

	1990 1_/	1991 1_/	1992	1993 1_/
	% BCE	% BCE	% BCE	% BCE
JAN	8.3	8.7	7.6	7.5
FEB	9.8	7.2	7.5	7.4
MAR	8.8	7.5	7.6	7.9
APR	8.3	8.0	8.2	7.5
MAY	8.6	8.2	7.5	6.9
JUN	8.2	8.6	7.9	6.9
JUL	8.7	8.6	7.5	7.0
AGT	8.6	8.5	8.0	7.0
SEP	8.1	8.3	7.6	8.5
OCT	7.8	8.5	7.9	8.2
NOV	7.7	8.0	7.1	7.4
DEC	7.6	7.9	7.3	6.4
TOTAL		8.0	7.6	7.4

The previous figures show that energy efficiency in the Salina Cruz Refinery is not very well controlled, but is improving slightly.

Tables 3.4.d., 3.4.e, 3.4 f and 3.4 g. show the energy intensity index calculations of the Salina Cruz Refinery for 1988, 1989, 1990 and 1993. This index is very useful to compare the energy efficiency of the Salina Cruz Refinery to other refineries with similar configuration and complexity.

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1 / Indexes obtained from operation statistical data

2 / Prontuario estadistico 1993. PEMEX-REFINACION

Table 3.4.d ENERGY INTENSITY INDEX CALCULATION 1_/ SALINA CRUZ REFINERY 1988

		UTILIZED CAPACITY BPCD	STANDARD ENERGY MBTU/D	ENERGY CONSUMED. %
SENSIBLE HEAT		158564	5598	
ATMOSPHERIC CRUDE DISTILLATION		160461	7942	
VACUUM DISTILLATION		63655	3361	
UTILITIES, OFFSITES, LOSSES		158596	10796	
VISBREAKING				
THERMAL CRACKING				
COKING				
CATALYTIC CRACKING		57469	11149	
HYDROCRACKING				
CATALYTIC REFORMING		19787	4121	
HYDROGEN GENERATION KSCV/D				
POLYMERIZATION				
DIMERSOL				
MTBE				
ALKYLATION				
ISOMERIZATION-	C4,C5,C6			
	C5/C6			
HYDROTREATING				
gasoline- naphtha		25000	2000	
kerosene		0	0	
distillate		19810	1981	
VACUUM GAS OIL DESULFURIZATION				
RESIDUAL DESULFURIZATION				
SOLVENT DEASPHALTING				
SULPHUR RECOVERY LT/D		31	372	
TAILGAS RECOVERY LT/D				
SULPHURIC ACID REGENERATION LT/D				
ASPHALT & BITUMEN				
SPECIAL FRACTIONATION				
PROPANE SPLITER				
DEISOBUTANIZERS				
DEISOHEXANIZERS				
DEHEPTANIZERS				
ALKYLATE/REFORMER SPLITTER				
SEC. CAT. CRACK. GAS. SPLITTER				
U37 MC & MAA				
U35 CH				
TOTAL STANDARD ENERGY CONSUMPTION		MMBTU/D	47320	
ACTUAL ENERGY CONSUMPTION		MMBTU/D		
EII				

1. The calculation of the energy intensity index is based on SOLOMON'S mehtology

Table 3.4.e
ENERGY INTENSITY INDEX CALCULATION 1_/
SALINA CRUZ REFINERY
1 9 8 9

	UTILIZED CAPACITY BPCD	STANDARD ENERGY MBTU/D	ENERGY CONSUMED %
SENSIBLE HEAT	190061	6986	14.91
ATMOSPHERIC CRUDE DISTILLATION	192335	8029	17.13
VACUUM DISTILLATION	76570	3561	7.61
UTILITIES. OFFSITES. LOSSES	190099	11406	24.34
VISBREAKING	0	0	0
THERMAL CRACKING	0	0	0
COOKING	0	0	0
CATALYTIC CRACKING	37500	7275	15.53
HYDROCRACKING	0	0	0
CATALYTIC REFORMING	17600	3666	7.82
HYDROGEN GENERATION KSCV/D	0	0	0
POLYMERIZATION	0	0	0
DIMERSOL	0	0	0
MTBE	0	0	0
ALKYLATION	0	0	0
ISOMERIZATION- C4	0	0	0
C5/C6	0	0	0
HYDROTREATING	0	0	
gasoline- naphtha	22100	1768	3.77
kerosene	0	0	0
distillate	24025	2403	5.13
VACUUM GAS OIL DESULPHURIZATION	0	0	0
RESIDUAL DESULOPHURIZATION	0	0	0
SOLVENT DEASPHALTING	0	0	0
SULPHUR RECOVERY LT/D	119	1431	3.05
TAILGAS RECOVERY LT/D	0	0	0
SULPHURIC ACID REGENERATION LT/D	0	0	0
ASPHALT & BITUMEN	0	0	0
SPECIAL FRACTIONATION			
PROPANE SPLITER	2480	335	0.71
DEISOBUTANIZERS	0	0	0
DEISOHEXANIZERS	0	0	0
DEHEPTANIZERS	0	0	0
ALKYLATE/REFORMER SPLITTER	0	0	0
SEC. CAT. CRACK. GAS. SPLITTER	0	0	0
U37 MC & MAA			
U35 CH			
TOTAL STANDARD ENERGY CONSUMPTION	MBTU / D	46858	100
ACTUAL ENERGY CONSUMPTION	MBTU / D	89704	
EII		191	

1_/ The calculation of the energy intensity index is based on SOLOMON'S methology

Table 3.4.f
ENERGY INTENSITY INDEX CALCULATION 1_/
SALINA CRUZ REFINERY
1990

	UTILIZED CAPACITY BPCD	STANDARD ENERGY MBTU/D	ENERGY CONSUMED %
SENSIBLE HEAT	251426	9316	15.59
ATMOSPHERIC CRUDE DISTILLATION	251110	10081	16.87
VACUUM DISTILLATION	100165	4527	7.57
UTILITIES, OFFSITES, LOSSES	251522	14387	24.07
THERMAL CRACKING	0	0	0
COKING	0	0	0
CATALYTIC CRACKING	48150	9341	15.63
VISBREAKING	0	0	0
HYDROCRACKING	0	0	0
CATALYTIC REFORMING	18600	3840	6.42
HYDROGEN GENERATION KSCV/D	0	0	0
POLYMERIZATION	0	0	0
DIMERSOL	0	0	0
MTBE	0	0	0
ALKYLATION	0	0	0
ISOMERIZATION- C4	0	0	0
C5/C6	0	0	0
HYDROTREATING			
gasoline- naphtha	23850	1908	3.19
kerosene	0	0	0
distillate	43200	4320	7.23
VACUUM GAS OIL DESULPHURIZATION	0	0	0
RESIDUAL DESULPHURIZATION	0	0	0
SOLVENT DEASPHALTING	0	0	0
SULFUR RECOVERY LT/D	134	1609	2.69
TAILGAS RECOVERY LT/D	0	0	0
SULPHURIC ACID REGENERATION LT/D	0	0	0
ASPHALT & BITUMEN	0	0	0
SPECIAL FRACTIONATION			
PROPANE SPLITER	3261	440	0.74
DEISOBUTANIZERS	0	0	0
DEISOHEXANIZERS	0	0	0
DEHEPTANIZERS	0	0	0
ALKYLATE/REFORMER SPLITTER	0	0	0
SEC. CAT. CRACK. GAS. SPLITTER	0	0	0
U37 MC & MAA			
U35 CH			
TOTAL STANDARD ENERGY CONSUMPTION	MMBTU/D	59770	
ACTUAL ENERGY CONSUMPTION	MMBTU/D	104266	
EII		174	

1_/ The calculation of the energy intensity index is based on SOLOMON'S methology

Table 3.4.g
ENERGY INTENSITY INDEX CALCULATION 1_/
SALINA CRUZ REFINERY
1993

	UTILIZED CAPACITY BPCD	STANDARD ENERGY MBTU/D	ENERGY CONSUMED %
SENSIBLE HEAT	309400	11443	12.8
ATMOSPHERIC CRUDE DISTILLATION	309400	12535	14.0
VACUUM DISTILLATION	97760	4448	5.0
UTILITIES, OFFSITES, LOSSES	309420	21783	24.3
THERMAL CRACKING	0	0	0
COKING	0	0	0
CATALYTIC CRACKING	549150	11836	13.2
VISBREAKING	0	0	0
HYDROCRACKING	0	0	0
CATALYTIC REFORMING	45600	9606	10.7
HYDROGEN GENERATION KSCV/D	0	0	0
POLYMERIZATION	0	0	0
DIMERSOL	0	0	0
MTBE	0	0	0
ALKYLATION	0	0	0
ISOMERIZATION- C4	0	0	0
C5/C6	0	0	0
HYDROTREATING			
gasoline- naphtha	57,512	4601	5.1
kerosene	0	0	0
distillate	41875	4188	4.7
VACUUM GAS OIL DESULFURIZATION	463000	5556	6.2
RESIDUAL DESULFURIZATION	0	0	0
SOLVENT DEASPHALTING	0	0	0
SULPHUR RECOVERY LT/D	112	1343	1.5
TAILGAS RECOVERY LT/D	0	0	0
SULPHURIC ACID REGENERATION LT/D	0	0	0
ASPHALT & BITUMEN	1408	162	0.2
SPECIAL FRACTIONATION			
PROPANE SPLITER	0	0	0.0
DEISOBUTANIZERS	0	0	0
DEISOHEXANIZERS	0	0	0
DEHEPTANIZERS	0	0	0
ALKYLATE/REFORMER SPLITTER	0	0	0
SEC. CAT. CRACK. GAS. SPLITTER	0	0	0
U37 MC & MAA			
U35 CH			
TOTAL STANDARD ENERGY CONSUMPTION	MMBTU/D	89,742	100.0
ACTUAL ENERGY CONSUMPTION	MMBTU/D	126426	
EII		141	

1 The calculation of the energy intensity index is based on SOLOMON'S methology

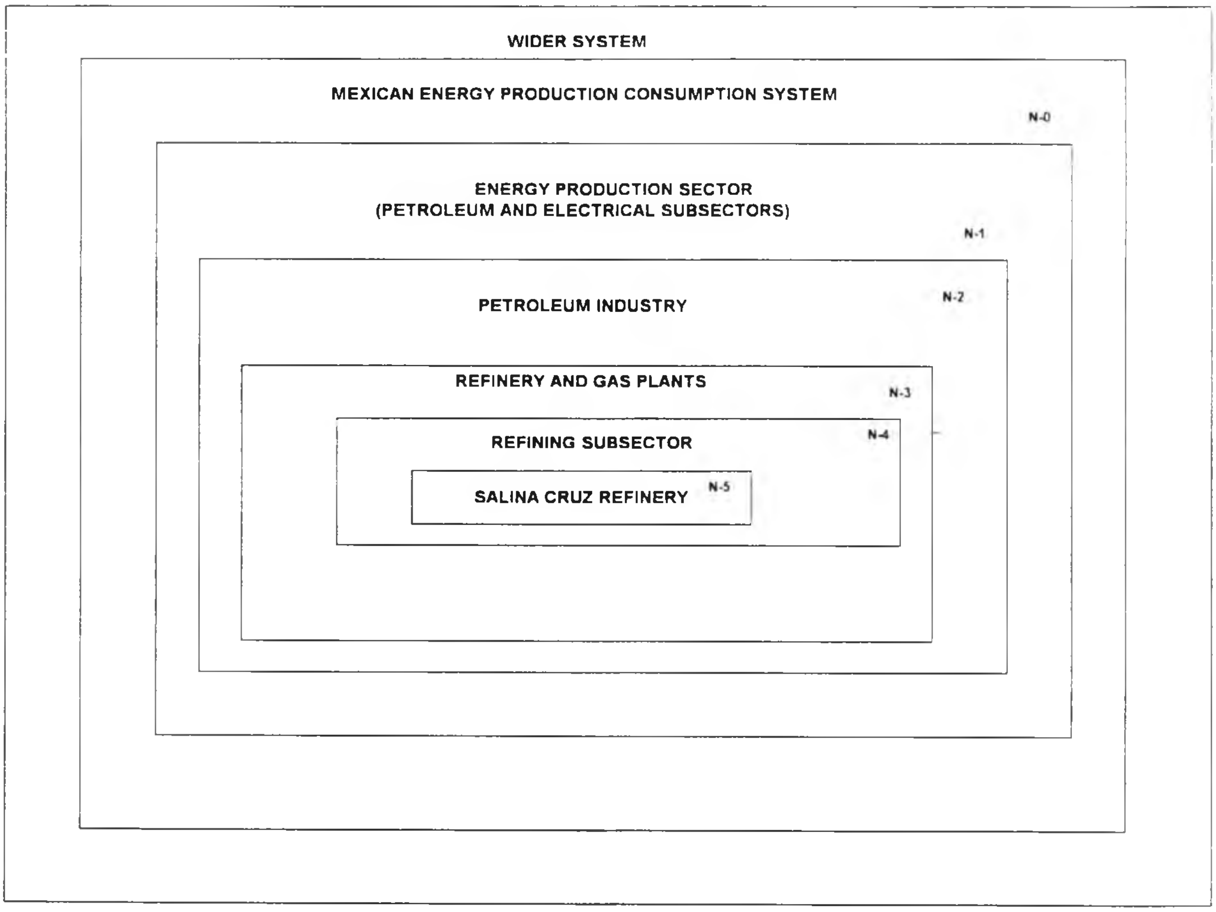
It is possible to estimate the consumption of the refinery after the installation of the planned new plants, if no additional measures for saving energy are taken. Another view is obtained when the two things are combined: adding the energy consumptions of the new plants to be installed and considering the energy savings as a consequence of the planned measures to be adopted.

3.5.0 ANALYSIS OF ENERGY BALANCES

Different balances provide partial analysis about the energy usage in the Mexican Petroleum Industry. The studied system is of Mexican Petroleum Refining, but in order to have a proper view of the problem a wider system is analysed fig. 3.5.a shows the wider system

DIAGRAM 3.5.a

WIDER SYSTEM



So as not to loose the general view of the uses of energy in Mexico, only a few conclusions from each kind of balance are included. They were obtained from the analysis described in diagrams 3.5 b, 3.5.c, 3.5 d, 3.5.e and 3.5.f.

3.5.1. GLOBAL ENERGY BALANCE

1.1 After a period of time when energy consumption rates increased for two decades, creating a high dependency on petroleum, since the 80's the total consumption shows a lower rate of increase

ANNEX 1

1.2 This reduction is explained by several national energy saving programs to face possible changes in the supply and cost of energy and, besides, because of the gradual shift to a more service oriented instead of a industrial service oriented.

1.3 Since 1970 energy consumption per unit of GDP has been falling continuously.

3.5.2 NATIONAL ENERGY BALANCE

2.1 Total energy production and consumption in Mexico show both variations, that derived from the problems of the national economy and that linked to the instability of the oil market.

2.2 After many ups and downs the produced primary energy in the country has the same level in 1992 as that at the beginning of the 80's

2.3 México is highly dependant on petroleum as this kind of energy represents 90% of the total

2.4 México exports primary energy. oil is 99.9% of these exports.

3.5.3 HYDROCARBON BALANCE

3.1 The total national petroleum energy consumption has two components; the main one is the final consumption that is 69.2% of the total, from which 7.5% goes to non energetic uses; the second component which rises up to 30.8% is the consumption of the sector which produces energy.

3.2 The petroleum and electrical sector, both of them state owned companies, are the most important individual energy consumers.

3.3 Consumption of intermediate products for basic and secondary petrochemical activity is growing fast in the industrial sector.

3.5.4. MEXICAN PETROLEUM INDUSTRY BALANCE

4.1 Petroleos Mexicanos is the largest energy consumer in the country.

4.2 Because of the complexity and magnitude of the petroleum industry, there are considerable numbers of factors that determine its use of energy.

4.3 The main uses in the petroleum industry are extraction, storing and transportation of crude oil; oil processing in refineries and in petrochemical plants and distribution of oil refined products.

3.5.5 MEXICAN REFINING BALANCE

5.1 Refining activity is the most important energy consumer in the Mexican petroleum industry. It consumes an average of 9% of the total crude oil processed in refineries. Self consumption and losses in transformation are the principal destinies of energy

5.2 In the refining activity energy costs represent 46% of the total operational costs.

5.3 Mexican refineries compared to similar pacesetters consume between 2 and 1.5 times more in terms of energy intensity indexes.

3.5.6 SALINA CRUZ REFINERY BALANCE

6.1 In 1991, the Salina Cruz Refinery consumed 8.16% of the total crude processed while the total Mexican Refining System consumed 9.41%.

6.2 Energy is supplied to the Refinery as fuel oil and refinery gas, 68.9% and 31.1 % of the total, respectively.

6.3 Compared to pacesetters, the refinery has had energy intensity indexes of 146, 191, 174 and 182 corresponding to 1989, 1990, 1991 and 1992 respectively.

6.4 There are two main areas where energy is used: processing plants and facilities areas.

6.5 The most important part of the consumption takes place in atmospheric distillation, catalytic cracking, reforming units, boilers and turbines.

DIAGRAM 3.5.b

ANALYSIS OF THE GLOBAL ENERGY BALANCE

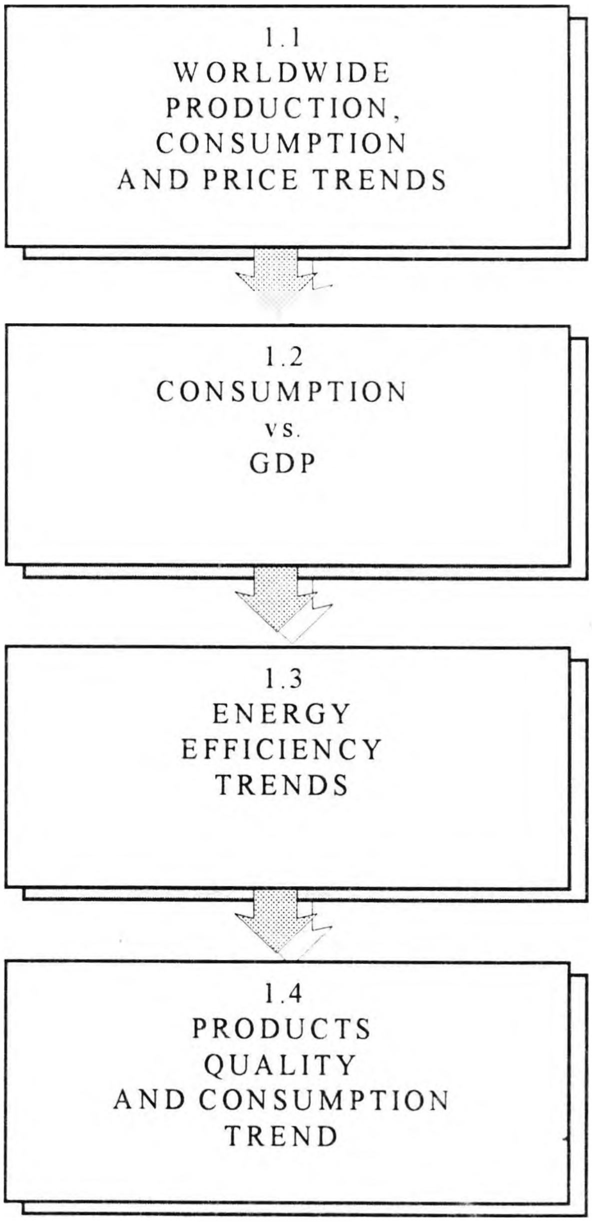


DIAGRAM 3.5.c

ANALYSIS OF THE NATIONAL ENERGY BALANCE

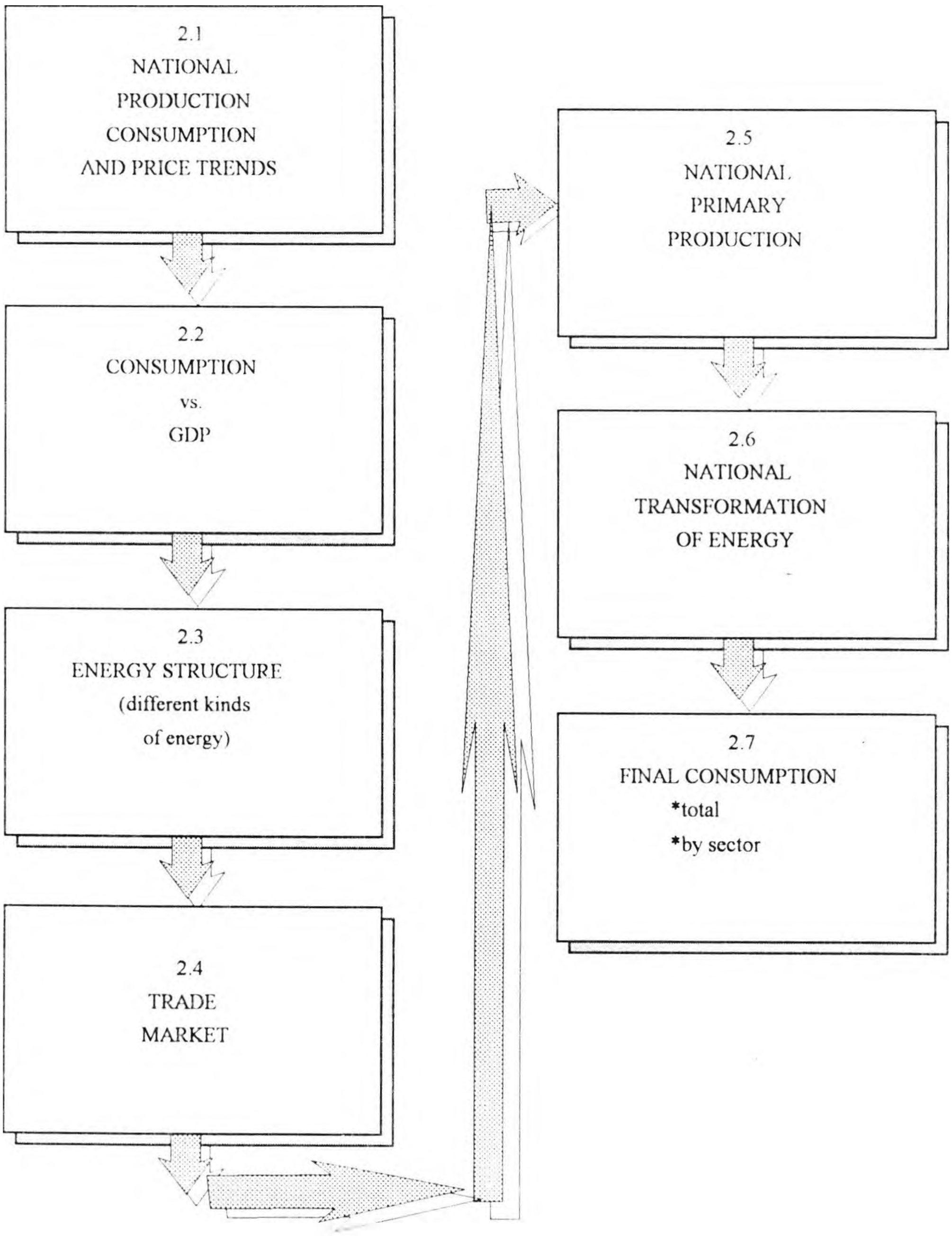


DIAGRAM 3.5 d

ANALYSIS OF THE HYDROCARBON BALANCE

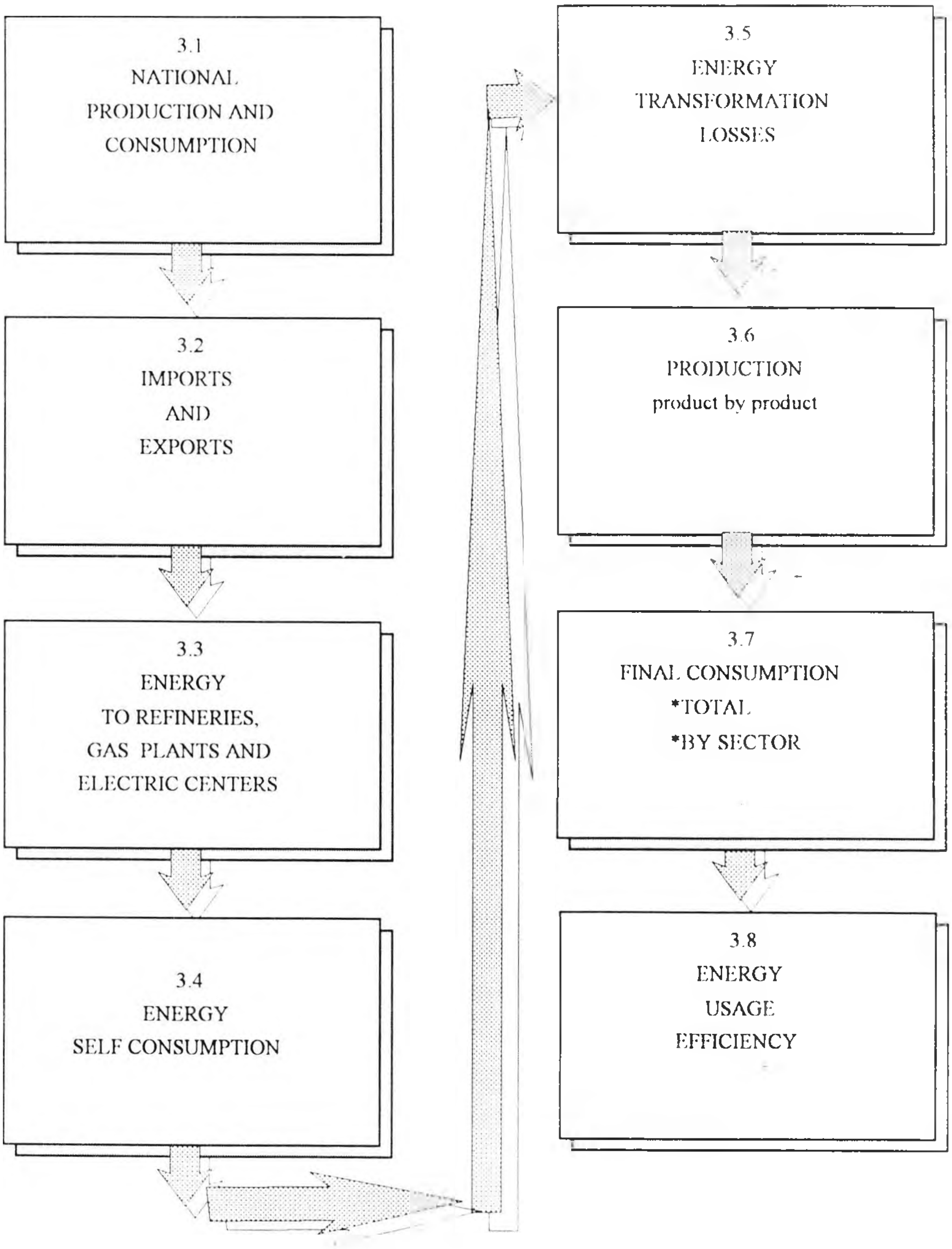


DIAGRAM 3.5.e

ANALYSIS OF ENERGY BALANCE IN REFINING SYSTEM

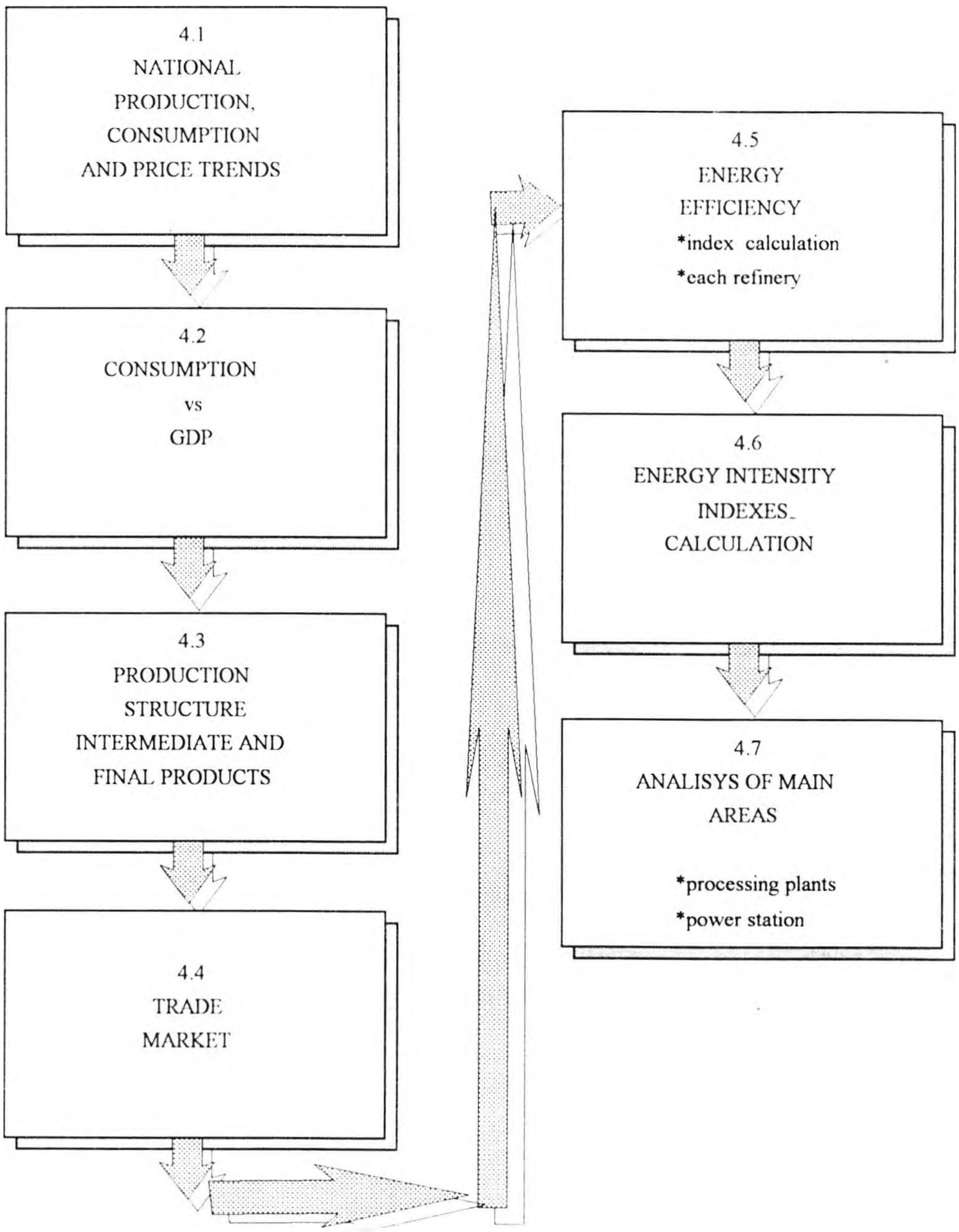
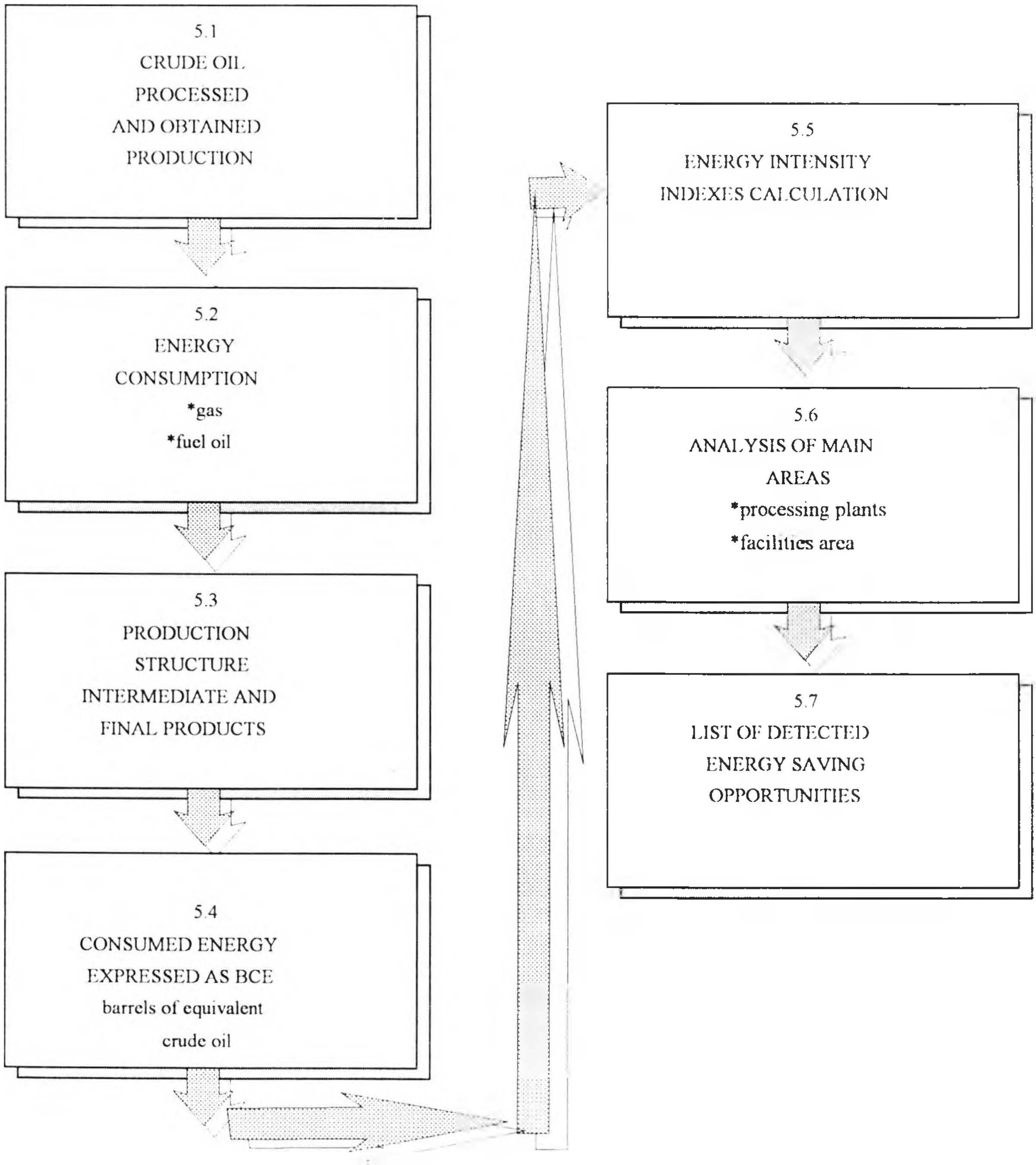


DIAGRAM 3.5 f

ANALYSIS OF ENERGY BALANCE IN A REFINERY



3.6.0 SAVING ENERGY CONCLUSIONS IN THE SALINA CRUZ REFINERY

3.6.1

The Mexican Petroleum Industry has been trying to improve its energy usage productivity for more than 12 years, nevertheless, to date the obtained results are still poor, since the energy efficiency indexes not only have not remained at the same level, but they have increased in the mentioned period.

The Mexican government is promoting the implementation of energy efficiency programs in several state-owned companies, although the petroleum industry hasn't implemented it very effectively

3.6.2

The Mexican Petroleum Industry has not always had an energy policy completely consistent with its energy conservation objectives: for example, energy price and taxation do not make it easy for consumers to get the optimal allocation of resources for saving energy; in fact, even now, there is still no effective conservation program; research and development in this field have been very limited. There hasn't been a defined economic criteria in the company to select the needed modifications for saving energy when the investment program is decided; and finally because in my opinion workers and supervisors aren't yet aware of the importance of saving and conserving energy.

3.6.3

In a first stage, Mexican Petroleum Industry tried to advance by itself. Pemex assigned several tasks to its engineers for reviewing the different aspects connected to the problem. So, many engineers from the company and from the Instituto Mexicano del Petroleo worked in energy auditing, operation improvement and project engineering for saving energy. Nevertheless, this effort hasn't had an appreciable result on the energy consumed as neither of the actions were strong enough to improve energy usage productivity.

3.6.4

On the other hand, in Mexico there are not many companies specialized in energy conservation, and only a few consultants offer services in this field; nor is there a leader who establishes and maintains the needed high professional standards. Because of that, only a limited amount of technical information about energy efficiency is distributed among users.

Lately, PEMEX signed several contracts with international firms specialized in energy conservation. These studies which have been recently developed, have more or less the same general ideas for improving energy usage efficiency, but the problem is how to implement them and how to create the interest of managers for making the needed investments and obtaining better results than the previous obtained through its internal expertise.

3.6.5

A permanent problem to build in PEMEX a more active program to save energy has been the limitation of economic resources and the lack of a defined and clear policy about investment hierarchy, to decide when a specific project to save energy is a better investment than a revamp project or a new one for increasing a plant capacity.

3.6.6

Later, I quote several figures to show what the situation is about energy usage efficiency in Mexican refining industry and, specifically, in the Salina Cruz Refinery:

a) In 1988, the Mexican petroleum industry consumed 507 588 BPCED (barrels of equivalent crude oil per day), 227 841 was energy consumed in petroleum processing 70% of this amount was used in refiners and petrochemical centers.

b) Refining has been a very important process to satisfy the domestic demand of main refined products: LP Gas, Gasoline, Kerosene, Gasoil and Fuel Oil. Mexican Refineries have, as a whole, 1.5 millions of barrels per day capacity. The average energy consumption was 10.38% of the crude oil charge in 1990 and in the first semester of 1991, 9.55%.

c) Among Mexican Refineries, the Salina Cruz Refinery was one of the most efficient in energy usage. According to energy auditing studies carried out in 1988 its energy consumption index was only 5.1 % of the oil crude charge. In the same period other Mexican refineries had the following monthly rates:

ENERGY CONSUMED % OF CHARGE	
ATZCAPOTZALCO	5.8 - 6.5
CADEREYTA	5.2 - 5.5
MADERO	8.0 -12.0
MINATITLAN	4.7 - 6.2
SALAMANCA	10.7 -15.3
SALINA CRUZ	4.7 - 5.2
TULA	4.8 - 5.8
TOTAL	6.7 - 7.5

3.6.7

In the same year, the average consumption in the Salina Cruz Refinery was 64 430 MMBTU/D, while the design data was 56 028 MMBTU/D. This means that there is at least an energy potential of 8 402 MMBTU/D, 13% of the whole consumption, for saving energy.

3.6.8

According to the observed net consumptions in each processing plant, the energy usage in 1988 was as follows:

Table 3.6. a
1988. NET CONSUMPTION IN PROCESSING PLANTS
SALINA CRUZ REFINERY

PLANT	FUEL AND GAS CONSUMPTION		NET CONSUMPTION	
	MMBTU/D	%	MMBTU/D	%
ATM. DISTILLATION	15,988	23.1	18,944	27.8
VACUUM DISTILLATION	3,242	4.7	4,073	6.0
NAPHTHA HYDRO	1,874	2.7	2,674	3.9
NAPHTHA REFORMING	4,670	6.8	4,735	7.0
MIDDLE DIST. HYDRO	2,078	3.0	3,090	4.5
CATALYTIC CRACKING	5,170	7.5	10,202	15.0
SULPHUR RECOVERY AND HYDROCARBON TREAT	792	1.2	1,991	2.9
BOILERS	35,194	51.0	11,933	17.5
FACILITIES	---	--	4,816	7.1
TURBOGENERATORS	---	--	5,625	8.3
TOTAL	69,018	100.0	68,083	100.0

The first column has data about fuel and gas consumptions. This is the direct consumption of external energy. This parameter allows us to identify those units which consume more external energy. In this case, the Atmospheric Distillation Unit and the boilers are the two main consumers of fuel and gas; Catalytic Cracking and Naphtha Reforming Unit are the second in importance. As direct consumers of fuel and gas, the boilers consume half of the total energy. The second consumer in importance is the Atmospheric Distillation Unit with 23.1% of the total energy.

Another point of view for analyzing energy consumption is the comparison of net consumptions, that is ,the difference between the sum of the energy content of all inner and outer streams. This figure is the most significant from the point of view of energy usage. In this case main consumers are in order of importance Atmospheric Distillation Unit 27.8%, boilers 17.5%, Catalytic Cracking 15%, Turbogenerators 8.3%, facilities 7.1% and Naphtha Reforming Unit 7.0% and Vacuum Distillation 6.0%. other processing plants have lower consumptions

3.6.9

With respect to project engineering, large and small projects are carried out in a traditional way, developing the different parts of each project, by areas which have the needed specialists in process, civil and electromechanical engineering; but without considering the integration of the total design with a system approach.

3.6.10

In the Salina Cruz Refinery, there are two main areas where energy is used: Processing plants and facilities area. In both there is a considerable wasted energy for different reasons. The most important are:

a) All the energy refinery balances show that the capability of steam and electricity generation is greater than the internal demand requires. This is because the capacity of the installed facilities does not have the needed equilibrium in respect to the energy demanded by current processing plants.

b) As a primary energy fuel and gas, are both produced in the refinery. Boilers, heaters and turbines are main consumers of fuel and gas. The performance of this equipment is lower than the one expected by the designer. Thus there is a considerable potential for saving energy by means of operational adjustments, corrective maintenance and specific redesign projects

c) The consumption by each processing plant shows that most part of the consumption takes place in the Atmospheric Distillation, Catalytic Cracking and Reforming Units and in boilers and Turbines. This information is shown in the table in conclusion number 8.

d) The uses of fuel and gas in the Salina Cruz Refinery are presented in table. Aside from this there are other energy consumptions like steam and electricity which are produced in the same refinery.

e) Because of the importance of the secondary energy (steam and electricity) produced in the refinery, is included an a specific analysis for steam and electricity is included further ahead in order to clarify the possibilities of saving energy in boilers and power station.

According to a study made on the period between december 1987 and march 1988, the steam and electricity consumptions expressed in MMBTU/D were:

	DESIGN	OPERATION	DIFFERENCE	
			NET	PARTIAL
			(1)	(2)
STEAM HIGH	20,035	23,797	3 762	6,614
STEAM MIDDLE	13,018	13,945	760	3,538
STEAM LOW P.	6,548	6,463	-85	1,254
ELECTRICITY	2,508	2,096	-412	122

(1) TOTAL DIFFERENCE IN WHOLE REFINERY

(2) PARTIAL DIFFERENCE CONSIDERING ONLY THE UNITS THAT CONSUMED MORE THAN THE DESIGN DATA

The above information shows that high and middle pressure steam is consumed in larger quantities than that the expected according to the design data. The opposite situation occurs with low steam and electricity.

f) Process control is based mostly on electronic instrumentation, except boilers which are in most part still pneumatic. Distributed control is being considered in planning. That is why only plants built in recent years or that are now being built are equipped with this kind of technology.

4.0.0 SYSTEM APPROACH TO THE PROBLEM

4.1.0 PROBLEM AND SYSTEM DEFINITION

PROBLEM DEFINITION

Processing plants in the Mexican Petroleum Refining System have been designed and constructed according to technical engineering criteria, trying more to save money in the total original investment than to improve its operational efficiency or assuring low operational costs.

The application of this criteria has quite often resulted in high operational and production costs.

Competition in the petroleum international market is very hard because of the war of prices among suppliers. If countries like Mexico do not carefully review their costs they might be pushed out of the refined products market.

Besides, Mexico does not have enough financial resources to increase its installed capacity and to build more modern plants in the refining activity. So it seems better to use the available financial resources to improve energy usage efficiency.

As a consequence, Mexico must have a strong policy to be able to meet the demand for high energy efficiency in the near future. The available financial resources should also be used to modernize the refineries.

PROBLEM SOLVING.

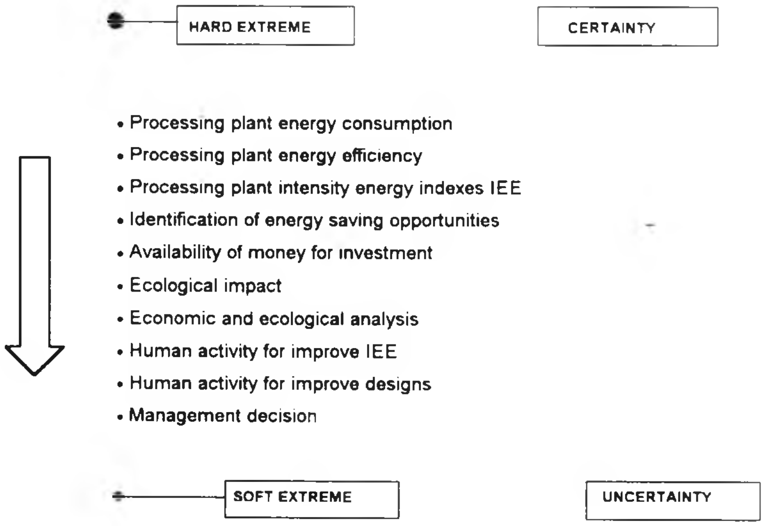
The problem of saving energy gets more complex as we move from the hard extreme to the soft extreme. The ever increasing uncertainty, linked to the nature of the situation, adds considerable complexity to the problem. Because of this, emphasis is put on methodologies that provide solutions using system engineering techniques.

Management science has been largely concerned with the development of these techniques, usually based on a mathematically oriented language to solve these kinds of problems.

The methodology applied to this research tries to consider the design problem. First, the problem is studied as a hard system and afterwards other methodologies are proposed to find solutions when more soft variables are included. Diagram 4.1.a shows the transition from hard extreme to soft extreme.

DIAGARAM 4.1.a

SOFT AND HARD VARIABLES 1_/



4.1.1 PARTIAL PROBLEMS AND OBJECTIVES

A system is usually defined as a complex organization of men, equipment, resources and operations, by which means integrated functions and operational needs are satisfied.

System behavior is dynamic and is of such character that it is not easily inferred from the inputs of the individual process in the organization.

1_/ Checkland Peter " Systems Thinking . Systems Practice" pp 125-189. Reference 63

In this research, the most important behavioral characteristic is the energy consumption The system behavior should be purposeful and directed towards the achievement of some energy saving goals, however, these cannot be isolated from other important performance and effectiveness goals, such as reliabilty, cost and adaptability.

System approach is the starting point to finding a solution as explained before. Three main partial problems have been taken into consideration in defining the system.

1.- Improvement of energy usage productivity in the existing installations

2.- Achievement of an optimal integral design or redesign so energy consumption is minimized at a given investment level

3.- Achievement of an optimal integral design using cost effectiveness criteria. In this case, energy consumption is only one of the variables to be considered in determining system performance

For the first two problems, the best and simplest system definition is to think of the Mexican petroleum industry as a man-machine macrosystem which includes the existing installations. This macrosystem consists of five systems: the human resource system, the *equipment* , the *material resources system*, the *operational system* an the management which links the whole system.

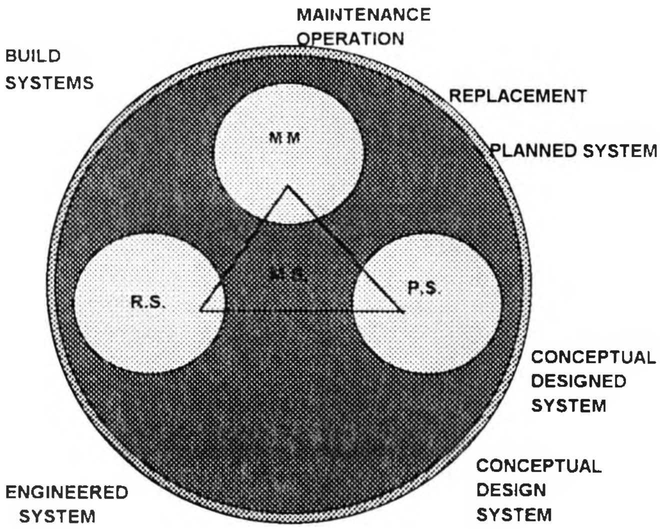
The third problem requires another system conceptualization since the main problem is to achieve an optimal integral design. In dealing with this problem some ideas from Mr. M'Pherson papers were taken. 1_/.The system structure in this case is more complex to make easier the analysis of its different parts and interactions.

1_/ M' Pherson "System Engineering. An Approach To A Whole System Design." Reference 16

FIGURE 4.1.b

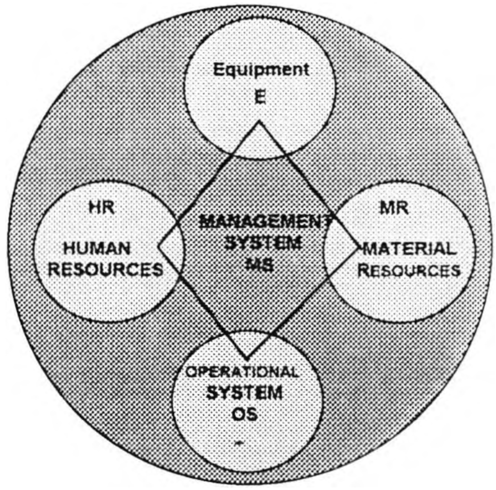
SYSTEM DEFINITION

MACROSYSTEMS STRUCTURE D.1

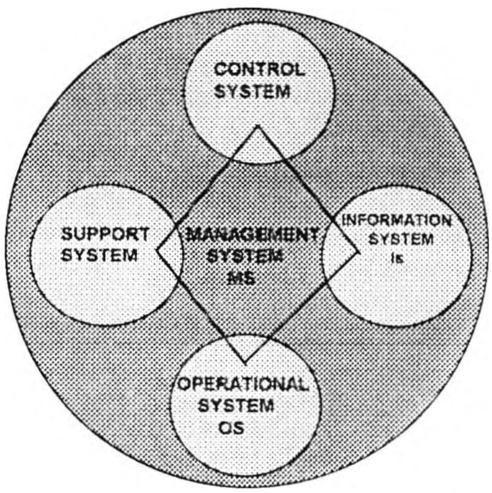


MM MAN MACHINE
PS PROTO SYSTEM
RS REALIZATION SYSTEM
MS MANAGEMENT SYSTEM

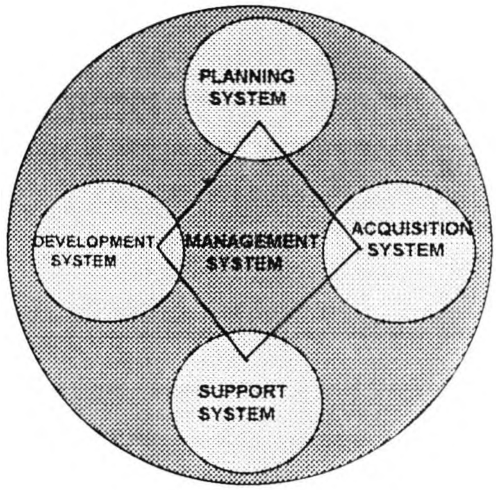
MAN- MACHINE SYSTEM (MN) D.2



PROTO SYSTEM (PS) D.3

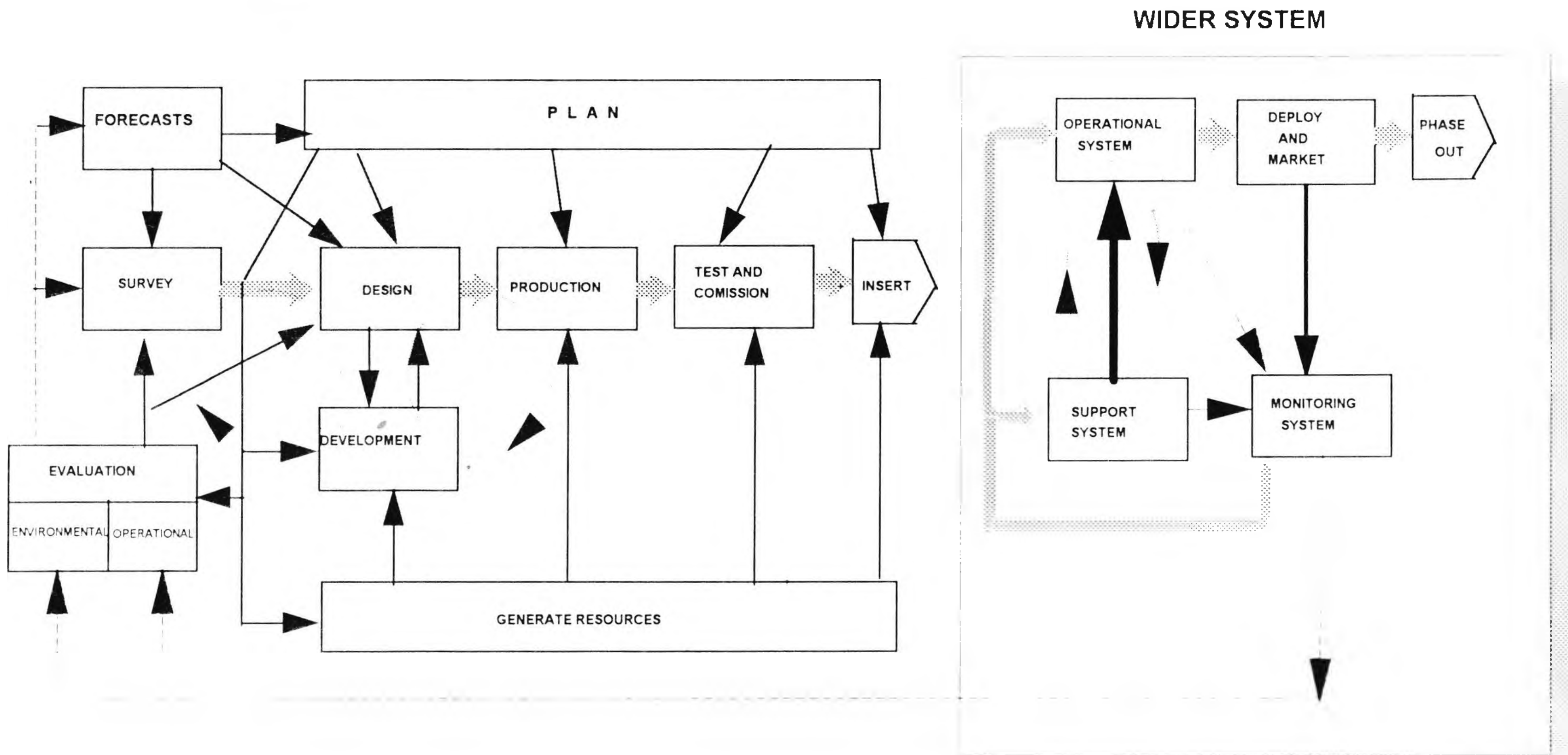


REALIZATION SYSTEM D.4



4.1.c PERSPECTIVE OF SYSTEM ENGINEERING

REALIZATION		ACQUISITION		OPERATION	
I CONCEPTION	II DESIGN	III PRODUCTION	IV INSERTION	V OPERATE AND SUPPORT	VI PHASE OUT



4.1.2 SYSTEM DEFINITION

To make a system concept definition it is important to facilitate the study of the different partial problems involved in the total problem. Saving energy is a very complex problem, since it is related to many facets of the petroleum industry. To facilitate the required studies to solve the problem, system definition should be appropiate for the analysis of the different parts of the Mexican petroleum industry and its environment. The socioeconomic situation in the country and in the international market for the entire petroleum industry are the main factors to be considered in the environment

Figures 4.1 b and 4.1.c show the system definition and the perspective of the system engineering respectively.[1] Both are very useful in making a system approach to the problem

THE MAN-MACHINE SYSTEM (MM)

This is a technological aggregate composed of processes, plants and equipment where the outputs are obtained. Men, money, material and machines are necessary resources for its operation, which purpose is to provide a useful function in aid of some operational activity. The subsystems are human resources, equipment, material resources and operations. In fact, this is the existing system.

THE PROTO SYSTEM (PS)

The proto system is the part of the system that is concerned with new projects from the life cycle point of view. The stages related to these macrosystems are planning and designing in order to define the new system as the part of the system that is to be engineered, to satisfy the new objectives. There are four essential systems in the proto system: operational system (OS) support system (SS), control system (CS) and information system (IS).

THE OPERATIONAL SYSTEM (OS)

This consists of the processes that provide the useful output. This output is often partially used up within the system itself before the final output is reached into the operational arena

1 These concepts and main ideas in section 4.1.2 are taken from M'Pherson. "A framework for system engineering design" Reference 17

The components of the operational system are the processes P_1, P_2, P_J; the information process **(IP):** The information control process **(IC)** and the operation control process **(OC)**

THE CONTROL SYSTEM (CS)

This system regulates the operational and other services systems.

The information system **(IS)**
Provides the feedback for the control system

The support system **(SS)**
To supply and maintain the other service systems

THE REALIZATION SYSTEM (RS)

The third macrosystem is the **realization system**. As the protosystem defines the new project or new system, the **realization system** makes it possible to construct the system after systems engineering has been applied from an initial concept right up to the final stage when it is brought into existence.

The **realization system** includes six main systems. The Planning System, Development System, Acquisition System, Support System, Information System and Management System. the function of each of these systems is resumed as follows.

PLANNING SYSTEM (PLS)

To analyze the problem of realization of several possible solutions, analyze and evaluate alternatives and develop the project plan.

DEVELOPMENT SYSTEM (DS)

To design, develop and engineer the selected system concept from the protosystem.

ACQUISITION SYSTEM (AS)

To manufacture, construct, test and launch the protosystem, thus taking it from a design concept to an operational system inserted into the real world

INFORMATION SYSTEM (IS) AND SUPPORT SYSTEM (SS)

To provide these necessary functions in the realization system (RS).

MANAGEMENT SYSTEM (MS)

To supply the decisions, policy making, coordination, administration, marketing and financial aspects in the RS

At this stage of the system life cycle, the operational experience is analyzed in order to arrive at proposals for modifications and improvements that can be incorporated into the system renewing it.

It can be seen that the system definition takes into account macrosystems, systems and subsystems. All of them having different levels of integration, as explained above. Although, to give the whole system a better structure to facilitate the study, it has been considered that the operative system is common to all macrosystems.

This system has been defined in this research work as the whole of production and commercialization processes of the Petroleum Refining Industry, represented by the subsystems listed below.

WIDER SYSTEM (WS)

The protosystem considered as a system of interest, is placed in a parent organization or a geographical region named the host system.

The operational arena is the part of the environment directly affected by the existence of the proto system.

The competing systems are other systems competing for the resources/ market/ territory or power.

The environment is the economic, social or natural part that is external to the operational area, but is affected directly or indirectly by the **SOI** throughout its operation

The monitoring system is composed by two parts: That specifically designed or inserted to provide information feedback to the management, designers or controllers; and the information and data gathering instrumentation or any other media which contributes to the available information

4.2.0 SYSTEM STRUCTURE.

4.2.1 INTRODUCTION

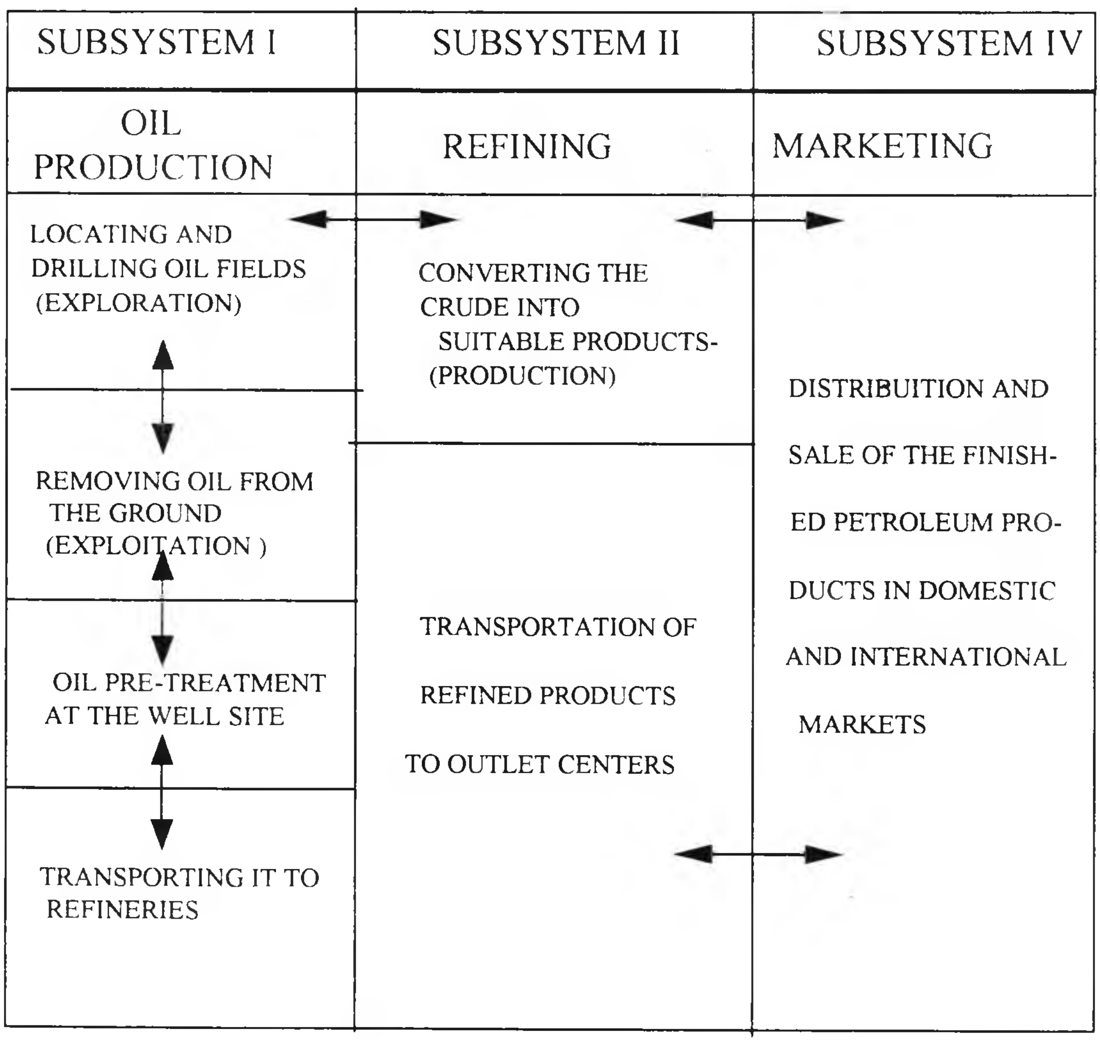
The Mexican Petroleum Industry is concerned with four major activities

- The production of oil and gas through exploration, drilling and exploitation
- The production of refining products from oil and gas processing
- The production of petrochemicals by means of petrochemical processes
- The distribution and commercialization of refined and petrochemical products in the domestic and international markets.

These four major activities are represented in figure 4.2.a and listed in section 4.2.2 where the subsystems are defined.

Figure 4.2.a

SCHEMATIC DIAGRAM OF PETROLEUM INDUSTRY INTERACTIONS AND THE AREA UNDER STUDY IN THIS RESEARCH WORK



4.2.2. S U B S Y S T E M S

Figure 4.2.a is a schematic diagram to represent the interactions in the petroluem industry

So, a refinery is such a complex installation, when it is considered as a man-machine system, the equipment should be defined taking in account the main divisions

A typical petroleum installation has the following subsystems:

SUBSYSTEM 1		Exploration and gas and oil production
	1.1	Exploration
	1.2	Drilling
	1.3	Production
SUBSYSTEM 2		Refining
	2.1	Processing plants
	2.2	Power station
	2.3	Facilities
SUBSYSTEM 3		Petrochemical
	3.1	Processing plants
	3.2	Power station
	3.3	Facilities
SUBSYSTEM 4		Distribution and commercialization
	4.1	Oil and gas transport
	4.2	Intermediate product transfer
	4.3	Final product distribution to terminals
	4.4	Final product distribution from terminal to sales agencies
	4.5	Product commercialization
SUBSYSTEM 5		Transport
	5.1	By sea
	5.2	By road
	5.3	By rail
	5.4	By pipe line

SUBSYSTEM 6 Regulation and control

6.1 Technical norms

6.2 Administrative norms

6.3 Measurements system

6.4 Instrumentation and control

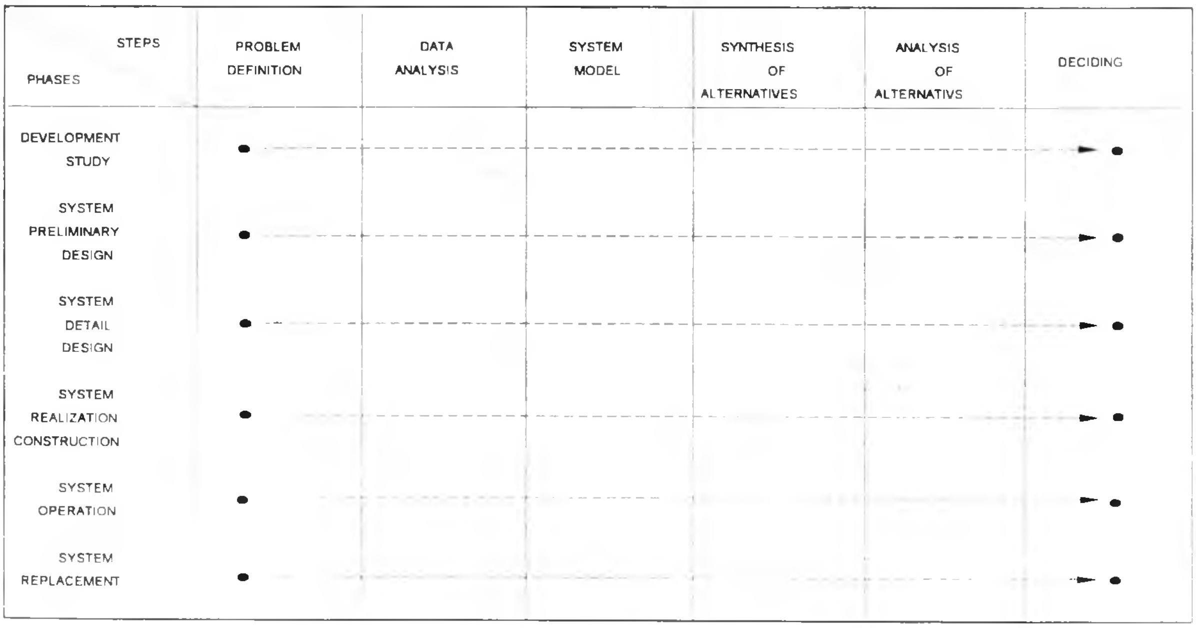
4.2.3 PHASES AND STEPS

It is thought that this double connection of steps, referred to each of the processes of the industry, facilitates the needed analysis along the research. In figure 4.2.b a matrix is presented which lets us visualize the combination of phases and steps. Each square of the matrix requires a methodological framework.

Figure 4.2.b [1]

PHASES AND STEPS IN SYSTEM METHODOLOGY

4 2 b



1 Gerez V., Grijalva M. "El enfoque de Sistemas" pp 21-35 Reference 65"

This conception can be integrated into a macro system of a higher level and, at the same time, allow the integration of the different lower levels down in the subsystems hierarchy, making it possible to analyze the component parts

In addition, it is convenient to take into account that a systems methodology is needed to carry out the analysis and studies in respect to the system from the point of view of energy saving

4.3.0 SYSTEM ANALYSIS METHODOLOGY

A formal methodology of systems analysis can be used for the saving energy problem The main elements are:

1.- The objectives to be accomplished. In this case the main objetive is saving energy and other objectives are:

a) To reduce the additional needed investment for saving energy as much as possible.

b) To achieve high returns on investments and fast pay backs.

c) To maintain a good system performance.

2.- Alternative techniques and tools to accomplish the objectives.

3.- Costs of the resources required by each system.

4.- Mathematical models for analyzing the problem and optimizing the solutions

This mathematical or logical framework shows the interdependence of objectives, the techniques and instrumentalities, the environment and the resources

5.- A criterion for choosing the preferred alternative

Systems analysis is the organized step by step study of the detailed procedures for the collection, manipulation and evaluation of data about an organization in order to determine what must be done and define the best way of improving the system's functioning

4.3.1 METHODOLOGY SCOPE

The research methodology will cover the following aspects

1. Definition of the theoretical foundation of system concepts.
2. Analysis of the initial engineering conditions of the Salina Cruz Refinery
3. Definition of the current energy efficiency as the initial point for improving it
4. Design a methodology for improving the energy efficiency of the refinery
5. Design a methodology for redesigning the refinery to improve energy efficiency usage
6. Design a methodology for designing a new refinery to improve cost - effectiveness

The methodology has to take into account the different investment levels needed

a) To increase production capacity to satisfy the domestic demand
b) To keep the present international market share
c) To increase the current participation in the international market
d) To analyze the cost of supplying products from the international suppliers.

4.3.2 SYSTEM ENGINEERING PLAN

Two stages are considered in the designing task: 1_/

a) Formulating the system.
b) Structuring the system.

Formulating the system consists of determining its outputs, inputs, requirements, objectives and constraints

Structuring the system provides the method of organizing the solution to the method of operation, the selection of parts and the nature of the performance requirements

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1_/ Chesnut H "System Engineering Methods", pp. 70. Reference 61

The formulating and structuring of the system consists of a detailed, technical appraisal of the specific needs of the system; in this appraisal the task is oriented in terms of what is needed for the system to accomplish its objectives. Both parts are highly creative and dependent on the state of the art in which the refinery is to be built and operated.

Organization for the redesigning of an existing refinery or designing a new one must have a balance between programme or project oriented activities, technology oriented activities, evolution oriented activities, as well as broad concept oriented activities, which provide new ideas for new systems.

Achievement of solutions for energy conservation depend on combined efforts to bring them about the following issues:

a) An appropiate policy framework
b) A better energy management
c) Increased investments in proven energy conservation technologies
e) Development and application of new technologies

System engineering comprises the set of activities which together lead to the creation of a man - made system. in this case the wanted man - made system is a refinery which is designed to have a high efficiency in energy utilization or a high cost - effectiveness ratio.

System analysis is the systematic appraisal of the system's behaviour through the study of the cost and implications of a definite solution.

4.3.3. SYSTEM ENGINEERING ANALYSIS

Four facets are included in system engineering analysis 1_/

a) System Analysis (broadly oriented)
b) System Development (technology oriented)
c) System Design (programme oriented)
d) System Evaluation (design evaluation oriented)

1_/ Chestnut H. "System Engineering Methods" . pp 70. Reference 61

For each facet it is necessary to have a group of engineers. For example, system analysis allows us to have a system engineering plan that provides a systemic identification of total requirements on an overall basis: Developing hardware, facilities, personnel and support information to optimize design.

In addition to the main objective, there are partial objectives: Improving the effectiveness of the overall system, increasing reliability, decreasing energy consumption, decreasing down time and maintaining cost-effectiveness. Great savings are obtained from a more effective personnel training, procurement of realistic quantities of spare parts and availability of support data.

The plan also provides the possibility of checking and cross checking all design details.

The following is a resume of the principal activities of the system engineering plan: 1

1. Identify the overall system requirement, concept and criteria
2. Prepare and record the system concepts and design criteria documents
3. Identify system criteria and preliminary design requirements
4. Prepare operational system functional analysis
5. Identify operational requirements and limitations for hardware, facilities, people and procedural support data.
6. Perform operational system evaluation
7. Prepare support system functional analysis
8. Identify support system, technical requirements and limitations
9. Perform support system evaluation
10. Perform operational - support system evaluation

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1 / Chestnut H " System Engineering Methods" , pp 27. Reference 61

11. Recommend design

12. Approve system design

13. Perform systems development leading to final specifications

14. Perform system design evaluation

4.4.0 ENERGY MANAGEMENT CONTROL SYSTEM.

There are three approaches in control: The empirical precision and discipline of the engineer where the system is essentially deterministic in nature; the concepts of rationality and quantification available from the operation researchers with their extension into econometrics, forecasting, inventory optimization, linear programming for effectively handling moderately stochastic problems or managing and controlling essentially stochastic system components; and the sensitivity to the human component from the behavioural and social scientist, to be much valued except where systems are entirely mechanical or automated.

The systems approach to system control and administration, like the system approach to science in general, try to order, and extend contributions from many different sources in the determination to achieve a constant congruence between problems and instruments.

System administration and control consists largely in finding ways to manage the human components of an enterprise. From the system science perspective, J. SHUTERLAND [1] has proposed that the sociobehavioural aspects of system control can best be approached as follows in table 4.4.a.

1_/ Sutherland J.W. "System Analysis, Administration and Architecture". Reference 23

TABLE 4.4 a
DIFFERENTIAL CONTROL MODALITIES 1_/

SYSTEM TYPE	PREDOMINANT CONTROL INSTRUMENT	PREDOMINANT CONTROL MODE	NORMATIVE BASIS FOR AUTHORITY	BEHAVIOURAL OBJECTIVE SOUGHT
I	DOGMA	RITUALISTIC	TRADITION	OBEDIENCE/ MECHANIS-TICITY
I	COERCION ESPRIT	ALGORITHMIC	POSITION	PROGRAMM-ABILITY PREDICTIVITY
III	RATIONAL ADVANTAGE	OBJECTIVE AUDIT	EXPERTISE /INTEREST	INNOVATION ASSIDUITY
IV	ETHICAL OR PROFESSIONAL CODES	AUTOREGU-LATION	INDIVIDUAL	CREATIVITY

For dealing with the various ecological postures associated with the ideal-type systems, each system type faces an effectively unique set of environmental conditions. The ecological mission forced on a socioeconomic system will largely determine which particular control intruments will be most effective and efficient in dealing with that systems constituents.

Each of the control modalities available will vary considerably in their precision, accuracy exactness, cost effectiveness and reliability.

The general control typology is presented in figure 4.4.b, where there is a vector of congruence which purports to set out the most efficient and effective instrument for exercising control, given the four idel type systems.

1_/ Sutherland J.W "System Analysis Administration and Architecture" . pp 282 Reference 23

To the left of vector there are conditions of inefficiency, such that the instrument we elect to employ, costs more than is theoretically required to realize control of the system. To the right of the vector there is ineffectiveness so the instrument elected is simply not powerful enough to realize control over the associated system type.

In order to precise some concepts about the characteristics of the four types of systems, six tables are added: 1_/

Table 4.4..b General control tipology

Table 4.4.c Ecological implications

Table 4.4.d Correlation between ideal-types and control administrative and cognitive models

Table 4.4.e Typology of dynamic correlations

Table 4.4.f Domain correlations

Table 4.4.g Administrative properties

1_/ Sutherland J.W. "System Analysis Administration and Architecture". pp 282 Reference 23

FIGURE 4.4.b 1_/

INSTRUMENTS AND METHODS

CONTROL INSTRUMENT/ CONTROL MODALITY	SYSTEM IDEAL TYPES			
	TYPE IV	TYPE I	TYPE II	TYPE III
ETHICS AUTO REGULATION	X		INEFFECTIVENESS	
DOGMA RITUALISM		X		
COERCION ALGORITHMS	INEFFICIENCY		X	
RATIONAL ADVANTAGE OBJETIVE AUDITS				X

1_/ Sutherland J.W "System Analysis. Administration And Architecture ". Figure 8.5. pp.'284 Reference 23.

FIGURE 4.4.c 1_/
TABLE OF ECOLOGICAL IMPLICATIONS

SYSTEM TYPE	ECOLOGICAL TYPE	ECOLOGICAL OBJECTIVE	ECOLOGICAL ADVANTAGE	PROBABLE SOURCE OF ECOLOGICAL ERROR
I	Autarchic	To institute essentially automatic (ritualized or mechanized) responses to a highly limited, precedented stimuli-set.	Automaticity in the face of an invariant set of environmental conditions.	Atavism, in that the system remains rigid even in the face of mayor environmental alterations.
II	Symbiont	To establish a set of algorithmic responses to a highly constrained stimuli-set and to maintain operational consistency throughout the entire system domain (among all functional parts).	Maximum internal efficiency and operative control in the face of routine, but often critical, performance demands.	Obsolescence, in that the system may tend to maintain internal consistency at the expense of environmental congruence.
III	Dominant	To make most efficient use of resources in a succession of variant short-runs... most thoroughly and expeditiously take advantage of emerging opportunities for exploitation	Effective optimality over the long-rung by exercising a continual trade-off between versatility and mechanisticity, between external congruence and internal efficiency	Misallocation of resources due to the time-lag between recognition of a new opportunity and internal readjustment (plus some danger that an adverse innovation or strategic change will be implemented).
IV	Heuristic	To ensure an effective response to unprecedented situations, to install creativity rather than mechanisticity.	Adaptivity in the face of nonrountine and unpredictable exogenous forces or influences through maximum structural and functional plasticity.	Dissolution, in that the largely autonomous parts only weakly cohered ...moreover, the constant quest for innovation responses entails a high probability of an error of commission.

1_/ Sutherland J.W "Systems, Analysis And Administration Architecture" pp 283 Reference 23

FIGURE 4.4.d 1_/
TABLE OF CORRELATIONS BETWEEN IDEAL-TYPES AND CONTROL, ADMINISTRATIVE, AND COGNATIVE MODALITIES

IDEAL TYPE REFERENT	CONGRUENT CONTROL MODALITY	CONGRUENT ADMINISTRATIVE MODALITY	COGNITIVE BASIS
Deterministic (type-I system)	Ritual/dogma Institutionalization	Finite-state system analysis	Optimization (often through trial-and-error).
Moderately stochastic (type-II system)	Implied or direct coercion/rules; programmation	Servocybernetic programming	Decision theory
Severely stochastic (type-III system)	Rational advantage/ objective audits	Stochastic-state techniques	Policy science
Indeterminate (type-IV system)	selt-regulation/ ethnical codes	Heuristic approach	System architecture

1_/ Sutherland J W "Systems, Analysis And Administration Architecture" pp 280 .Reference 23

FIGURE 4.4.e 1/
TYPOLOGY OF DYNAMIC CORRELATIONS

SYSTEMIC IDEAL TYPE	ANALYTICAL STATE	DYNAMIC IDEAL TYPE	ASSOCIATED CONTROL ASPECTS
I. Primitive system	Deterministic	Mechanical	Dogma/ritual
II. Bureaucratic system	Moderately stochastic	Nonequifinal	Implied coercion/ algorithms/esprit
III. Competitive system	Severely stochastic	Equifinal	Rational advantage/ objective audits
IV. Emergent or professional system	Indeterminate	Heuristic	Autoregulation/ethical codes

1 / Sutherland J.W. "Systems, Analysis And Administration Architecture" pp 306. Reference 23

FIGURE 4.4.f 1_/
TABLE OF DOMAIN CORRELATIONS

SYSTEMIC IDEAL-TYPE	ECOLOGICAL POSTURE	DOMAIN IDEAL-TYPE
I	Autarchic	Fully segmented
II	Symbiont	Structurally segmented/ functionally differentiated
III	Dominant	Fully differentiated
IV	Dependent	Structurally differentiated/ functionally segmented.

1_/ Sutherland J.W "Systems, Analysis And Administration Architecture" pp 306 Reference 23

FIGURE4.4.g 1_/
TABLE OF ADMINISTRATIVE PROPERTIES

SYSTEMIC IDEAL TYPE	MORPHOLOGY OF THE ADMINISTRTATIVE SYSTEM	DECISION LATITUDE (AUTONOMY) ALLOWED PARTS	DECISION-MAKING PREMISES
I	Coextensive with the social estructure	None: all behavior programmed via dogma driven ritual	Mystery, dogma, or exegesis
II	Hierarchical and centralized	Little: most decisions are highly constrained, the constraints dependent on level of organization	Precedent, tradition,,and legislated premises
III	Decentralized (except for major policy direction)	Moderate: within assigned sphere of influence or expertise	Rational or scientific in origin... i.e., objective
IV	Amorphous and adhocratic	High: there are often formal sanctions against constraints	Intuitive or idiographic

1_/ Sutherland J.W "Systems, Analysis And Administration Architecture" pp 307. Reference 23

4.4.1 CONTROL SYSTEM DESIGN

Throughout history, man has attempted to control nature's forces in order to help him perform physical tasks which were beyond his own capabilities. During the dynamic twentieth century, many of man's imagined devices have been made into reality.

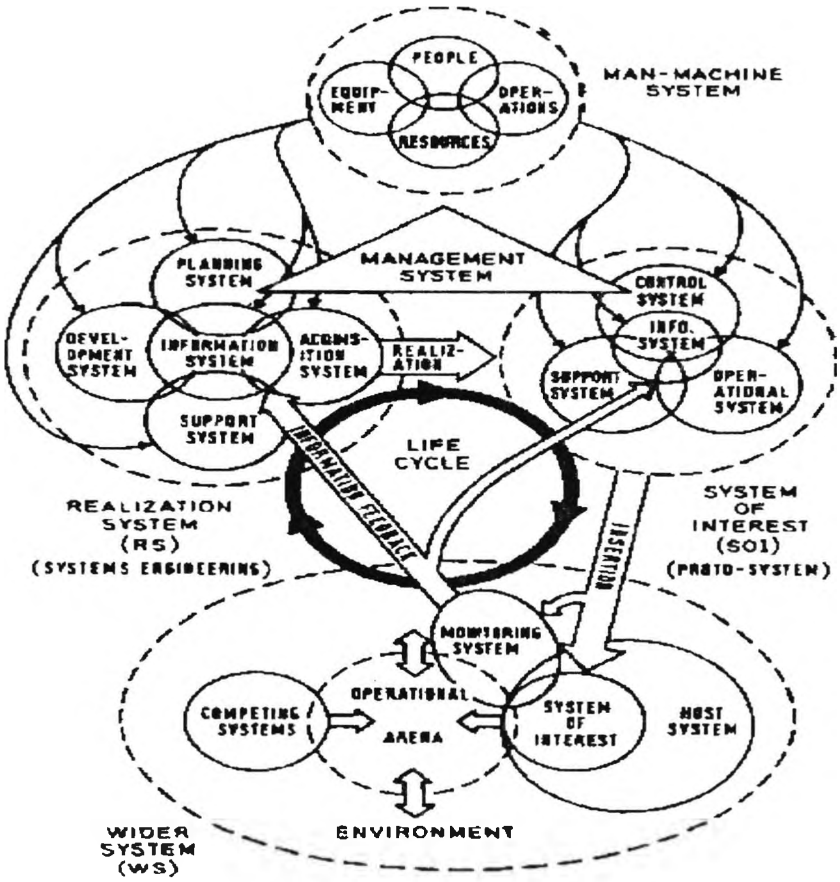
The knowledge of automated control theory has been applied to industrial uses for machines in automated factories and process plants today, the field of automatic control ranks as one of the most promising fields in industry; its growth potential appears unlimited.

Control systems can be defined as devices which regulate the flow of energy. Their arrangement, complexity and appearance vary according to their purpose and function. Control systems can be categorized as being open-loop or closed loop. The distinguishing feature between these is the use of feedback comparison for closed loop operation. Several characteristics of feedback control systems can be linked to human behaviour. Feed control systems can think in the sense that they can replace, to some extent, human operations. These devices do not have the privilege of freedom in their thinking process and are constrained by the designer to some predetermined function. Adaptive feedback control systems which are capable of modifying their functioning in order to achieve optimum performance in a varying environment, have recently gained wide attention.

4.5.0 SPECIFIC METHODOLOGY TOWARDS A WHOLE SYSTEM DESIGN

M' Pherson 1_/ proposed a model for the representation of the whole system, when the task of designing is carried out and concepts of system engineering are applied. Figure 4.5 a

FIG. 4.5.a THE WHOLE SYSTEM CONCEPT OF SYSTEM ENGINEERING



1_/ M Pherson P.K."System Engineering. An approach to Whole System design" pp 545. Reference 16

The part of the system that is to be engineered is the protosystem **(PS)** or system of interest **(SOI).** This system requires four essential service systems:

1. The operational system. To provide the useful output
2. The control system. To regulate the operational system
3. The information system. To provide feedback to the control system
4. The support system. To supply and maintain the other service systems.

4.5.1 REALIZATION SYSTEM (RS) 1_/

The **SOI** can be a modified or a new system.

If the **SOI** is an existing system, the **RS** can be considered to be the instrument for modifying and improving the system by means of the experience.

When it is a new system it is carried out from an initial concept. The structure and methodology for developing the **RS** are based on the system compartmented in the following way:

1. The planning system. To produce possible solutions, analyze and evaluate alternatives.
2. The development system. To design, develop and engineer the selected **SOI** concept.
3. The acquisition system. To manufacture, construct, commission and launch the **SOI**.
4. The information system. To provide information to **RS**.
5. The support system. To provide this function in the **RS**.

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1 M. Pherson P.K: "System Engineering. An approaoch to whole system desgin". pp 551 . Reference 16

After designing, commissioning and acceptance-launching, the **SOI** is inserted into a wider system.

4.5.2 WIDER SYSTEM

It is compartmented into:

1. The host system. The parent system in which the **SOI** nests.
2. The operational arena. The part of the environment which is directly affected by the **SOI** because of its existence, its requirements or its outputs.
3. The competing systems. Other systems competing for the resources, market, territory or power.
4. The environment. The part of the environment that is affected directly or indirectly by the **SOI**.
5. The monitoring system. The information retrieval and feedback system.

4.5.3 THE SYSTEM'S LIFE CYCLE

The life cycle is an important concept in systems engineering for orienting the design of the **SOI** towards effective operations throughout its useful life rather than just satisfying its performance specifications at the start of its operational life.

Systems engineering leads to the consideration of whole life costs for studying the economic aspects of the **SOI.**

The system life cycle is characterized by the following modes and phases:

TABLE 4.5 b

THE SYSTEM LIFE CYCLE [1]

MODE	PHASES
REALIZATION	**CONCEPTUAL AND PRELIMINARY DESIGN**
	System survey and analysis
	System synthesis
	Initial design studies
	Project Plan
	Evaluation
	DESIGN AND DEVELOPMENT
	Detailed Design and Development
	Specifications
ACQUISITION	**PRODUCTION**
	Acquire facilities and resources
	Manufacturing engineering
	Production and Quality control
	Assemble and test
	Recruit and train personnel
	INSERTION
	Advance parties
	Distribution
	Construction
	Commission
	Provision support
OPERATION	**MARKET AND DEPLOYMENT**
	Deployment of operational units and personnel
	Marketing and sales
	OPERATIONAL
	Operate system
	Monitor performance
	SUPPORT
	Maintain, repair, overhaul
	Provisioning
	Evaluate operational information
RENOVATION	**RENEWAL**
RETIREMENT	**PHASE OUT**
	Place in reserve

4.5.4 METHODOLOGY BASES TOWARDS A WHOLE SYSTEM DESIGN

Systems engineering puts emphasis on the whole system, life cycle and integral design concepts. These concepts are the base for building a framework with which to tackle the problems of planning, designing and managing the whole system realization problem.

1 M Pherson. "System Engineering. An approach to whole system design" ,pp 553. Reference 16

System engineering is an organic process that has to be conceived, organized and managed as a whole. Figure 4.5.c shows the phases to be considered in the process which includes resource inputs, operations, controls and information feedbacks. System engineering becomes a dynamic multivariable, multiloop system which will have a specific behaviour

In our case, the refinery design has all these characteristics and needs to be done in order to have a successful system.

If this task is not supported by proper concepts and tools, projects can be wrong. Hence, the tendency in systems engineering to see project management more as "the design of design", as a feedback system rather than an open-loop sequence.4.5.c. 1_/

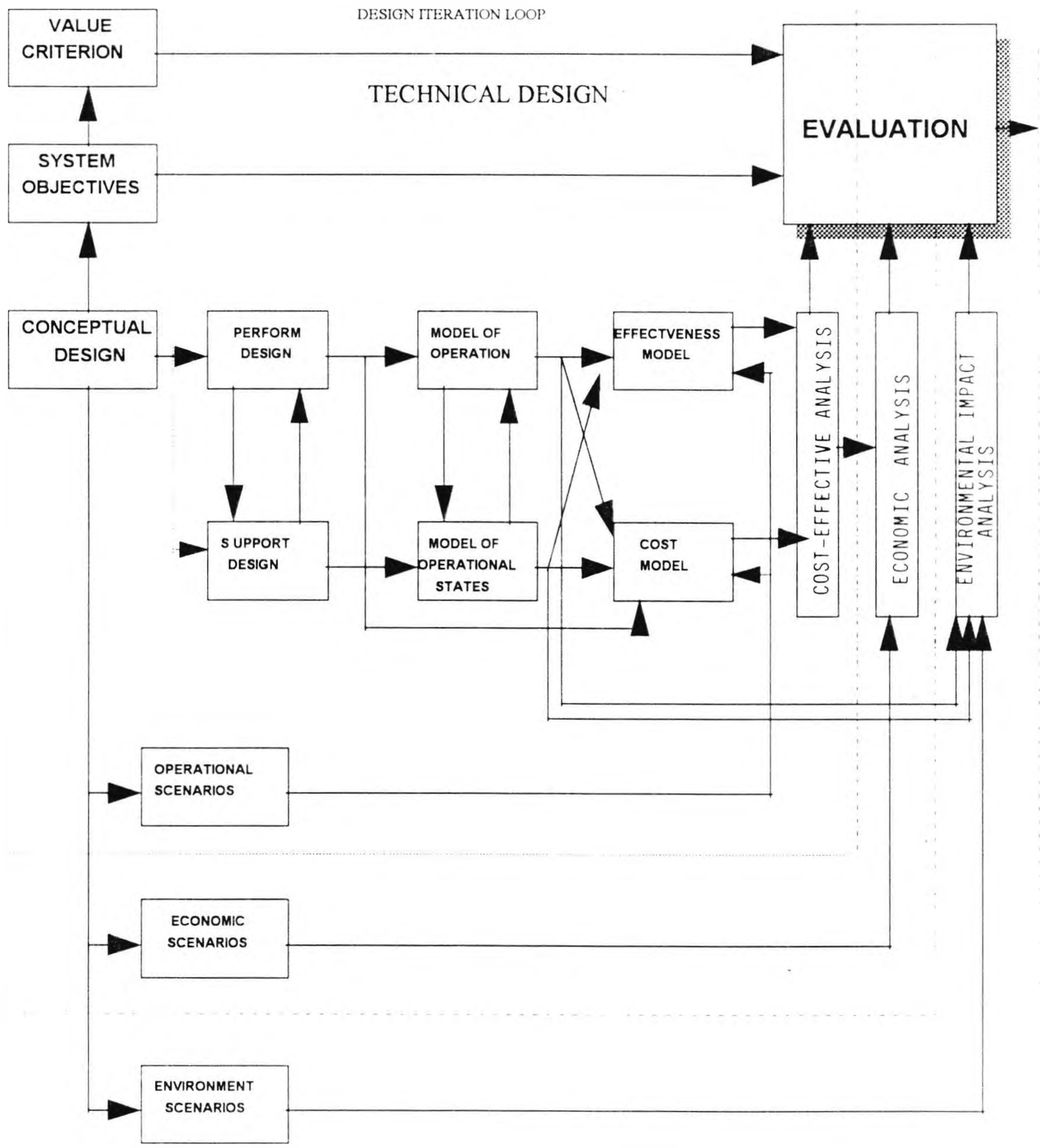
1_/ M'Pherson " System Engineering. An approach to whole system design." pp 555. Reference 16

FIGURE 4.5.c

SYSTEM DESIGN PERSPECTIVE 1_/

ENVIRONMENTAL ASSESSMENT

COMMERCIAL ASSESSMENT



M'Pherson " Systems Engineering. An Approach To Whole System Design " pp 555. Reference 16

The effort of planning and organizing a system can be largely wasted if it is the wrong system. There are several reasons which explain this possible failure:

a) Not meeting the customer's real objectives or the actual operational environment

b) Not matched to the operational environment

c) Badly timed

d) Not matched to the social or natural environment

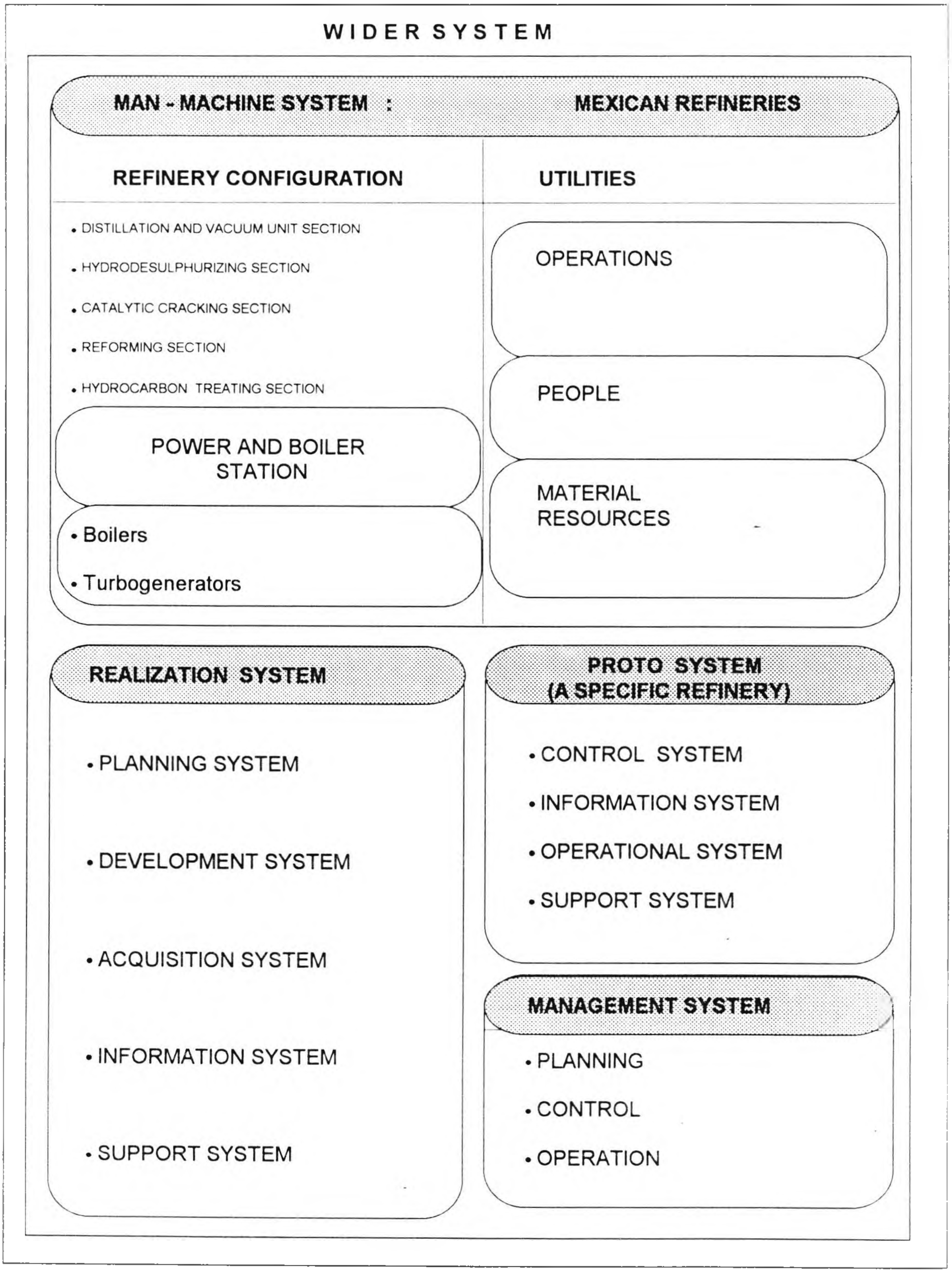
e) Badly designed in respect to any of the following characteristics

Capability, availability, reliability, maintainability, supportability, survivability, marketability, operability, ergonomic factors, safety, internal or external compatibility, trade-off balance and life cycle costs

FIG. 4.5.d shows the whole system design applied to a refinery. In fact, this figure is a representation of the whole system shown in fig. 4.5.a, but with the typical elements of a refinery except the wider system

Figure 4.5.d

WHOLE SYSTEM DESIGN SCHEME APPLIED TO A REFINERY



The main idea for developing a good design is to select from a set of alternatives the optimal configuration and then the optimal detailed system. In this case the optimality is refereed to:

a) Life-cycle optimality is evaluated over the systems entire life

b) Technical optimality takes into consideration the technological performance and non-commercial costs

c) Economic optimality where the attributes are returned on investment, break-even time and market penetration.

d) Environmental optimality is evaluated through the impacts of the system on the social and natural environment.

What is evaluated as a good design depends entirely on the initial statement of system objectives, the value criterion used and the adoped specifications

Assuming that the objectives are all oriented to maximizing, the value increases the more the system meets the objectives.

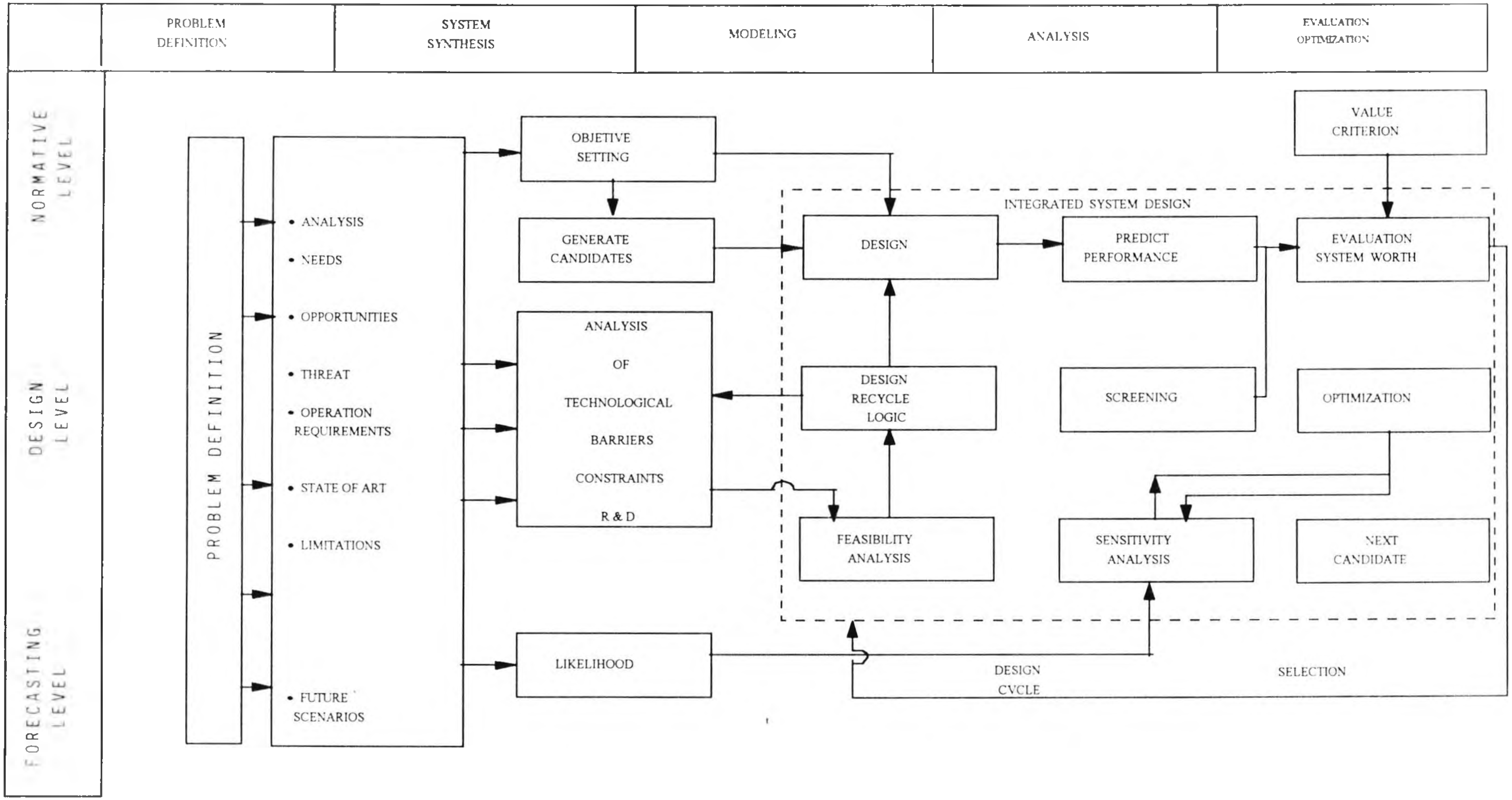
The **SOI** is the end result of a concerted design process covering six aspects: The operational plant and the associated equipment, the maintenance and logistics systems to support operations, the manpower system providing the required management and operational skills and the management system for operational, support and financial control. All combine to produce a cost-effective system.

For major projects, the project manager may have to organize the effort of hundreds of individual decision-makers and designers in the parent organization and in the subcontractor's. careful plans must be prepared for the handover, commissioning and insertion of the system into the operational environment. Fig. 4.5.e shows a planning network for a project according to concepts of M'Pherson 1_/

1_/ M'Pherson P. K. " A framework for Systems Engineering Design " pp. 67 Reference 17

A PLANNING NETWORK FOR A PROJECT DESIGN 1_/

FIGURE 4.5 e



1 M PHERSON P K "A framework for Systems Engineering Design " pp 66 Reference 17

In this chapter the accent has been placed on the application of the broad concepts of system engineering whole-system and whole-life to improve a specific large-scale design. The realization phase of the system engineering process is studied in order to have alternative solutions to the design problem and to lead to the selection of an alternative to go forward for detailed design, development and acquisition.

The objective is to design the system, as per the system specification it has obtained at the end of the phase by developing an advanced design of the system as-a-whole which can be evaluated for whole-life performance and costs.

So, system design means the overall process necessary to produce a system specification that has been selected on the basis of its predicted whole-life performance and to integrate the subsidiary process of performance design, reliability, maintenance and logistic design within the overall design concept.

There is a hierarchy of system design levels ranging from the analysis of an overall technological strategy down to the design of finite technical systems, according to figure 4.5.f1_/

A good system should satisfy the following operational criteria:

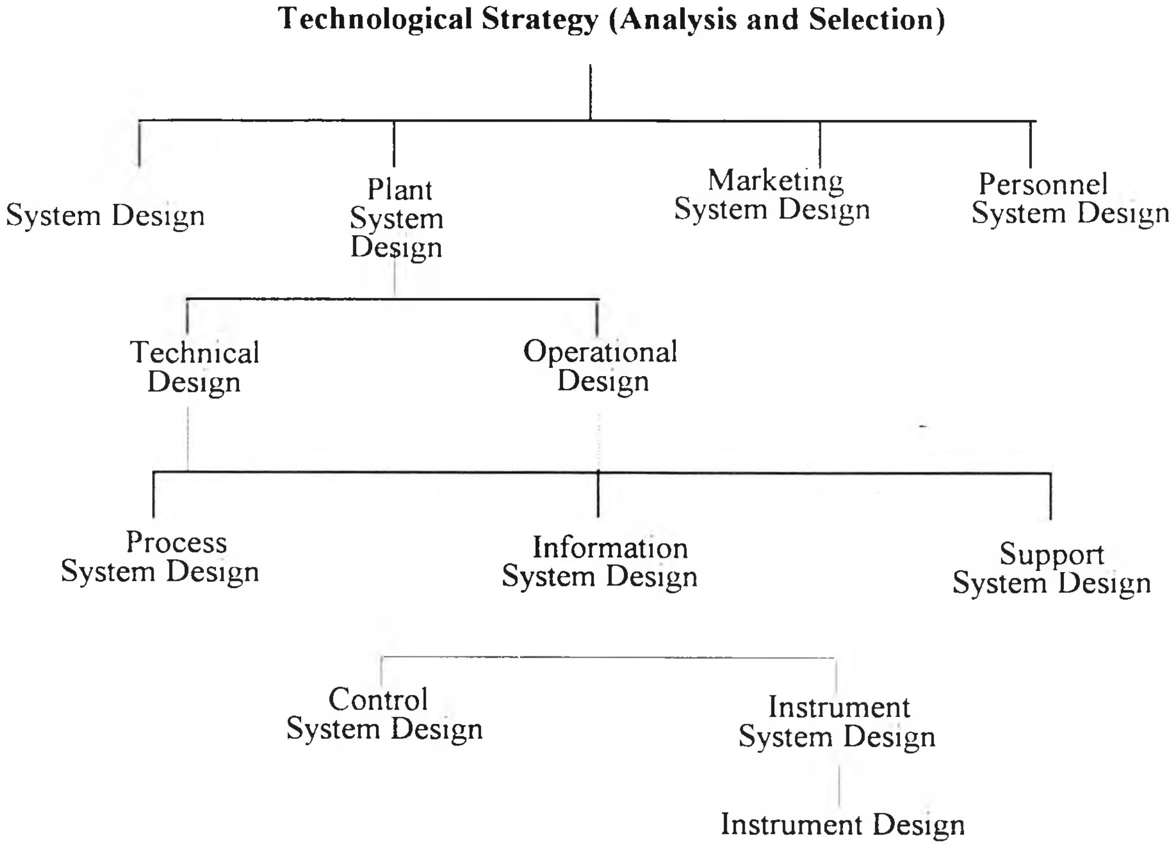
- Operational matching
- Whole-life cost-effectiveness
- Resilience
- Environment and safety
- Embedding

In figures 4.6.a, 4.7.a and 4.8.a several frameworks are presented for to redesign a refinery or to design a new one, both to achieve objectives to improve energy usage productivity and cost effectiveness. These frameworks were the result of the application of the mentioned concepts in this chapter to the three main problems under study in this research work.

1_/ M'Pherson P.K "Systems Engineering. An approach to whole System Design" pp 558. Reference 16

FIGURE 4.5.f

HIERARCHY OF SYSTEM DESIGN LEVEL 1/



1/ M'Pherson "Systems Engineering. An Approach To Whole System Design", pp 558, Reference 16

4.6.0. FRAMEWORK FOR REDESIGNING A REFINERY TO IMPROVE ENERGY USAGE PRODUCTIVITY

This framework is the simplest of the proposed three ones because it corresponds to the least complex problem In this case the system exists, so its subsystem and components are completely defined, and the objective is only to improve the energy usage productivity of the system.

The redesign artery is focused to those parts which can help to improve the energy efficiency. That is why this proposed system design framework includes four partial designs **PD** performance design, **HRD** heat recovery design, **SD** support design and **ISD** integrated system design To make possible the system analysis, it includes also five models, functional model, capability model, operational cost model, capital cost model and life cost model. In this framework, economic analysis and construction of operational scenaries are mainly applied, so the problem is quite simple.

Since the system exists, in fact it is the existing refinery, it is only necessary to improve its energy usage productivity. The starting point is the existing system itself and the analysis provide the tools for measuring the systems worth as a consequence of the proposed modifications.

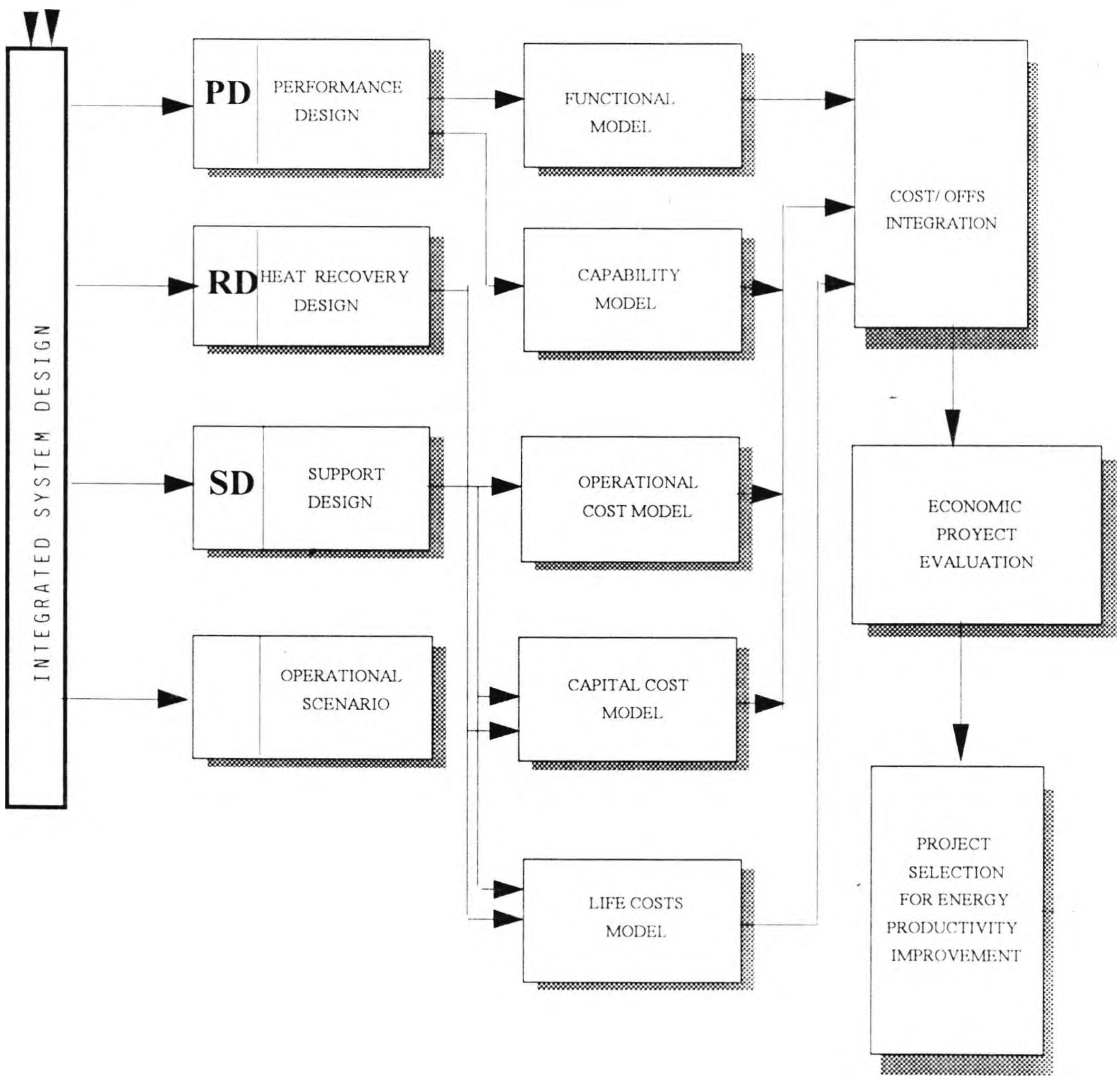
A simple modification on the system or a set of them define a new system candidate. Each candidate has different parameters to measure its performance or its economic result. As the system is operating, its performance is known and the proposed modifications only change the heat recovery level and therefore its performance.

PD, **SD**, **HRD** and **ISD** only describe the existing system in a first stage. After that, each proposed modification is analyzed through the models which represent the system The most important analysis is to determine how a proposed modification changes the original design, how the economic parameters are modified in each alternative and how the needed investment for each modification is recovered. The interactions and conflicting objectives are analyzed in the "Integrating Cost-Offs" and then the whole new design is analyzed by means of the economic project evaluation.

Figure 4.6.2 represents schematically the interactions between the partial designs and the different models to evaluate the whole design.

FIGURE 4.6.a

FRAMEWORK FOR REDESIGNING A REFINERY TO IMPROVE ENERGE USAGE PRODUCTIVITY



4.7.0. FRAMEWORK FOR INTEGRATED REFINERY DESIGN TO IMPROVE ENERGY USAGE PRODUCTIVITY

The framework to analyze the problem of improve energy usage productivity in an new design considers the specific designs that were proposed in section 4.6.a. The difference respect to this section is that in this case the system does not exist, so it is necessary to formulate and to structure the system. Both of them are included in the configuration design, the framework provides a methodology for analyze the performance design, the heat recovery design, the support design and the environmental impact design. This framework is shown is figure 4.7.a.

Models for representing functional aspects, capability and availability and impact analysis should be conceptualized in order to analyze in more detail the system behaviour

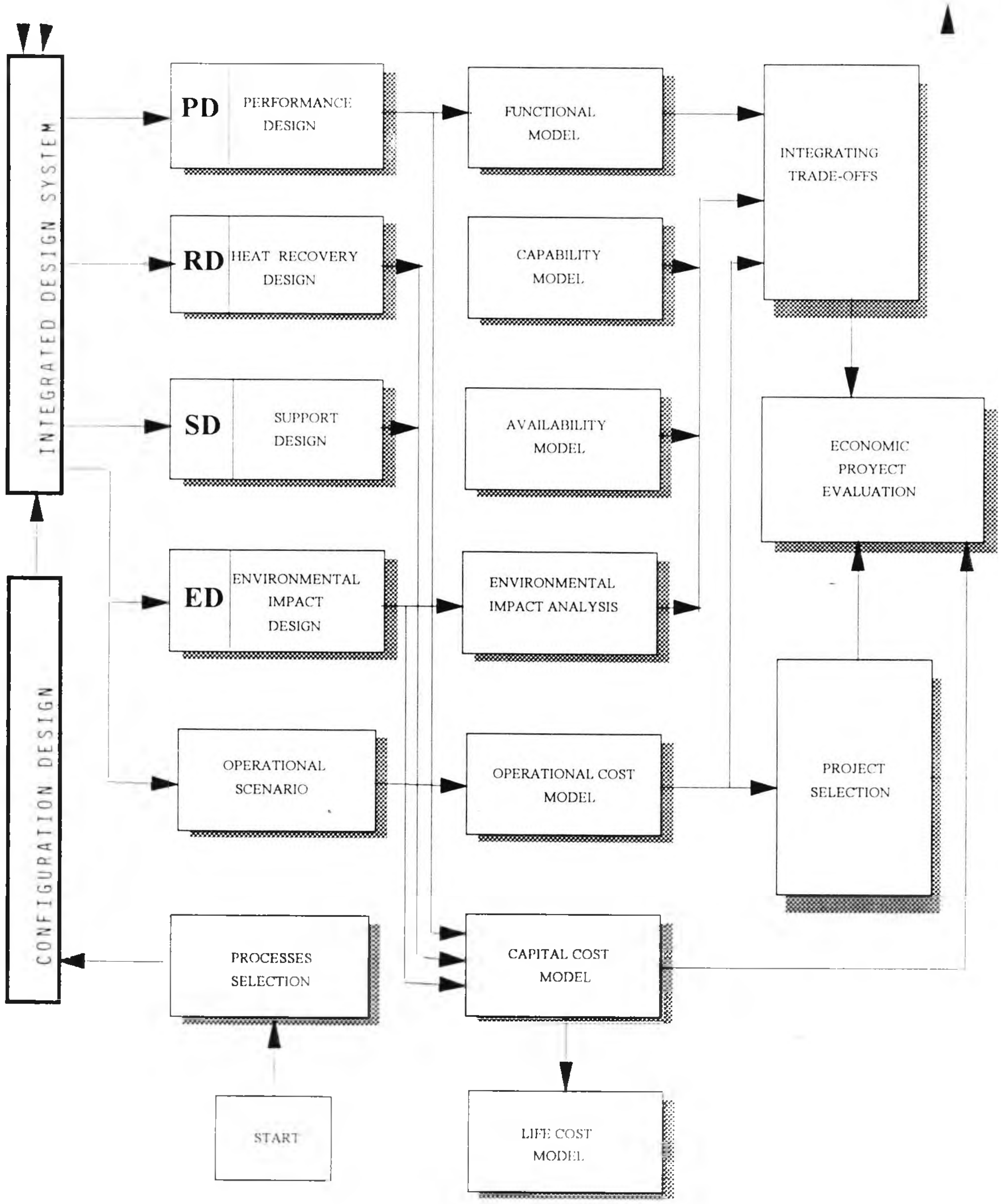
To integrate the different results an integrating trade-offs step and an integrated system design is previewed; the same economic model can be applied to analyze the profitability of the investment for each proposed modifications.

To apply this framework it is supposed that the engineering group, should propose several system candidates. In fact, there is a contradiction in this framework because the energy usage efficiencies are analyzed once the system is designed in other aspects. This method diminishes the integrity of the solution so the design is defined through a serial steps without considering at the sametime all the possible modifications

This methodology is a middle point from the point of view of complexity between the frameworks considered in 4.6.a and 4.8.a sections. It is supposed that as a consequence of the previous tasks there are system candidates which were result of the configuration design

FIGURE 4.7.a.

FRAMEWORK FOR INTEGRATED REFINERY DESIGN TO IMPROVE ENERGY USAGE PRODUCTIVITY



4.8.0. FRAMEWORK FOR INTEGRATED THROUGH COST EFFECTIVENESS ANALYSIS

This framework takes into account cost-effectiveness analysis within a system approach. The most important characteristic of this framework is that it considers all the different variables that assure the best cost-effectiveness ratio. It includes performance, reliability, availability, survivability, environmental impact, operational and capital cost variables. All these aspects are evaluated through a cost-effectiveness analysis and a cost offs integration. The same economic evaluation model is utilized to analyze the investment profitability of the considered projects.

The system design process establishes overall system performance requirements and ensures the system candidate that goes forward for acquisition and operation satisfies whole system, whole life cost-effectiveness criteria, besides of that, it ensures that detailed design, development and production during the acquisition phase are so planned and integrated that the assembled and operating system does in fact achieve the specified performance within the required cost-effectiveness boundary.

These functions of system engineering are considered within the "System Assurance" which includes design assurance and quality assurance.

In this framework, six designs are considered: **PD** Performance Design, **RD** Reability Design, **SD** Support Design, **ED** Environmetal impact Design, configuration design **CD** and **ISD** Integrated System Design, besides of these, several models are used in respect to the following aspects: Functional, capability, availability, operational cost, capital cost, life cost and integrated trade-offs.

A more detailed explanation about cost-effectiveness criteria and methodology is given in chapter VII.

Figure 4.8.a shows interactions between partial designs and specific models to have an integrated system design

Figure 4.8.b shows how the project organization is for managing four different design levels whole system , macro system, subsystem and system integration levels

FIGURE 4.8.a

FRAMEWORK FOR INTEGRATED REFINERY DESIGN THROUGH A COST EFFECTIVENESS ANALYSIS

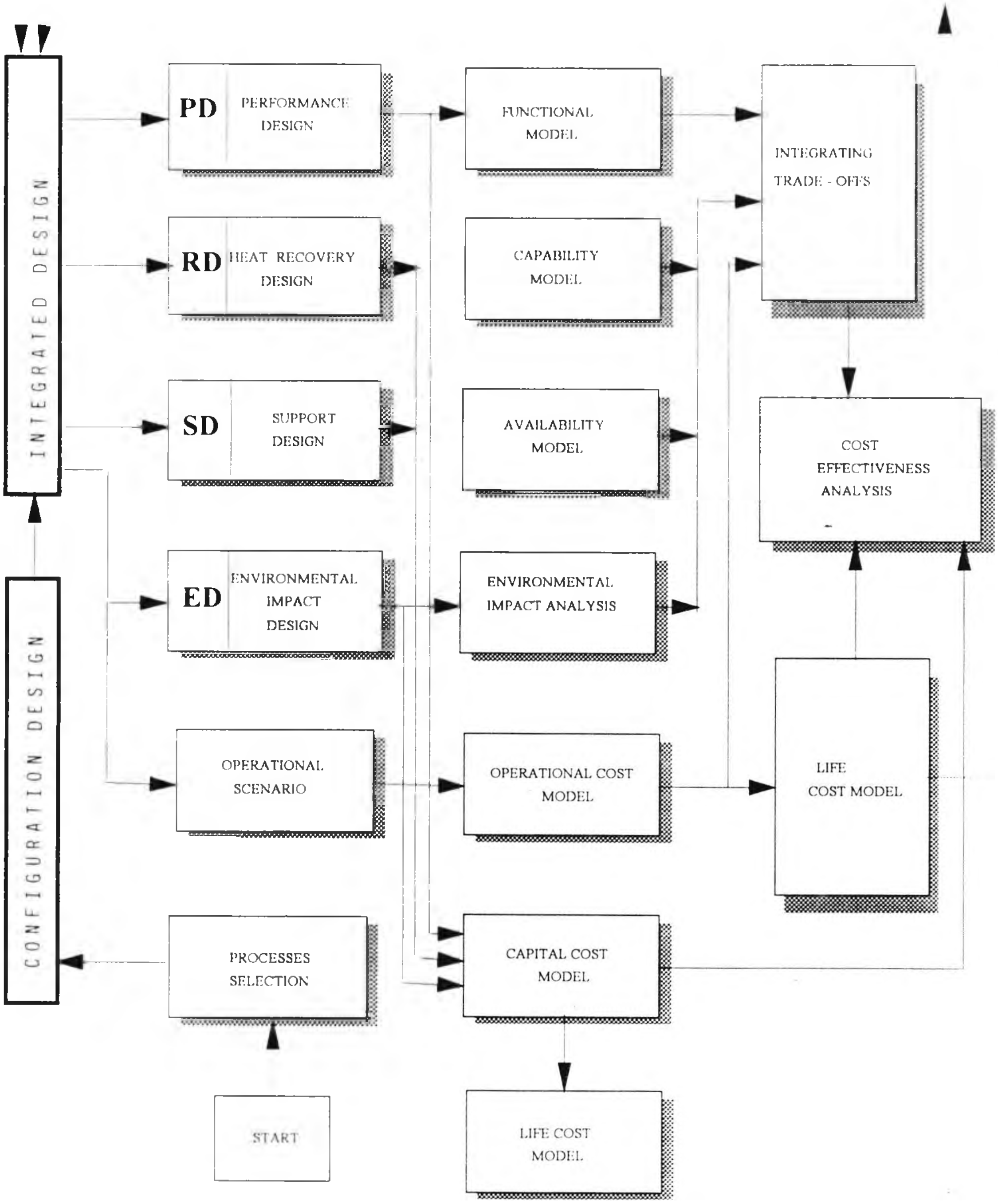
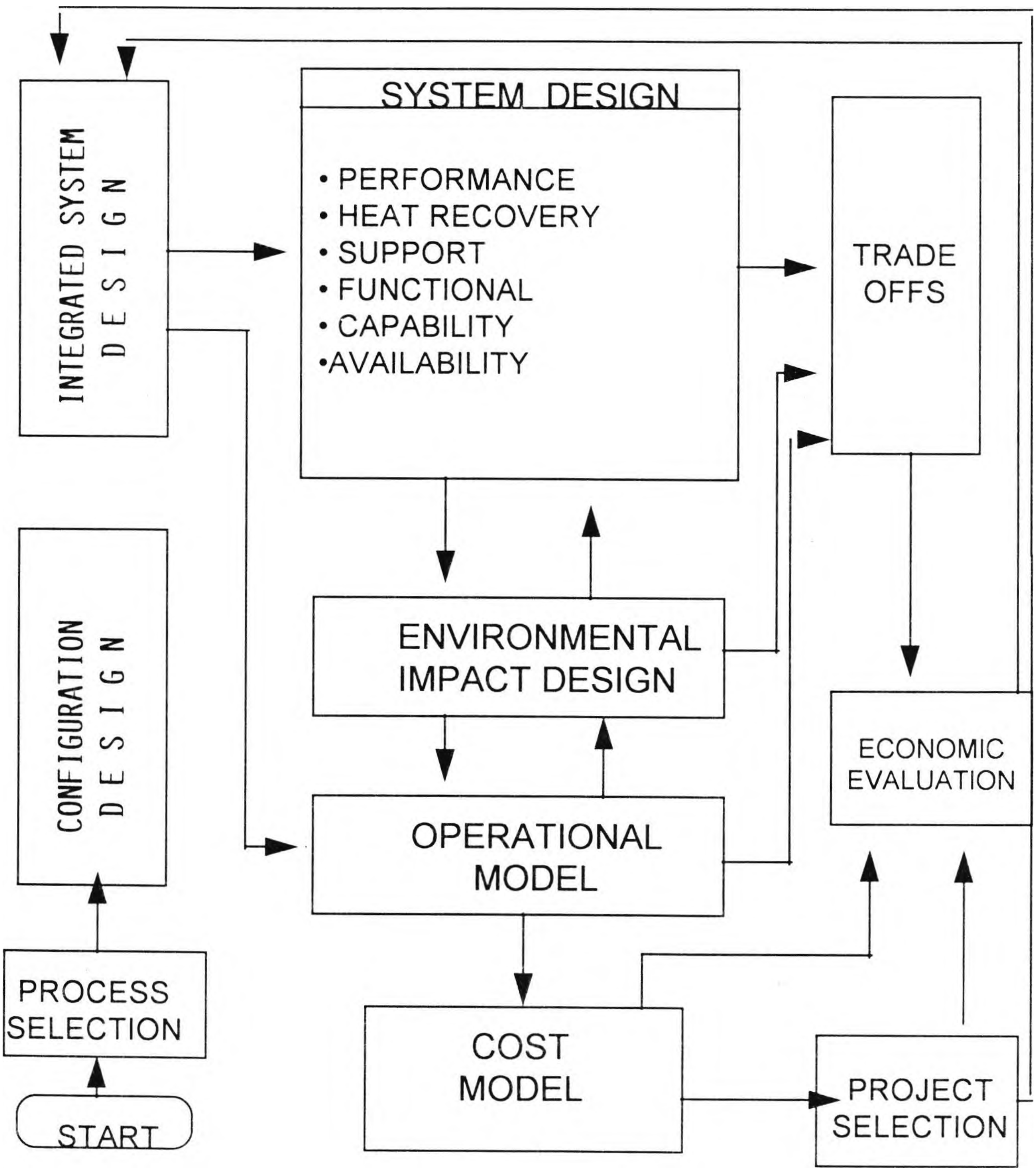


FIGURE 4.8. b

PROJECT ORGANIZATION



5.0.0 REDESIGNING AN EXISTING REFINERY TO IMPROVE ITS ENERGY USAGE PRODUCTIVITY

5.1.0 ANALYSIS OF THE WHOLE SYSTEM

System definition should be of both substantive and methodological significance. When we raise our consideration of systems to a sufficient level of abstraction, real differences among subjects sorted into traditional disciplinary classification schemes often tend to disappear.

System definition is so deeply affected by narrowness of application that any attempt of generalization is frustrated. Therefore it is necessary to have a whole vision on the problem to be solved before trying to define the system boundaries. There are three major applications for System Analysis

a) Problem solving
b) Policy setting
c) Decision making

The general problem-solving is going to be based on the "Prescriptive Model-Building Process". This process demands us to develop a descriptive-predictive model of the problem to be solved to serve as reference for the design of the system to solve it.

The appropiate techniques for the analysis and design of complex systems are collected the system architecture platform. To introduce its attributes, we shall consider the tactical aspects of large-scale system analysis and design projects.

System architecture is the prescriptive model-building process aimed at solving essentially mechanical or deterministic problems. Thus, prescriptive models help to structure a solution to a problem which is itself defined as a system. There are no lack of paradigms purporting to set out the procedural conditions for problem solving. 1

1_/ Sutherland J.W. " Systems. Analysis, Administration And Architecture. " pp 185-197 . Reference 23

When we consider that the proper problem-definition model will project conditions to support the point where we intend to take action and that a problem-solving system will have to be responsive to these projections, then a problem-solving paradigm becomes necessary to carry out the several tasks in this process:

a) Goal clarification
b) Trend description
c) Analysis of conditions
d) Projections of developments
e) Invention, evaluation and selection of alternatives

These tasks together conform the problem solution method. The first step is the isolation of the major structural factors that are expected to be the principal determinants to the problem; the second step is the reduction of the major problem determinants to causal sequences; the third step in the construction of a problem definition model, is a synthesis in order to come to a basic structural description of the problem through a system approach.

In order to analyze the redesigning of an existing refinery in term of improving its energy usage productivity, the whole system is defined as the conjunction of three main subsystems:

a) Processing plants
b) Power station, boilers and facilities
c) Instrumentation, control and information systems

5.2.0 ANALYSIS OF PARTIAL SYSTEMS

5.2.1 SUBSYSTEM OF PROCESSING PLANTS

A typical refinery has this set of processes: atmospheric distillation, vacuum distillation, catalytic cracking, catalytic reforming, hydrocracking, hydrorefining and hydrotreating

In 1989, the distribution of these processes in respect to the capacity of oil in the average refinery of the United States of the total oil capacity, was: thermal operations 12%, catalytic cracking 34.7 %, catalytic reforming 23.9%, hydrocracking and hydrorefining 7.6% and 1.7%, respectively and hydrotreating 44.3%. 1_/

Table 5.2.a

REFINERY PROCESSES GROWING IN USA
1 9 8 9 2_/

• CRUDE REFINING	0.9%
• FCC	2.0%
• CATALYTIC HYDROCRACKING	4.1%
• ALKYLATION	1.4%
• AROMATICS-ISOMERIZATION	1.2%
• HYDROTREATING	2.2%
• CATALYTIC NAPHTHA REFORMING AND NAPHTHA DESULFURIZATION	2.8%
• DISTILLATE HYDROTREATING	17.9%
• HYDROTREATING OF OTHER DISTILLATE	14.2%
• RESIDUE AND HEAVY GAS OIL HYDROREFINING	2.0%
• NUMBER OF REFINERIES	2.0%

In 1991, processes in the refineries which were being built were: 32.5% catalytic cracking, 23.9% catalytic reforming, 7.7% hydrocracking, 34.4 hydrorefining, 6.5% alkylation and 3.5% coking. 3_/

Three years later, in 1994, the situation has changed, so processes in new refineries which are being built are as follows. 4

1_/ International Petroleum Encyclopedia 1989, pp 355 . Reference 69.

2_/ International Petroleum Encyclopedia 1989, pp , Reference 69

3_/ International Petroleum Encyclopedia 1991, pp 328. Reference 71

4_/ International Petroleum Encyclopedia 1994, pp 281 , Reference 74

Processes in operating refineries in USA at January 1, 1994 were distributed; catalytic cracking 34.5%, catalytic reforming 24.1%. 1_/

It can be seen, through these figures, how the refinery's configuration is changing. Current and future subprocess mixes depend on policies adopted by each enterprise. Although it is clear how most refineries progress toward new technologies in order to improve their performance and energy efficiency and minimize waste.

A product demand determines the need of a specific subprocesses mix. For example, an increasing demand for low-sulphur fuels will result in increased use of hydrocracking and hydrotreating.

So, after the definition of the proposed subprocesses, the designer should evaluate the convenience of those mixes by means of the preparation of an industry profile related to the combination of processes and subprocesses. For this task three different levels of technology and three ranges of refinery size are advisable.

The technological level is important from the point of view of energy usage, performance and pollution, because it defines the production process, the energy productivity and the environmental pollution level.

Energy usage depends on refinery design and operation. Both of them are important and closely connected to technological and economic aspects. For forecasting future refining, the starting point is the current process mix.

This research tries to analyze the most relevant technological factors which determine the energy usage productivity in the petroleum industry, through reviewing the main processes to identify those which are the most determinant from the point of view of energy consumption and cost-effectiveness.

The processing capacity in Mexican refineries, in barrels per day, for the whole refinery system as for the Salina Cruz Refinery, is as follows:

1_/ International Petroleum Encyclopedia 1994. pp 281. Reference 74

FIGURE 5.2.b

PROCESSING CAPACITY OF THE MEXICAN REFINERIES

BL/CD

DATE	CRUDE CAPACITY	CATALYTIC CRACKING	CATALYTIC REFORMING
THE WHOLE SYSTEM			
JAN 1,1990 1_/	1,514,000	267,000	158,800
		17.6%	10.4%
JAN 1,1994 2/	1,524,000	243,000	170,800
		15.9%	11.2%
SALINA CRUZ REFINERY			
JAN 1, 1990 3_/	165,000	40,000	20,000
		24.2%	12.9%
JAN 1,1994 4_/	330,000	80,000	50,000

BL/CD =barrel per calendar day

5.2.2 SUBSYSTEM POWER STATION, BOILERS AND FACILITIES

This subsystem is now structured by five boilers and four turbines. From the point of view of energy usage productivity the analysis should be focused on having an evaluation of the structure of the system now, as well as in the future, when several processing plants are added to the refinery.

Another point for analysis is the operating condition of the power station and the alternatives for modification or revamp of the power station according to the steam and power balance

1_/ International Petroleum Encyclopedia 1990.- Reference 70

2_/ International Petroleum Encyclopedia 1994. pp 270, 275 . Reference 74

3_/ Memoria de labores 1990. pp 157 . Reference 11

4_/ Memoria de labores 1993, table 59. pp 208. Reference 14

5.2.3 INSTRUMENTATION, CONTROL AND INFORMATION SYSTEMS

Instrumentation, control and information is a very important subsystem in the refinery because it determines the efficiency of energy usage. There are several levels of action.

a) Pneumatic or electronic instrumentation
b) Distributed control
c) Partial advanced control schemes
d) Whole advanced control system.
e) Real time control and optimization
f) Integrated data management

In general, Mexican refineries are in either of the first two levels, so there is a lot to do for improving their control systems.

From energy auditing it was concluded that a precise repair and maintenance strategy for the instrumentation of the Salina Cruz Refinery has been very poor. There is a programme for improving the maintenance of instrumentation and control in the refinery.

A higher level of control is achieved when an information system platform that combines the capabilities of both real time and relational data base to produce accurate, timely and consistent information for the refinery's managment is adopted. In this case there are three features: Data integration from a multiplicity of sources into a single relational database; effective real-time data and data processing. Benefits of this technological scheme are: Improved quality of products, increased market share, reduced product losses, better response to short term opportunities, improved yields and lower energy consumption.

5.3.0 DIAGNOSIS FORM AUDITING

Information derived from auditing of Mexican refineries and specifically of the Salina Cruz Refinery, are shown in sections 2.5.0, 2.6.0 and chapter 3. Main conclusions on energy auditing in the Salina Cruz Refinery are presented in section 3.6.0. Indexes for energy consumption, energy efficiency and energy intensity were also included in several analysis of these sections.

5.4.0 SOME ECONOMIC CONCEPTS APPLICABLE TO A PROJECT EVALUATION MODEL

INTRODUCTION.

An economic analysis for achieving a redesign of a refinery, optimizing its energy efficiency, was proposed as part of this research. The analysis included the following parts:

a) Operating cost determination
b) Energy cost and energy usage efficiency
c) Return on investment
d) Net present value

Diagram 5.4.a 1.attached to this chapter, shows the main ideas included in the preliminary scheme proposed for carrying out the economic analysis, at the beginning of the research. After some specialized papers on this matter were reviewed, various concepts of the original scheme for the research problem were changed and modified. 1_/

The following is a resume of the conclusions obtained on the economic project evaluation.

From energy balances and auditing, it was possible to identify many energy saving measures; most of which were related to operational improvement or corrective maintenance. In practically all cases it has been easy to relate each measure with its correspondent cost, but it has been hard to precise how much energy could be saved if each action were taken, because, in general, a saved energy amount is the result of the interaction between several measures.

It was concluded that improving the refinery's operation and maintenance should be the priority because the needed investments for these are non significant.

In contrast, a refinery's redesigning requires considering several integrated projects in order to change the refinery structure and improve its performance.

1_/ Diagrams 5.4.a.2, 5.4.a.3, 5.4.a.4 shows the detailed analysis proposed to get the energy saving programme

5.4.1 ECONOMIC PARAMETERS

Investment decisions are often based on such criteria as annual return on investment (**ROI**), payout time (**PT**), net present value (**NPV**) and internal rate of return (**IRR**). These parameters are analyzed in order to determine which are the best for measuring profitability of the projects in total design.

RETURN ON INVESTMENT (ROI)

The most elementary profitability parameter is the annual return on investment, that is defined generically as:

$$ROI = \frac{\text{ANNUAL RETURN}}{\text{INVESTMENT}} X100$$

The annual return may be the gross income, net pre-tax income, net after-tax income, cash flow or profit.

Investment may be the original total investment, depreciated book-value investment, life time average investment, fixed capital investment or equity investment. The investment usually includes working capital and may include capitalized expenses such as interest during construction

In this case, **ROI** will be expressed as the economic value of the saved energy at international prices divided by the needed investment to achieve such energy saving.

PAYOUT TIME (PT)

Payout time is the time needed to pay off the investment with the accumulated return, using average return to simplify the calculation.

$$PT = \frac{\text{INVESTMENT}}{\text{AVERAGE ANNUAL RETURN}}$$

NET PRESENT VALUE (NPV)

The above two criteria are not generally suitable for multi year ventures, because the time value of money is ignored. In this case there are several discounted criteria that can be applied:

The **NPV** (Net Present Value) is the sum of the discounted cash-flows, with the discounting to some present time at a specified rate. The **IRR** is the interest rate that makes the sum of the discounted annual cash flows equal to zero.

Maximizing these two criteria can lead to different choices when comparing different ventures The **NPV** is considered a better evaluation criterion.

PROFITABILITY PARAMETERS

When we have several optional projects it is necessary to choose the best term of profitability. Largest return, highest rate of return or the smallest investment are possible options. The problem is knowing which one is the best. Depending on the objective and factors such as risk or availability of money, any of the choices could be considered as preferable. The investment size, return and rate of return are all useful decision aids.

For mutually exclusive projects, profitability can be evaluated, taking into account each additional increment on investment. The smallest investment is considered as the base case. Then, the incremental analysis yields the incremental investment, return and rate of return. These concepts are not adequate when the time value of money must be considered. In such cases, the criteria can be extended to include the discounted cash flow.

NET ANNUAL CASH FLOW

Discounted criteria

The economic analysis is based on the accounting of all financing charges through the discount rate. This is equivalent to assuming that all capital requirements are equity financed The net annual cash-flow is

Net Annual Cash Flow	=	Yearly - Invest ment +	Annual Incomes +	Depre- ciation +	End of Life Items

This is an estimate of the projected cash movement for the venture, independent of management decisions on dividend schedules. The cash flows are converted to a common present point, by multiplying them by a discount factor $(1 + r)^{-n}$ where **r** is the discount rate generally selected as the cost of capital.

There are three parameters based on the concept of discounting:

NET PRESENT VALUE (NPV)

It is the cumulative sum of the discounted cash flows which corresponds to the total discounted net return, above and beyond the cost of capital and the recovery of the investment. The **NPV** represents a discounted return or profit, but is not a measure of profitability. The positive discounted cash-flows are first used to offset the negative investment flow until the investment is recovered.

NET RETURN RATE (NRR)

The net return rate is defined as:

$$NRR = \frac{NPV}{\left(\text{DISCOUNT INVESTMENT}\right)\left(\text{PROJECT LIFE}\right)} \times 100$$

By which the investment is discounted to the same point as the NPV. It is a normalized measure of the total discounted return over the life of the investment. However, it is desirable to divide by the number of cash-flow increments so that the **NRR** corresponds to the average discounted net return on investment. The cost of capital has already been taken care of by the discount rate in the **NPV** calculation so that the **NRR** is the true net return rate and provides a rate of return criterion that is consistent with the **NPV** as a measure of return.

NET PAYOUT TIME (NPT)

This parameter has been defined as the number of years it would take for the cumulative discounted to consider years when the cash flows have been discounts to a single time point. The **NPT** is useful in that it provides a relative measure of the early cash flow pattern associated with a venture

FIGURE 5.4.a 1

ECONOMIC EVALUATION MODEL
IMPROVING ENERGY EFFICIENCY OF AN EXISTING REFINERY

PART 1	**MODEL OBJECTIVE DEFINITION** • Main And Partial Objectives
PART 2	**ECONOMIC ANALYSIS OF REFINING ACTIVITY** • Oil Price Forecast Scenarios • Refining Profitability • Energy Efficiency Indexes
PART 3	**ECONOMIC EVALUATION OF PROJECTS** • Data Gathering • Investment • Life Time • Parameters Calculation • Constraints
PART 4	**PROGRAMME FORMULATION** • Priorization of Opportunities • Results, Constraints, Evaluation • Sequence Analysis • Available Budget • Programme Formulation

FIGURE 5.4.a 2

ECONOMIC PROJECT EVALUATION MODEL

IMPROVING ENERGY EFFICIENCY OF AN EXISTING REFINERY

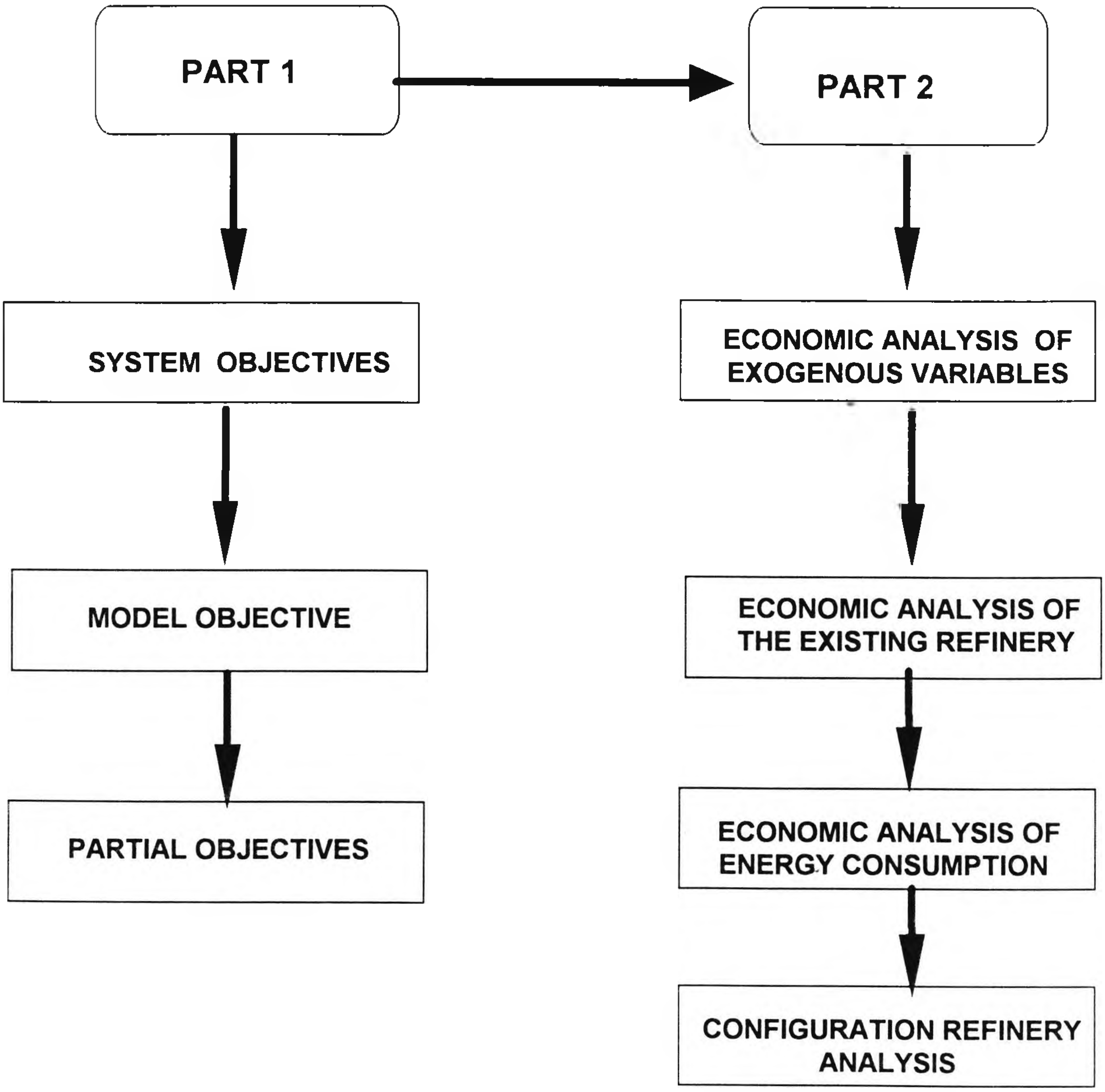


FIGURE 5.4.a.3

ECONOMIC PROJECT EVALUATION MODEL IMPROVING ENERGY EFFICIENCY OF AN EXISTING REFINERY

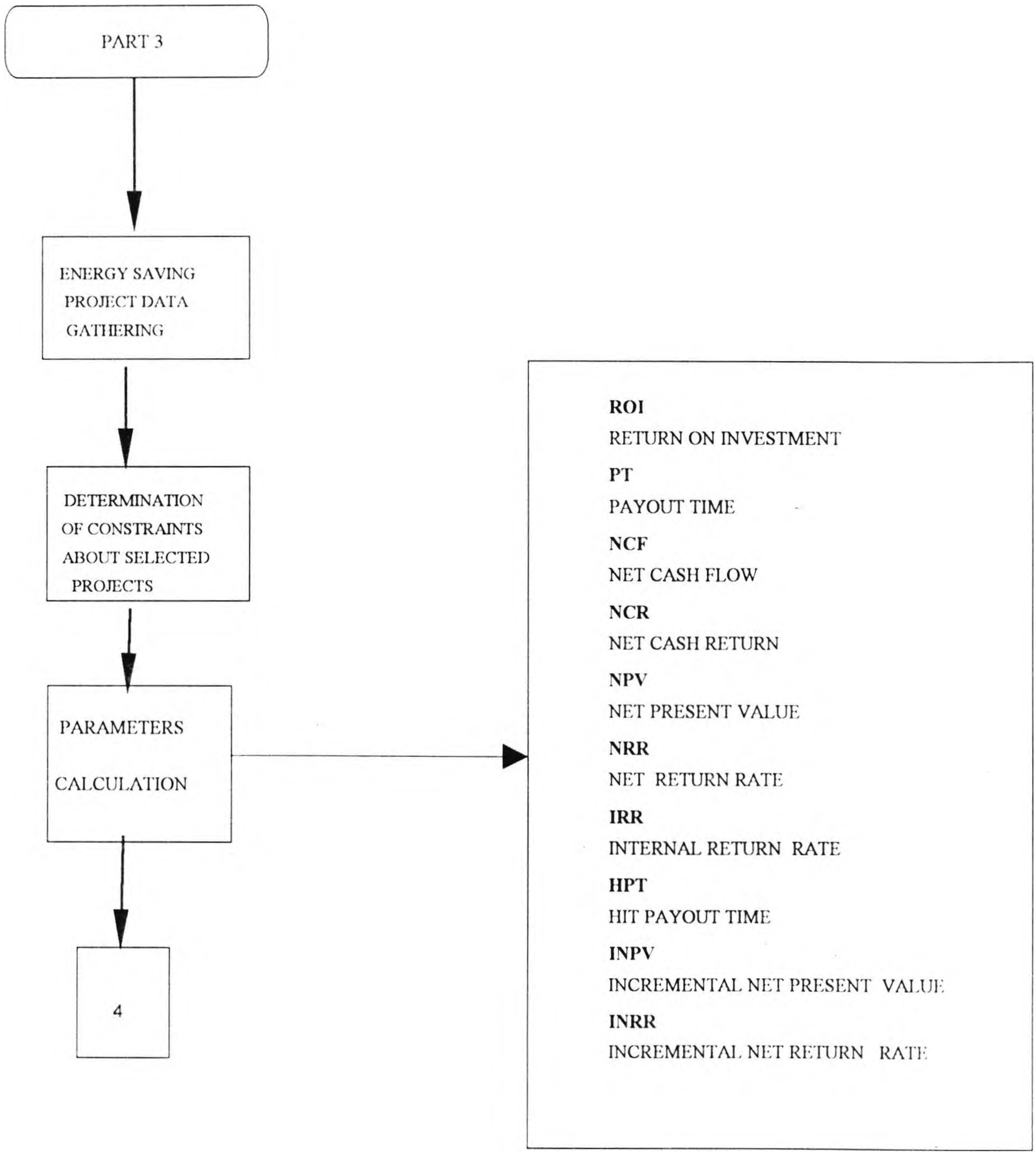
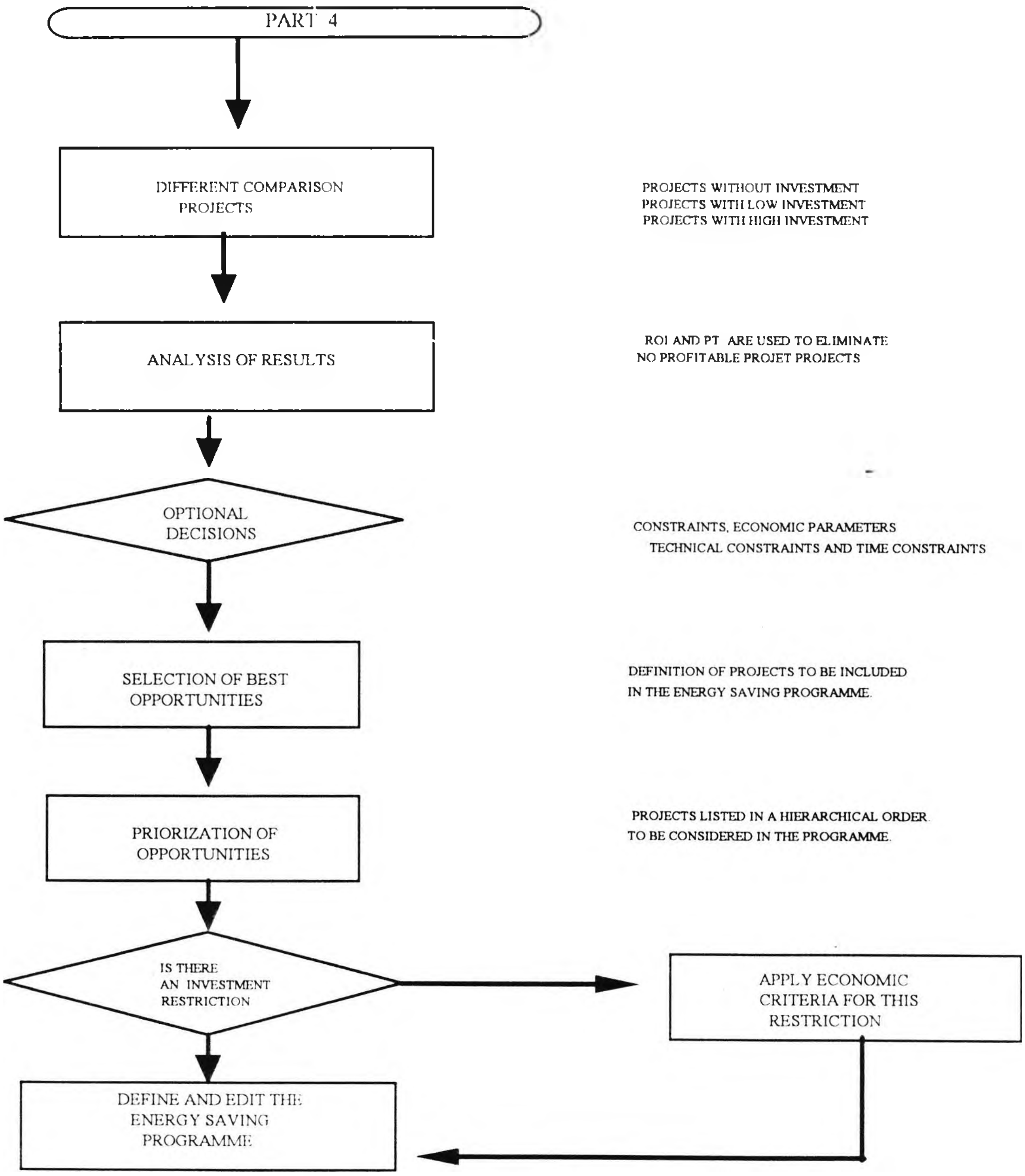


FIGURE 5.4.a.4

ECONOMIC PROJECT EVALUATION MODEL
IMPROVING ENERGY EFFICIENCY OF AN EXISTING REFINERY



5.5.0 IDENTIFICATION OF OPPORTUNITIES FOR SAVING ENERGY IN THE SALINA CRUZ REFINERY

Up to date some partial work in energy auditing has been done in the Salina Cruz Refinery.In spite of information from auditing is available, it is not enough to have a complete view of all the opportunities for saving energy. This is why information was integrated from four different sources.

1 Energy auditing of the refinery

2 Technical papers about energy saving

3 Proposed actions for other refineries applicable to this case

4 Specialized engineer's opinion

Unfortunately, not all the identified opportunities have the necessary information for their evaluation. Many of them are only preliminary ideas for saving energy, so it would be necessary to make technical and economic studies to reach conclusions on their feasibility.

But as this work is beyond the objective of such research, they were taken into account in the list of opportunities and their benefit and cost were roughly estimated with the idea of trying to analyze these attributes through the evaluation model.

In the next section the identified opportunities are listed and some information is added, when it contributes to a proper specification of the action to be taken: code, description, method, energy saved and cost.

This code allows us to classify each action, in accordance with the definitions given above; the description gives some information about the kind of action; the method tries to determine the main activities to be performed; the estimation of the saved energy and cost, makes it possible to evaluate the cost-benefit ratio for each action.

5.5.1 CODIFICATION OF ENERGY SAVING ACTIONS

To identify the different actions to be considered in the energy saving programme, it is convenient to codify the actions, taking into account four aspects:

a) Activity field code, for separating the actions corresponding to design, operation and maintenance. In general, the actions of these three groups are much different: design and redesign actions require considerably greater investments, time and work than the operation and maintenance ones.

b) Action code number, to identify each different action in each activity field. The key in this case is a sequential number for each activity field code.

c) Plant code, to identify where the action has to be performed. The processing plants codes are conventional keys according to the different units in the processing plants in the refinery.

d) Equipment code. This code is to identify which equipment in each plant is affected or modified by the action. In this case, conventional keys for each kind of equipment are defined.

So, the code for each action has four parts, as follows:

Activity Field Code	-	Action Code Number	-	Plant Code	-	Equipment Code

Following, the conventional keys for each part are listed

ACTIVITY FIELD CODE

D	Design or redesign
O	Operation
M	Maintenance

ACTION CODE NUMBER

It is a sequential number for each activity field. There is no a particular order to assign each consecutive number.

PROCESSING PLANT KEYS

P 01	Distillation unit
P 02	Vacuum distillation unit
P 03	Hydrodesulphurizing naphtha unit
P 04	Naphtha reforming unit
P 05	Hydrocarbon treating
P 06	Intermediate distillation products hydrodesulphur-rating unit
P 07	Catalytic cracking unit
P 08	Sulphur recovery unit
P 09	Boilers
P 10	Facilities area
P 11	Effluents treatment
P 12	Cooling towers
P 13	Product movement area
P 14	Turbogenerators
P 15	Whole refinery

EQUIPMENT CODE

1 Boilers
2 Furnaces or heaters
3 Engines
4 Pumps
5 Air or water coolers
6 Heat exchangers
7 Cooling towers
8 Turbogenerators
9 Heat recovery systems
10 All equipment

CODE EXAMPLES

Action: Air preheating of the charge to hydrodesulphurizing naphtha unit
CODE : D- 01 - P 03 - E 09

5.6.0 LIST OF OPPORTUNITIES FOR SAVING ENERGY IN SALINA CRUZ REFINERY

5.6.1 PHASE 1 OPERATIONAL ADJUSTMENTS

SPECIFIC ACTION: To improve the combustion control in boilers and direct fired heaters. 1_/
CODE: O - 01 - P 15 - E O2

SPECIFIC ACTION: To reduce the amount of gas to burners
CODE: O - 02 - P 15 - E 00

SPECIFIC ACTION: To reduce reprocessing
CODE : O - 03 - P 15 - E 00

SPECIFIC ACTION: To increase condensate recovery
CODE : O - O4 - P15 - E 00

SPECIFIC ACTION: To improve the operational conditions of pumps
CODE : O - 05 - P 15 - E 04

SPECIFIC ACTION: To improve the operational condition of engines
CODE: O - 06 - P 15 - E 03

SPECIFIC ACTION: To improve the operational condition of turbines
CODE : O - 07 - P 15 - E 08

1_/ "Bases y guias generales para el desarrollo del programa de conservacion y ahorro de energia" . appendix B. pp. 1-12. Reference 81

SPECIFIC ACTION: To verify the amount of water used in toilettes and to adjust the water supply to use the required volume.
CODE : O - 08 - P 10 - E 00

SPECIFIC ACTION: To reduce to the minimum possible level the hot water temperature.
CODE : O - 09 - P 10 - E 00

SPECIFIC ACTION: To turn off the hot water distribution system when offices are closed (not applicable to Salina Cruz Refinery)
CODE : O - 10 - P 10 - E 00

SPECIFIC ACTION: To verify the suitable performance of the control system in order to compress the air at the minimum pressure required.
CODE: 0 - 11 - P 10 - E 00

SPECIFIC ACTION: To avoid the use of compressed air systems for applications other than the predetermined ones.
CODE: O - 12 - P 10 - E 00

SPECIFIC ACTION: To reduce in some degrees of the heating level in working areas where heating system are used
CODE: O - 13 - P 10 - E 00

SPECIFIC ACTION: To increase in some degrees of the cooling level in working areas where air conditioning systems are used
CODE : O - 14 - P 10 - E 00

SPECIFIC ACTION: To shut off air conditioning and heating systems when the environment temperature is comfortable and when installations are closed.
CODE: O - 15 - P 10 - E 00

SPECIFIC ACTION: To shut off or to remove the air conditioning or heating systems in areas which really do not require environmental conditioning.
CODE : O - 16 - P 10 - E 00

5.6.2 PHASE 2 CORRECTIVE MAINTENANCE

GENERAL ACTION CORRECTIVE MAINTENANCE AND OPERATIONAL FITTING OF INTERNAL COMBUSTION ENGINES. THIS ACTION CONSISTS IN PERFORMING THE FOLLOWING FUNCTIONS IN ACCORDANCE WITH A PRE-ESTABLISHED PROGRAMME 1_/

SPECIFIC ACTION: To adjust air fuel ratio

CODE: M - 01 - P 10 - E 03

SPECIFIC ACTION: To adjust ignition time
CODE: M - 02 - P 10 - E 03

SPECIFIC ACTION: To adjust valve calibrations
CODE: M - 03 - P 10 - E 03

SPECIFIC ACTION: To adjust the BMEP at 56 to 59 PSI and a maximum piston speed of 960 feet per minute for low speed and two cycle engines
CODE: M - 04 - P 10 - E 03

SPECIFIC ACTION: To adjust the BMPED at 70 to 80 PSI and a maximum piston speed of 1200 feet per minute for high speed engines
CODE: M - 05 - P 10 - E 03

SPECIFIC ACTION: To adjust the fuel injectors
CODE : M - 06 - P 10- E 03

SPECIFIC ACTION: To periodically check the operation of the turbofeeder (at least once a week)
CODE: M - 07 - P 10 - E 03

SPECIFIC ACTION: To verify the proper balance of the power cylinders.
CODE : M - O8 - P 10 - E 03

1_/ "Bases y guias generales para el desarrollo del programa de conservacion y ahorro de energía". Appendix B. pp. 1-12., 8-11. Reference 81

GENERAL ACTION: CORRECTIVE MAINTENANCE AND OPERATIONAL FITTING OF ELECTRICAL ENGINES. 1_/

SPECIFIC ACTION: To balance the three-phase power supply
CODE: M - 09 - P 10 - E 03

SPECIFIC ACTION: To insure that the mechanical alignment between the engine and the equipment driven by it, is properly done.
CODE : M - 10 - P 10 - E 03

SPECIFIC ACTION: To insure that the specified input voltage is supplied and adjust it if it is lower or higher
CODE: M - 11 - P 10 - E 03

SPECIFIC ACTION: To regularly lubricate the engine and the transmission bearings
CODE: M - 12 - P 10 - E 03

SPECIFIC ACTION: To replace the worn bearings
CODE : M - 13 - P 10 - E 03

SPECIFIC ACTION: To verify if there is some overheated condition at the engine, that could be caused by an abnormal operational condition because of inadequate ventilation
CODE: M - 14- P 10 - E 03

SPECIFIC ACTION: To check if there is excessive noise or vibration, to determine the cause and correct the fault.
CODE: M - 15 - P 10 - E 03

SPECIFIC ACTION: To inspect the bearings and the driven belts making the necessary adjustments or replacements when they are needed
CODE : M - 16 - P 10 - E 03

1_/ "Bases y guias generales para el desarrollo del programa de conservacion y ahorro de energia" . Appendix B. pp. 6,7. Reference 81

SPECIFIC ACTION: To maintain the engines clean
CODE : M - 17 - P 10 - E O3

GENERAL ACTION: CORRECTIVE MAINTENANCE AND OPERATIONAL FITTING OF PUMPS 1_/

SPECIFIC ACTION: To perform preventive maintenance according to a pre-established programme
CODE: M - 18 - P 10 - E O4

SPECIFIC ACTION: To determine the actual pump efficiency
CODE: M - 19 - P 10 - E 04

SPECIFIC ACTION: To fit the pump capacity to the pumping the required volumes.
CODE: M - 20 - P 10 - E O4

SPECIFIC ACTION: To avoid unnecessary steps at multistage centrifugal pumps, when no high pressure requirements are present
CODE: M - 21 - P 10 - E 04

GENERAL ACTION: CORRECTIVE MAINTENANCE AND OPERATIONAL FITTING OF BOILERS 1_/

SPECIFIC ACTION: To carry out registers of temperature, pressure, amount of steam produced and water and fuel consumption.
CODE: M - 22 - P 09 - E O1

SPECIFIC ACTION: To generate the steam at the minimum pressure and temperature required.
CODE: M - 23 - P 09 - E 01

1_/ "Bases y guias generales para el desarrollo del programa de conservación y ahorro de energia". Appendix B pp. 8. Reference 81

SPECIFIC ACTION: To detect and eliminate the existing water, steam and fuel leaks in piping and valves.
CODE: M - 24 - P 09 - E O1

SPECIFIC ACTION: To check and to repair, if necessary, the boiler's and steam piping's insulation.
CODE: M - 25 - P 09 - E 01

SPECIFIC ACTION: To verify the burners' condition and its proper functioning
CODE: M - 26 - P 09 - E 01

SPECIFIC ACTION: To verify that cleaning inside boilers is executed under a pre established program and to perform all the repairs required in order to get the maximum heat transference
CODE: M - 27 - P 09 - E 01

SPECIFIC ACTION: To verify the appropriate operation of the boilers' combustion air blowers and to perform the required adjustments
CODE: M - 28 - P 09 - E O1

SPECIFIC ACTION: To check the appropriate operation of the set of test instruments and of the automatic control systems in the boilers section and to emphasize on the fuel feeding control. To perform all the repairs required
CODE: M - 29 - P 09 - E 01

SPECIFIC ACTION: To perform a combustion gas analysis to determine the excess of air and to adjust if necessary
CODE : M - 30 - P 09 - E 01

SPECIFIC ACTION: To verify that the fuel filters are in good condition and to replace them if required
CODE: M - 31 - P 09 - E 01

SPECIFIC ACTION: To check the proper functioning of the fuel and water preheating equipment and to perform either adjustments or repairs, as the case may be.
CODE: M - 32 - P 09 - E 01

GENERAL ACTION: CORRECTIVE MAINTENANCE OF HOT AND COLD WATER DISTRIBUTION SYSTEMS 1_/

SPECIFIC ACTION: To check the appropriate operation of the water meter and to adjust it, if necessary

CODE: M - 33 - P 10 - E 00

SPECIFIC ACTION: To detect leaks in valves and piping, and to repair them.

CODE : M - 34 - P 10 - E 00

SPECIFIC ACTION: To check the hot water pipes insulation and to repair them, if necessary

CODE : M - 35 - P 10 - E 00

SPECIFIC ACTION: To verify that heat exchangers cleaning programs are carried out

CODE : M - 36 - P 10 - E 06

5.6.3 PHASE 3 REDESIGN THE REFINERY TO IMPROVE ENERGY USAGE EFFICIENCY

GENERAL ACTION: PROCESS OR EQUIPMENT MODIFICATIONS OF INTERNAL COMBUSTION ENGINES 1_/

SPECIFIC ACTION: To use chimney gas analyzers in order to have an optimum fuel consumption and longer time between maintenance actions

CODE: D - 01 - P 15 - E 01

CODE: D - 02 - P 15 - E 02

SPECIFIC ACTION: To use electronic analyzers to verify the optimum operation of the internal combustion engines.

CODE : D -03 - P 15 - E O3

1_/ "Bases y guias generales para el desarrollo del programa de conservación y ahorro de energia". Appendix B pp.7 10, Reference 81

SPECIFIC ACTION: According to the load required, use the proper engine. avoid using engines with higher power than required. Adjust the design figures when necessary.
CODE: D - 04 - P 15 - E 03

SPECIFIC ACTION: To condition the engine capacity to load in order to improve the power factor and its efficiency.
CODE: D - 05 - P 15 - E 03

SPECIFIC ACTION: To install electrical engines with multiple or variable speed for use with variable load in blowers, pumps and compressors.
CODE: D - 06 - P 15 - E03

SPECIFIC ACTION: To select the electrical engines with enough capacity to work adequately under " Peak Conditions". Avoid the over dimension of the engine.
CODE: D- 07 - P 15 - E 03

SPECIFIC ACTION: To consider energy efficiency as an important factor for new engines and to analyze the old engines replacement by new ones in order to have a higher power factor.
CODE: D - 08 - P 15 - E 03

GENERAL ACTION: PROCESS OR EQUIPMENT MODIFICATIONS IN PUMPING SYSTEMS 1_/

SPECIFIC ACTION: To substitute the pump engine by electrical engines in systems handling constant volume of fluids with frequent pressure changes.
CODE: D - 09 - P 15 - E 03

SPECIFIC ACTION: To take advantage of the level difference in building new pumping systems so the gravity force can be used for transportation of fluids.
CODE: D - 10 - P 15 - E 04

1_/ "Bases y guias generales para el desarrollo del programa de conservación y ahorro de energia.". Appendix B. pp. 13,17,18,21,22.. Reference 81

SPECIFIC ACTION: Relocate the pumps not meeting the design parameters due to operational condition changes.
CODE: D - 11 - P 15 - E 04

GENERAL ACTION: MODIFICATIONS IN BOILERS 1_/

SPECIFIC ACTION: To verify the appropiate operation of water treatment plant and to make the changes required to improve the quality of treated water; if possible.
CODE : D - 12 - P 10 - E 00

SPECIFIC ACTION: To determine the feasibility of installing supplementary insulation in the boiler´s body in order to reduce heat losses.
CODE: D - 13 - P 09 - E 01

SPECIFIC ACTION: To replace the obsolete burners with others of higher efficiency.
CODE: D - 14 - P 09 - E 01

SPECIFIC ACTION: To install an economizer in the boiler's chimney, in case it does not have one and if it is economically feasible .
CODE: D - 15 - P O9 - E 01

SPECIFIC ACTION: To replace old or in bad condition boilers with others of higher energy efficiency
CODE : D - 16 - P 09 - E 01

GENERAL ACTION: MODIFICATIONS IN HOT AND COLD WATER DISTRIBUTION SYSTEMS 1_/

SPECIFIC ACTION: To install water saving valves in toilets
CODE : D - 17 - P 10 - E 00

SPECIFIC ACTION: To install insulation in exposed hot water piping
CODE: D - 18 - P 10 - E 00

1_/ " Bases y guias generales para el desarrollo del programa de conservación y ahorro de energía. Appendix B.pp. 13,17,18,21,22,. Reference 81

GENERAL ACTION : PROCESS OR EQUIPMENT MODIFICATIONS OF AIR COMPRESSED SYSTEMS 1_/

SPECIFIC ACTION: To verify that the compressor capacity in use is adequate to the requirements. In case it is not, replace it avoiding higher capacity than needed.
CODE : D - 19 - P 10 - E 00

SPECIFIC ACTION: To install additional air storage tanks when a contingent demand occurs. Avoid installing high capacity compressors to meet this kind of requirement.
CODE: D - 20 - P 10 - E 00

SPECIFIC ACTION: To install additional control shut off valves on the air piping to prevent accidental air leaks.
CODE: D - 21 - P 10 - E 00

SPECIFIC ACTION: To install additional compressors when the air requirements are increased and to avoid replacing existing compressors with higher capacity equipment. This solution allows a sequential operation which saves energy.

GENERAL ACTION: OTHER MODIFICATIONS

SPECIFIC ACTION: To repair or to replace all damaged windows and doors and to seal doorframes and windowframes. To check the suitable performance of lock mechanism of doors and windows and to repair if necessary.
CODE: D - 22 - P 15 - E 00

SPECIFIC ACTION: To install " Automatic Close Doors" in sites where air conditioning or heating is used in order to prevent energy leaks

SPECIFIC ACTION: To verify the suitable performance of all system thermostats and temperature controls and to repair or replace if necessary.
CODE: D- 24 - P 15 - E 00

1_/ "Bases y guias generales para el desarrollo del programa de conservacion y ahorro de energia   Appendix B. pp. 13,17,18,21,22,.   Reference 81

SPECIFIC ACTION: To check the space between ceiling and roof to verify the absence of energy leaks at electrical and hydraulics installations and repair if necessary.
CODE : D - 25 - P 15 - E 00

SPECIFIC ACTION: To plant trees, climbing plants, in front of windows directly exposed to sun to isolate them from overheat.
CODE : D - 26 - P 15 - E 00

SPECIFIC ACTION: To relocate areas with continuous air conditioning requirements to make them independent from the areas with non continuous air conditioning needs. This measure avoids using air conditioning in installations where not needed.
CODE : D - 27 - P 15 - E 00

SPECIFIC ACTION: To make the power supply used for fan system independent from that used for air conditioning, in order to shut off each area when not required.
CODE : D - 28 - P 15 - E 00

5.7.0 SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY

5.7.1 DECISION TREE DIAGRAM

When a new design has to be made , it is possible to use old designs for many parts of a macro project or to try to innovate all the process through new ideas or technologies. Using old design doesn´t improve the known performance of the system and new technologies can improve it but also it can be no successful, so they can have high risk.

The combination of the best alternatives in an exisiting refinery or in a new one depends on the economic aspect, the capital availability and the risk that the top level wants to take. Figure 5.7.a shows how old designs and new ones affect the levels of performance and risk.

In a refinery this difference is not so dramatic, so the selection of new projects is determined more by the demand requirements and the technology evolution. Risk levels are not very high

5.7.2 PREVIOUS EFFORTS FOR ENERGY SAVING IN THE REFINERY

Many efforts have been made to accomplish an energy saving program in the Salina Cruz Refinery. A lot of measures have been proposed and many brain storm meetings carried in the refinery out to take the worker's opinions into account. Also, several areas have developed different studies to integrate the measures with more potential saving energy into the program. Nevertheless, the results have been poor.

In order to organize the information related to the mentioned efforts, a resume was made with some of the measures which after analysis, were found not to be interesting enough as to be considered for further evaluation.

In fact, there are two main structured efforts to study energy usage in the petroleum industry. The first was developed by the Instituto Mexicano del Petroleo, which is a technological institution working for the Mexican Petroleum Industry. This company has developed more than 20 studies on different problems of energy usage. Half of them have enough information about a general scope of this field to understand where the main problems are. Specifically for the Salina Cruz Refinery there are different studies which could be partially used for our purpose.

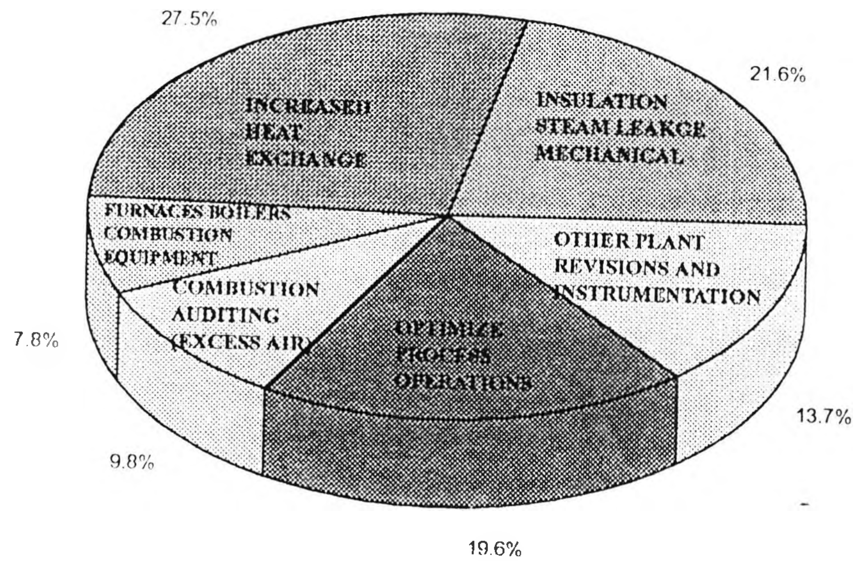
a) Instituto Mexicano del Petroleo"
b) External consultants"
c) Pemex's engineers and workers"
d) Technical literature"

To evaluate the proposed measures it was necessary to analyze them from the following point of view

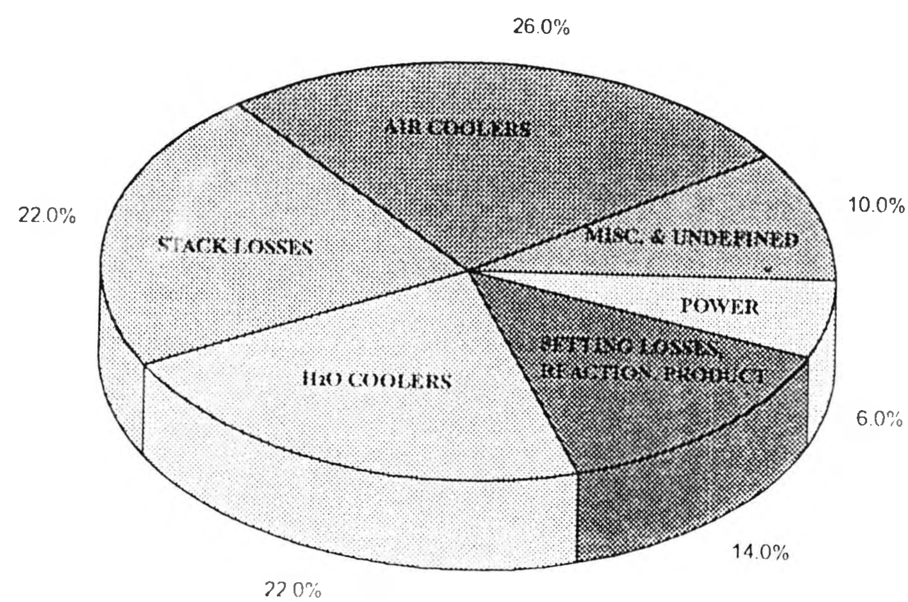
1. Technical feasibility
2. Economic feasibility
    2.1 Non cost

Diagram 5.7.2

Experience of other refineries 1_/



Conservation according to type



Refinery fuel balance

1_/ Grace E.C., III Fidoe, " U.S., refineries conserve energy " Reference 35

2.2 Low investment
2.3 Middle investment
3. Interaction

1. MEASURES PROPOSED BY **INSTITUTO MEXICANO DEL PETROLEO**

In order to have a better understanding , the **IMP** analyzed in 1988 the usage of energy in the Salina Cruz Refinery. Its main objective was to identify the opportunities for saving energy:

a) How to improve energy usage productivity through a better operation. In this case, the aim is to reduce the difference between the actual operational consumption and the design consumption. As starting point the consumption pattern provided by the engineering supplier was taken into consideration.

b) How to improve energy usage productivity through modifications of the processing plant. As mentioned above, in comparison with the design consumption, actual operational consumption was of 64 430 MMBTU/D instead of 56 028. That means that the refinery consumed 13% more than the expected consumption, according to the design data.

According to the **IMP**, the implementation of the measures proposed for the Salina Cruz Refinery, may have the following savings, shown in table 5.7.b, expressed as barrels of equivalent crude oil.

Table 5.7.b ENERGY SAVINGS
THROUGH PROPOSED MEASURES BY IMP 1_/ 2_/

	POTENTIAL ENERGY MBCE/YR	INVESTMENT MM DOLLARS
ATM. AND VACUUM DIST.	150	2.6
REFORMING	127	0.8
MIDDLE DIST. HYDRO	18	
CATALYTIC CRACKING	120	1.0
FACILITIES	130	0.7
HEATERS AND BOILERS	200	1.0
TOTAL = 2.2 MBCE/d	745	6.1

1_/ IMP Instituto Mexicano Del Petróleo
2_/ Data from different studies which identify energy saving opportunities

The refinery charge in 1988 was of 165 MBD, and the total effect of this programme would be 3% in energy saving if an investment of 6.1 million dollars would have taken place. Although, as the measures were not applied the consumption indexes did not improve.

IMP's proposals seemed too optimistic, since the investment would be recovered in less than a year. Other analysis showed higher investment and lower savings for the same projects, so the **ROI's** in this case seems overly optimistic.

2. MEASURES PROPOSED BY OTHER EXTERNAL CONSULTANTS 1_/

According to several studies there are three kinds of measures:

a) Without investment
b) Insignificant investment
c) Middle investment

2A. PROPOSED ACTIONS TO SAVE ENERGY WITHOUT INVESTMENT

- Compensation of gas turbine power
- Export power
- Adjustment of a boiler mode of operation
- Increase the steam pressure at deaereators
- Load management

2B. NON INSIGNIFICANT INVESTMENT MEASURES

- Installation of automatic blow down devices
- Low pressure consumer
- Reconnecting the blow down vessel of boilers
- Increasing process coil surface in heaters

2C. MIDDLE INVESTMENT MEASURES

- Rehabilitation of gas turbine
- Modification of gas turbine for using refinery gas
- Installation of a waste heat boiler
- Instrumentation in the plant
- Substitution of direct air cooling instead of water cooling
- Air preheaters
- Pump change over
- Redesign the waste heat boiler FCC

Following in tables 5.7.c., 5.7.d and 5.7.e the above three kind of measures are shown:

1_/ These measures are included in technical analysis made by different consultants

Table 5.7.c

NON COST SAVINGS MODIFICATIONS 1_/

FUEL OIL SAVINGS TON/YR	ENERGY SAVING MMDLS/YR	MEASURE DESCRIPTION
32 964	5.87	COMPENSATION OF GT POWER (1A)
---	5.76	EXPORT POWER
18 190	1.64	ADJUSTMENT OF BOILER MODE OF OPERATION (II)
15 472	1.57	INCREASE THE STEAM PRESSURE AT DEAERATORS
	0.57	LOAD MANAGEMENT
66 626	15.41	TOTAL NON COST MODIFICATIONS

Table 5.7.d.

INSIGNIFICANT INVESTMENT MEASURES SAVINGS / INVESTMENTS 2_/

FUEL OIL SAVING TON/YR	ENERGY SAVING DLS/YR	INVESTMENT MM DLS	ROI	MEASURE DESCRIPTION
7 606	0.76	0.13	0.17	INSTALLATION OF AUTOMATIC BLOWDOWN DEVICES PROJECT 11
SUBJECT OF FURTHER DETAILED STUDY				LOW PRESSURE CONVERTIBILITY INCLUDED IN PROJECT 5
SUBJECT OF FURTHER DETAILED STUDY				RECONNECTING THE BLOWDOWN VESSELOF BOILERS INCLUDED IN PROJECT
				INCREASING PROCESS COIL IN HEATERS PROJECT 3
5 280	0.53	0.92		PC-1A
1 280	0.13	0.26		PC 1 V
960	0.09	0.46		PC 2 V
15126	1.51	1.77		

1_/ This is a resume of several non cost proposals taken from differrent studies and brain storms about energy saving.

2_/ This is a resume of the insignificant invstment measures taken from different studies.

Table 5.7.e MIDDLE INVESTMENT MEASURES 1_/

SAVINGS-INVESTMENT

SAVINGS FUEL OIL SAVING TON/YR	ENERGY SAVING MMDLS/ YR	INVESTMENT MMDLS	ROI	MEASURE DESCRIPTION
		6.53		REHABILITATION OF GAS TURBINE
75 864	18.98	6.40	1.7	MODIFICATION OF GT FOR USING REFINERY GAS WASTE HEAT
		15.92		BOILER
36 776	3.68	3.42	0.9	PUMP CHANGE OVER
				AIR PREHEATERS
21 680	2.17	6.38		XIV HEATER HH 01 A/B NO. 1 CRUDE UNIT
12 480	1.25	6.49		XV HEATER A -BA 1/2 NO. 2 CRUDE UNIT
7 520	0.75	4.39		XVI HEATER H - 201 A/B NO. 1 VACUUM UNIT
4 560	0.46	4.62		XVII HEATER V -BA 1/2 NO. 2 VACUUM UNIT
6 160	0.62	5.20		XVIII HEATER BA- 501 NO. 1 PLATFORMING
				AIR COOLERS
SUBJECT TO FURTHER DETAILED STUDY				1 C, EA 408 II, EA 402 I, EA 702 I, EA 802 I,
165 040		59.35		TOTAL MIDDLE INVESTMENT MEASURES

1_/ This is a resume of middle investment measures, according to different studies.

5.8.0 PROPOSED PROJECTS FOR REDESIGNING THE SALINA CRUZ REFINERY

The proposed projects for redesigning the Salina Cruz Refinery are:

oo Energy analysis of furnaces and boilers
Project 1

oo Air preheating to heaters
Project 2

oo Increasing area on preheating of charge by means of addition of process coil surface
Project 3

oo Rehabilitation of gas turbine and recovery of the heat contained in the exhaust gas flow
Project 4

oo Steam production and distribution optimization
Project 5

oo Redesigning heat transfer in a processing plant. Case naphta hydrodesulphurization unit
Project 6

oo Hydrocarbon gas recovery from blowdown
Project 7

oo Redesign atmospheric distillation and vacuum units for integrating a combined unit
Project 8

oo Dearator pressure modification
Project 9

oo Improving plant instrumentation
Project 10

oo Redesigning the waste heat boiler FCC unit
Project 11

oo Export of power
Project 12

oo Replacing water coolers by air coolers
Project 13

oo Load managment
Project 14

oo Methology application for determing the maximum potential of energy recovering

a) Exergia, project 5

b) Pinch technology, project 25

oo Installing software for energy usage control and management
Projects 16, 17, 18, 19, 20 and 21

a) Setpoint package for a power station project 16

b) EMS package, project 17

c) Utopia package, project 18.

d) Mod. edit optim and estim, project 19.

e) Pluto II. project 20

f) Kraftanlagen. project 21

oo Design and development of a washing machine for heat exchangers
Project 22

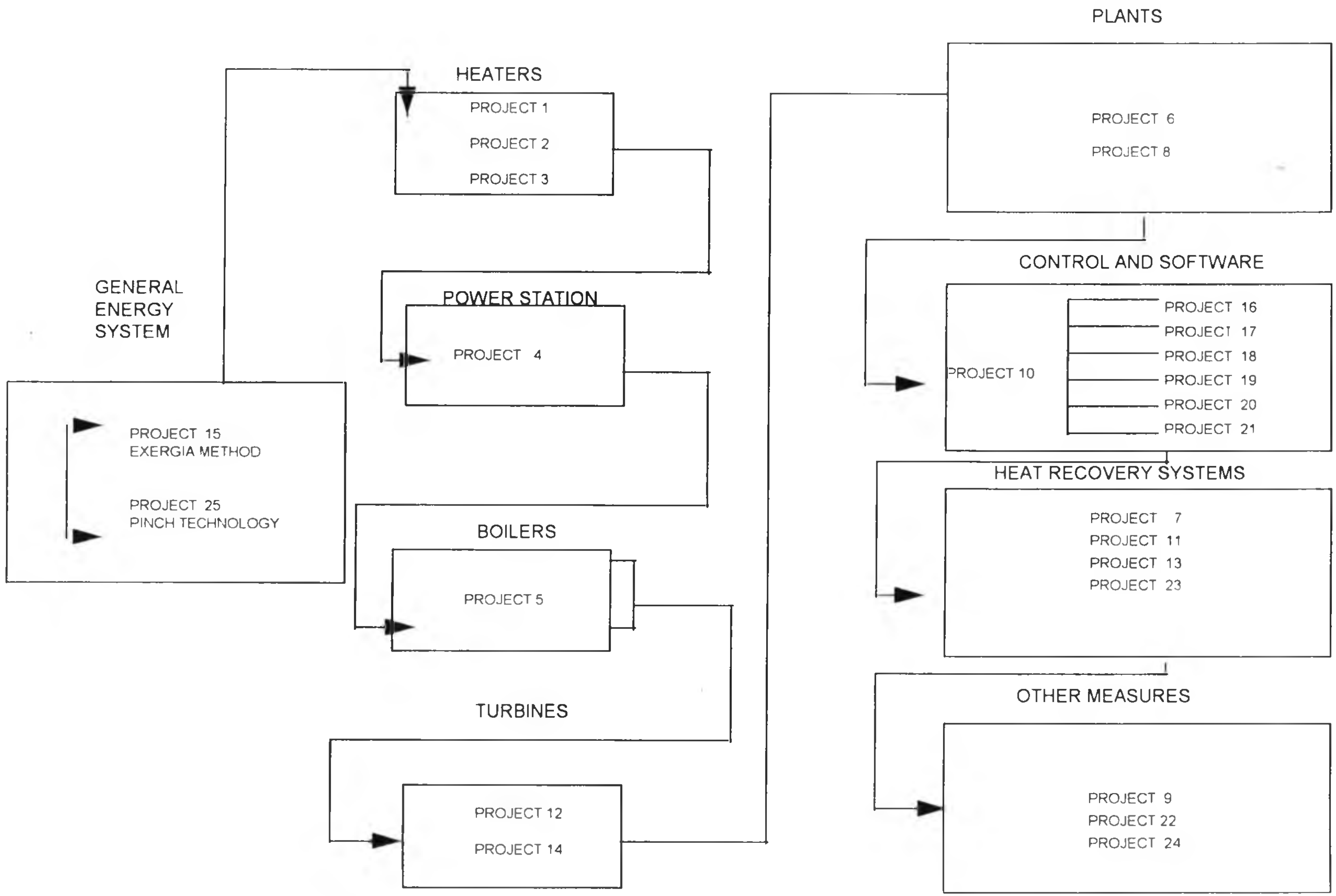
oo Addition of an energy economizer for recovering heat from the combustion gases
Project 23

oo Installation of continuous oxygen analyzers in heaters and boilers
Project 24

Most projects presented above are independent, but in some cases they are optional and mutually exclusive. A decision tree was built to make this situation clear and it is presented in figure 5.8.a.

Each project sometimes includes several measures that could be otpional or not. When the energy saving programme is formulated it is necessary to decide if measures is enough convenient to be included and which measure should be selected when there are several options to achieve an specific objective

FIGURE 5.8 a PROJECT DECISION TREE



SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY
PHASE 3 PART B
PROJECT 1

ENERGY ANALYSIS OF FURNACES AND BOILERS

This project includes the technical study for making several definitions respecting the following points: 1_/

a) Operational adjustments

b) Decision of using or not chimney gas analysis

c) Determining the feasibility of installing supplementary insulation

d) Thermograph inspection

e) Evaluation of thermal efficiency, insulation, leaks and burners

f) Determination of the convenience of installing a system for air combustion preheating or extending the charge preheating exchangers area.

Code : D 29 - P O1 - E 02	(No. 1 Crude distillation unit atmospheric crude heater)
Code : D 30 - P 02 - E 02	(No. 1 Vacuum unit reduced crude heater)
Code : D 31 - P O1 - E 02	(No. 2 Crude distillation unit atmospheric crude heater)
Code : D 32 - P 02 - E 02	(No. 2 Vacuum unit reduced crude heater)
Code : D 33 - P - E 02	(Debutanizer tower reboiler)
Code : D 34 - P 07 - E 02	(FCC. feed preheat furnace)
Code : D 35 - P 03 - E 02	(No. 1 Naphtha hydrodesulfurization unit reactor feed heater)
Code: D 36 - P 03 - E 02	(No. 1 Naphtha hydro unit deisohexanizer bottoms heater)

1_/ Reed D.R. "Recovery energy from stacks " Reference 29

Code: D 37 - P 04 - E 02 (No.1 Naphtha reforming platforming heater)

Code: D 38 - P 04 - E 02 (No. 1 Naphtha reforming debutanizer reboiler heater)

Code: D 39 - P 06 - E 02 (Hydrodesulfuration u 700 reactor feed heater)

Code: D 40 - P 06 - E 02 (Hydrodesulfuration u 800 reactor feed heater)

Code: D 41 - P O6 - E 02 (Hydrodesulfuration u 700 fractionator reboiler heater)

Code: D 42 - P 06 - E 02 (Hydrodesulfuration u 800 fractionator reboiler heater)

Code: D 43 - P 09 - E 01 (Boiler CB1)

Code: D 44 - P 09 - E 01 (Boiler CB2)

Code: D 45 - P 09 - E 01 (Boiler CB3)

Code: D 46 - P 09 - E 01 (Boiler CB4)

Code: D 47 - P 07 - E 01 (CO boiler)

INTRODUCTION :

Preliminary technical studies show that it is possible to save an important amount of energy by adjusting operational conditions and redesigning heaters and boilers. However, this possible energy saving depends on a first study devoted to review the heat balance and analyze energy losses. After that, it is necessary to design equipments to recover the lost energy and, once the study is concluded, the recommended modifications must be implmented after proving their economic advantage.

It is estimated that 15% of the whole energy consumed in heaters and boilers can be saved by operational adjustments and redesigning. Aside from such, a definition of a general strategy to reestablish a proper balance between the produced and consumed energy is required.

From the whole energy saving, 25% corresponds to operational adjustments and 75% to the refurbishment of several equipments to recover the waste heat. In this case, the study can be justified mainly because of the definition of a general strategy for improving energy usage and production efficiencies.

The following presents the potential saving, required investment and estimated ROI for the specific studies of each heater and boiler.

TABLE 5.8.b.

POTENTIAL ENERGY SAVING IN HEATERS

	WHOLE POTENTIAL ENERGY SAVING	ENERGY SAVINGS BY OPERATIONAL ADJUSTMENTS		INVESTMENT STUDY (M DLS)	ROI (MONTH)
	MM BTU/HR	MM BTU/HR	M DLS/YR		
D 29	128.8	25.7	589.5	17.20	< 1
D 30	44.7	8.9	206.6	5.97	< 1
D 31	74.2	14.8	343.5	9.90	< 1
D 32	26.8	5.3	123.0	3.56	< 1
D 33	5.4 +	1.3	30.2	0.90	< 1
D 34	intermittent				
D 35	25.1	5.0	116.0	3.33	< 1
D 36	4.6	1.1	25.5	0.77	< 1
D 37	36.7	7.3	169.4	4.87	< 1
D 38	2.3	0.8	18.6	0.53	< 1
D 39	5.5	1.3	30.2	0.90	< 1
D 40	5.2	1.3	30.2	0.87	< 1
D 41	5.5	1.3	30.2	0.90	< 1
D 42	5.2	1.3	30.2	0.87	< 1
D 43	49.7	12.4	287.8	8.27	< 1
D 44	49.7	12.4	287.8	8.27	< 1
D 45	49.7	12.4	287.8	8.27	< 1
D 46	49.7	12.4	287.8	8.27	< 1
D 47	55.4	13.8	320.3	9.13	< 1
TOTAL	898.7	193.5	3214.4	92.78	< 1

SPECIFIC PROJECT FOR REDESIGNING THE REFINERY
PHASE 3 PART B
PROJECT 2

AIR PREHEATING TO HEATERS

Code : D 48 - P 01 - E 02 (Distillation unit No. 1
Code : D 48 - P 01 - E 02 (Distillation unit No. 2)
Code : D 50 - P 02 - E 02 (Vacuum unit No. 1)
Code : D 51 - P 02 - E 02 (Vacuum unit No. 2)
Code : D 52 - P 07 - E 02 (Feed preheat furnace FCC)
Code : D 53 - P O4 - E 02 (Platforming heater)

According to energy auditing it is known that it is possible to save an important amount of energy installing air preheaters, taking advantage from heat contained in hot waste gases to atmosphere. This opportunity to save energy represents half of the total savings in furnaces and boilers.1_/

In the following, potential savings and required investments, necessary for calculation of estimated **ROI** are presented.

TABLE 5.8. c

CODE	POTENTIAL ENERGY SAVING RETURN AVERAGE	INVESTMENT (MM DLS)
D 48	2.393	- 6.38
D 49	0.831	4.39
D 50	1.379	6.49
D 51	0 499	4.62
D 52	0.466	4.50
D 53	0.682	5.20

1_/ Reed. R.D. Recover energy from furnace stacks. Reference 29

SPECIFIC PROJECT FOR REDESIGNING REFINERY PROCESS OR EQUIPMENT
PHASE 3 PART B
PROJECT 3

AREA INCREASING ON PREHEATING OF CHARGE

Code: D 54 - P 01 - E 00 (Distillation unit No. 1)
Code: D 55 - P 02 - E 00 (Vacuum No. 1)
Code: D 56 - P 02 - E 00 (Vacuum unit No. 2)

Charge to heaters can be preheated to have a higher temperature than the current one in the process. For this purpose, several heat exchangers are going to be added to increase heating interchanged. following next table presents, potential saving and required investment:

CODE	POTENTIAL ENERGY SAVING (RETURN AVERAGE)	INVESTMENT (MM DLS)
D 54	0.529	0.923
D 55	0.129	0.265
D 56	0.094	0.459

SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY PROCESS
PHASE 3 PART B
PROJECT 4

REHABILITATION OF THE GAS TURBINE AND RECOVERY OF THE HEAT CONTAINED IN THE EXHAUST GAS FLOW BY MEANS OF A WASTE HEAT REBOILER.

This is a combined project which includes several parts: 1_/

a) To shut off the existing gas turbine
Code : D57 - P 09 - E 08

b) To compensate the electric power produced from gas turbine with the steam turbines
Code : D58 - P 09 - E 08

1_/ Wilson W. B. and Kovacik J.M. "Electricity, generate or by" Reference 85.

c) To rehabilitate the gas turbine to improve its efficiency
Code: D59 - P 09 - E 08

d) To use refinery gas instead of turbosine once the gas turbine is rehabilitated
Code: D 60 - P 09 - E 08

e) To install a waste heat boiler to recover the heat contained in the exhausted gas flow
Code : D 61 - P 09 - E 08

INTRODUCTION

Electric power is produced in the refinery by four turbogenerators TG1, TG2, TG3 and TG6 with nominal rating of 32, 32, 40 and 40 MVA, respectively. Three of them are steam turbines and the last one is a gas turbine fueled with turbosine. according to the present demand the gas turbine power is not needed in the refinery. Meanwhile, the 8.2 MW electric power can be compensated by the three current steam turbines.

The relative cost of electricity generation when the turbine is fueled with turbosine or gas refinery is 0.12 or 0.02 Dls / kw.

Rehabilitation of the gas turbine to solve technical problems that do not permit taking advantage of achieving its maximal capacity. The turbine generation is of 11 MW compared with the design capacity that is 29.8 MW. Thus the turbine should be rehabilitated to generate full power. To make this change, installing a gas compressor and its linkage to the refinery gas distribution system is necessary.

Another recommended modification, once the gas turbine is rehabilitated, is the design and building of a waste heat boiler to recover the heat contained in the exhaust gas flow and generate 60 bar steam.

It is difficult to implement only part of the above measures, so the five should be considered together in a project. If it were necessary to advance by steps, it would be convenient:

1 To begin with the operational adjustment
2 To follow with the conversion from turbosine to the refinery gas
3 The turbine to rehabilitate
4 The finally implementation of the waste heat boiler

TECHNICAL DATA ABOUT TURBINES

TABLE 5.8.d.

	1990 MW	MAX. CAPACITY MW	1991 ACTUAL MW
TG1	18.2	25	17.3
TG2	16.4	25	18.3
TG3	3.1	25	3.7
TG4 FUTURE	0.0	32	0.0
TG6	3.5	30	8.2

Once the gas turbine is refurbished and converted to refinery gas, one 55 Ton/hr waste heat boiler is implemented to recover the heat contained in the exhaust gas flow.

PROJECT 4 ENERGY SAVING AND INVESTMENTS

TABLE 5.8. e

CODE	POTENTIAL ENERGY SAVING Ton/Yr	POTENTIAL ENERGY SAVING MM Dls/yr	INVESTMENT MM DLS	PT Yr
D57	--	---	---	--
D 58	32964	5.87	---	0.0
D 59 (1)			6.53	
D 60 (2)	75864	17.29	6.40	1.7
D 61 (3)			15.92	
D 59-61	75864	17.29	28.85	1.7

1) Investment covers the inspection, rehabilitation and engineering of the gas turbine

2) Investment covers the gas compressor and pipeline between compressor and the gas turbine, instrumentation and engineering

3) Investment covers the waste heat boiler, ductwork and pipeline, instrumentation, feedwater supply and engineering.

4) Wilson W. B. and Kovacik J.M " Electricity: Generate or buy". pp. 75-78. Reference 85

Savings evaluation

Total savings revenues=23.16 MM Dls/Yr
Required investment=28.85 MM Dls
Payout time=1.7 Yr

SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY PROCESS
PHASE 3 PART B
PROJECT 5

STEAM PRODUCTION AND DISTRIBUTION OPTIMIZATION

Steam and electricity generation are the main products of the power station of the refinery There are five boilers and four turbines. In operation. the boilers produced high pressure steam and are fired with 85% fuel and 15% refinery gas, besides, there is an economizer at the co boiler but it has been bypassed for a long time. There are plans to replace it by a new one.

So, the existing power station has four fired steam generators of 200 Ton/hr equipped with dual burners Besides, there is one co boiler of 180 Ton/hr capacity which contributes to steam generation. All boilers have common feed water headers.

In 1990 , turbines were in a discontinuous operation., average operation was as follows: Steam generation 593 Ton/hr, steam to turbine 429570/17 Ton/hr, steam extraction 396 Ton/hr, condensing part 103 Ton/hr and load to 60/19 bar reduction station 80 Ton/hr.

According to energy efficiency recommendations, boilers should be operated in a range of 165 to 170 Ton/yr steam output. The comparison between generation and maximum capacity of boilers was:

GENERATION AND MAXIMUM CAPACITY COMPARISON
TABLE 5.8.f

	1990 GENERATION TON/HR	MAX. CAPACITY TON/HR	LOAD %	1991 GENERATION TON/HR	LOAD %
CB1	97	150	65	113	75
CB2	121	200	61	114	57
CB3	114	200	57	83	41
CB4	107	200	54	130	65
CO	121	180	67	126	70

The average load in 1990 and 1992 was 59% and 62%, respectively. The system supplies steam to 2 turbo-sets per generation of internal electric power, turbine- driven drivers and the processing units of the refinery. The nominal ratings of existing and future turbogenerators are: TG1 and TG2 32 MVA; TG3, TG4 and TG6 40 MVA.

The power demand is on an average of between 44 and 49.5 MW. There are two voltage levels 13.8 KV at main distribution frame in the central power plant, and 480 V at refinery substations. These are located at various refinery sections where electric power consumption is high

PROJECT OBJECTIVE

This project has two main parts: 1_/

a) To define a strategy for using the steam now produced by boilers, with more efficiency.

b) To improve boiler efficiency to save energy

The measures included are going to be implemented as soon as the new processing plants are added to the refinery, so the steam demand increases.

The refinery has been extended into two steps:

1) Implementation of units 700-2 and 800-2 in the middle of 1991

2) Implementation of the visbreaker and FCC II, in 1993.

The amount of steam from the power station will be reduced by steam generation in several 19 bar waste steam boilers.

In 1991 and 1993 the steam demand was expected in the range of

---

1_/ Daneking. W.E. " Steam management in a refinery".pp. 71-74. Reference 80.

1991	1993	
55.4	89.7	Ton/hr at 60 bar steam pressure
550.7	647.7	Ton/hr at 19 bar
164.5	220.4	Ton / hr at 3.5 bar

The maximum steam capacity generation is 930 Ton /hr of 60 bar steam. Once the waste heat boiler in the new FCC section was installed, the steaming capacity is 970 ton /hr. so the recommended measures are:

a) To increase boiler efficiency to make it possible to have 30% more steam produced

b) To diminish the amount of steam, the pressure of which is reduced from 60 bar to 19 bar.

c) To take advantage of the refinery revamp to supply the steam needed from the same boilers, once these efficiency are improved

d) To diminish operational costs, the main measure is to set a proper balance between steam generation and power generation as the refinery revamp depends on the incorporation of new plants, the economic solution is related to these events and to the addition of waste heat boilers.

The economic advantage of the proposed measures can be evaluated from the following figures:

60 Bar steam production (Ton / hr)

	BOILERS	CO BOILER	TOTAL
YEAR 1	452.2	126.0	578.2
YEAR 2	566.6	141.6	708.2
YEAR 3	608.5	152.1	760.6

60 Bar steam uses (Ton / Hr)

	TURBO-GENERATORS	REDUCTION	PROCESSING PLANTS		TOTAL
YEAR 1	427	89.9	55.4	23.5	595.5
YEAR 2	600	23.6	55.4	29.2	708.2
YEAR 3	600	80.5	49.7	30.4	760.4

Steam and power balance are closely related, so the best solutions should be analyzed from the point of view of both services, taking into account their dynamic modification. Several statements should be considered:

1) Through operational adjustments the five boilers will improve their efficiency

2) This improvement will increase steam production capacity

3) Once the steam production is increased, one of the boilers can be kept in maintenance and provide hot stand by capacity.

4) FCC and visbreaking units were included in processing plants before 1993, so the increased demand can be satisfied with the present installed capacity.

5) All the above conditions are necessary to diminish the operating costs, to improve energy usage efficiency and to save energy.

MEASURES 1_/ 2_/

1) To define a strategy for using the steam now produced by boilers, with more efficiency and put it in operation
CODE : D - 62 - P10 - E 01
Investment 0.20 MM Dls return: 2 089 MM dls

2) To improve the boiler efficiency
Code : D -63 - P10 - E 01
Investment --- return 1.63 MMDLS

3) To replace or repair the CO boiler economizer
Code : D - 64 - P10 - E 01
Investment 1.50 MMDLS return 0.800 MM DLS

Evaluation of savings: 10.9 MM DLS/YR

1_/ Dancking, W.E. " Steam management in a refinery", pp 75-84. Reference 80

2_/ Duckham h. and Fleming J. " Better plant design saves energy". Reference 36

TABLE 5.8. g

STEAM AND POWER BALANCE ALTERNATIVES 1_/

		1		2		3
	MIDDLE 1991	**1991 1992 YEAR 1**	**1993 1994 YR 2-3**	**1991 1992 YEAR 1**	**1993 1994 YR 2-3**	**1993 1994 YEAR 2**
STEAM GENERATION 60 BAR 5 BOILERS						
TON/HR	577	660	788	708	800	720
%	62	71	80	75	84	87
WASTE HEAT						
BOILER						55
FCC II			40		40	40
STEAM TO TURBINE TON/HR	409	570	570	600	60	600
60/19 BAR REDUCTION	80.4	1	89	11	80	0
LOAD OF AUX. CONDENSER	52	100	93	96	73	0
AVERAGE POWER						
DEMAND	47.5	48.8	52.2	48.8	52.2	58.
GENERATION	47.5	48.8	52.2	48.8	52.2	71.
CFE SUPPLY						14
STEAM TURBINE						
LOAD	52	65	69	65	69	69
GT (MW)	8.2	8.2	8.2	8.2		20
ST (MW)	39.3	40.6	44.0	48.8	52.2	52
FUEL DEMAND TON/YR						
BOILERS	279041	326682	326805	347099	381748	288991
GT	32964	32964	32964			
COSTS	61	69	75	59.	65	43
FUEL SAVINGS				32964	32964	108828
MM DLS				7.91	7.9	

1_/ This table is the result of several analysis on steam and power balance.

SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY PROCESS
PHASE 3 PART B
PROJECT 6

REDESIGNING NAPHTHA HYDRODESULPHURIZATION UNIT

CODE D65-P03-E10

INTRODUCTION

It is necessary to review the criteria for redesigning processing plants to increase energy usage productivity. Partial objectives are: 1_/

a) Selecting optimal separation sequence

Separation sequence determines investment costs and energy costs. It is necessary to analyze several possibilities before selecting one to minimize consumed energy.

b) Define nearer temperatures in heat exchangers

From heat transfer theory it is known that the most rational use of energy is derived from two fluids exchange, when these have a reduced difference between their temperatures.

c) Replace air coolers instead of water coolers where possible

Utilization of air coolers saves cooling water and saves energy

d) Combustion air preheating

Air preheating instrumentation increases heaters efficiency in 10% , so energy is saved in the same percentage. In this case the analysis is apply on the naphta hydrodesulphurization unit.

e) Optimal operation reflux

Determination of optimal reflux helps to save energy. Distillation columns design is now based on a step calculation for obtaining a given separation

f) Catalysis selection

This factor has influence on light products yields, minimizing expenses, compression and separation.

1_/ Tellez R.M., De la Concha M.R., Duron M.E. and Polo O.V. "Ahorro de energia en plantas hydrodesulfuradoras Naftas" Seminario sobre aplicaciones factibles de conservacion y ahorro de energia en la fase de proyecto. pp 89-96. Referencia 40.

MODIFICATIONS TO BE IMPLEMENTED IN THE HYDRODESULPHURIZATION PROCESS

This plant has two major sections: Reaction and stabilization and fractionation. The proposed modifications are:

1) To eliminate the first preheater and the second preheater to debutanizer tower
2) To modify the temperatures at the second charge preheater for diminishing size and energy consumption.
3) To preheat combustion air of charge
4) To determine optimal separation sequence by an heuristic method and adopt it
5) To adopt the optimal reflux at desisohexanizer and debutanizer towers
6) To preheat combustion air at deisohexanizer tower

ECONOMIC ANALYSIS

The economic analysis takes into account the following concepts: Heavy fuel oil, cooling water, electricity and steam. Conclusions about economic effects are shown in the following table

TABLE 5.8. h

ANALYSIS OF NAPHTHA HYDRODESULPHURIZATION UNIT REDESIGNING INVESTMENT AND ENERGY SAVING 1/

	ACTUAL FLOW DIAGRAM MMDLS	PROPOSED FLOW DIAGRAM MM DLS.	% SAVING
HEAVY FUEL OIL	2.727	1.003	
COOLING WATER	3.039	0.372	
ELECTRICITY	0.528	0.699	
STEAM	1.539	1.203	
TOTAL	7.833	3.277	58
INVESTMENT	8.784	6.184	29
SAVING		50% 3.092	4.556 MM DLS

1_/ Data From "Seminario sobre aplicaciones factibles de conservación y ahorro de energia en fase de proyecto" pp 92. Reference 40

The current hydrodesulphurization unit has an operational cost of 7.833 MM dls/yr. the proposed modifications imply an operational cost reduction to 3.277 MM dls, so the saving is 4.556 m dls /yr. the investment is lower than the original, but in this case it is additional since the original investment, estimated in 8.784 MM dls was already done, so the 3.092 MM dls for the modifications is added to the plant investment, supposing 50% of the cost of the proposed modifications in the flow diagram.

The advantage of this solution is clear since both the operational costs and investment costs are lower than the ones in the current refinery. Following a resume is presented, in MM Dls:

TABLE 5.8.i

	INVESTMENT	INCOME	PT
REDESIGN OF SALINA CRUZ REF.	+ 6.184	4.556	1.4
NEW DESIGN	- 2.600	4.556	0

SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY
PHASE 3 PART B
PROJECT 7

HYDROCARBON GAS RECOVERY FROM BLOWDOWN 1_/

Code: D 66 - P15 - E10

INTRODUCTION:

This measure has been studied for the Minatitlan and Atzcapotzalco refineries. Technically it is possible to apply it also to the Salina Cruz Refinery. The potential energy saving in each refinery is different. It depends on their operation complexity, feed streams and process capacity for treating the recovered streams to obtain final products.

1_/ "Seminario sobre aplicaciones factibles de Conservación y Ahorro de energia ". pp 45-50. Reference 40.

The objective in this case is to install a gas compression system on blowdown line to process the gas stream to be desulphurized and used as fuel gas at the refinery. Liquid stream will be treated in the same way and converted to LP gas and naphtha to blend of final gasoline.

Gases to blowdown are different in composition, so the design is based on 34.7 to 27.7 molecular weight and operational pressure of 26 PSIG at output. A first compressor delivers gas to 26 PSIG at the output and a second one to 313 PSIG. The installation consists of compressors, tanks, coolers, condensers and instrumentation.

The red streams go to the hydrocarbon recovery unit where they are treated with ethanolamine before sending it to the fuel gas line and to add to other liquid streams in the plant. Detail engineering and equipment procurement are necessary to achieve energy saving. It can be estimated that the energy saving the investment and the payout time are as follows.

Energy saving value= 7.355 DLS/YR
Required investment= 2.167 DLS
Payout time= 2.167 17.355= 4 MONTHS

SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY PROCESS
PHASE 3 PART B
PROJECT 8

REDESIGN ATMOSPHERIC DISTILLATION AND VACUUM UNITS FOR INTEGRATING A COMBINED UNIT 1_/

OBJECTIVE

To redesign or develop a new design for a combined plant as a whole for processing a crude 50% Maya and 50% Istmo optimizing the energy consumption by means of the introduction of new energy saving techniques.

CODE: D 67-P 01- E 10

1_/ Cuéllar J.F., Perez A. González G.G., Manzanilla N.F., "Ahorro de energia en plantas de destilacion combinada". Seminario sobre aplicaciones factibles de conservación y ahorro de energia en la fase de proyecto" pp 157 Referencia 40.

INTRODUCTION

Atmospheric distillation and vacuum units are two of the most important energy consumers at the refinery. Together they consume between 2-3% on charge, respectively. At the Salina Cruz Refinery the current charge is 310 000 B/D.

The most critical parts from the standpoint of energy consumption are: The heat exchanger train, the direct furnace heaters and distillation and stripping columns. These areas have solutions for optimizing energy consumption.

The combined plant achieves a proper oil separation in fractions through atmospheric and vacuum distillations. In the first processes, Gas, Light Naphtha, Light Gasoil, Heavy Gasoil and primary residue are obtained; in the second one, vacuum and residue.

PARTIAL OBJECTIVES

1) Flexibility to accept different oil feed
2) Achieving quality product specifications
3) Reliability and optimization in operation
4) Investment and operational cost specifications

Trends toward heavy crudes make it neccesary to feed distillation and vacuum units with 50%-50% Maya and Istmo crude; for future analysis 100% Maya crude will be processed.

The new design should take into account specific analysis for crude preheating, crude heaters, distillation and stripping towers and product cooling. In regards to the crude preheating train, there is one main cool stream and 13 hot streams and it is possible to recover heat from three strippers.

Through specialized software , several solutions are defined and carefully evaluated. So, heat exchanger, air and water coolers are designed to optimize thermic efficiency.

Direct fired heaters are expensive, so their efficiency is very significant in the whole process. Estimation can show that it is possible to save 10% of energy consumed when combustion gases are utilized for heat recovery

Required investment for design=10.65 MM Dls
Energy saving revenues=39.7 MM Dls/yr
Payout time=3 months

REDESIGNING THE REFINERY
PHASE 3 PART B
PROJECT 9

DEAERATOR PRESSURE MODIFICATION 1_/

CODE D68-P09-E10

Raising the pressure in the deaerators the efficiency in the power plant can be improved. A technical analysis has determined that the pressure should be raised from the present 0.4 bar/109°c to 2.0 bar/ 134°c; the design pressure in the deaerators is 3.5 bar.

The pumps which supply the deaerators with treated water have a design delivery head of 4.5 bar, so it should be possible to operate them at an increased pressure of 2.0 bar, without need of changing the system.

The additional heating steam for the deaerator can be derived from the boilers or from the excess steam which is condensed in the auxiliary air condenser. It is convenient in both cases to wait for the additional steam demand after the enlargement of the refinery with a new visbreaker.

In the first case, it is supposed that the steam drives had been converted to electric drives to avoid excess steam in the low pressure line. 2.2 MW can be generated in the high pressure part and 1.5 MW in the medium and low pressure part of the turbines.

In the first case, the steam drives had supposedly not been converted to electric drives. Thus there are 100 Ton/hr excess steam left for the auxiliary air condenser and the additional

1_/ Moore F.G. "Save energy in plant operations". Hydrocarbon Processing. July 1973. pp 67-71. Reference 92 heating steam for the deaerators. In this case 2.69 Ton/hr of reduction of heavy fuel oil due to a higher feedwater inlet temperature upstream of the 60 bar boiler battery.

ECONOMIC DATA

Saved fuel oil = 15 472 Ton/yr
Revenues = 1.55 MM Dls /yr
Required investment=0.0

SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY PROCESS
PHASE 3 PART B
PROJECT 10

IMPROVING PLANT INSTRUMENTATION 1_/

INTRODUCTION

Instrumentation in the Mexican refineries has several problems. At first, from the technological point of view, it is outdated because financial resources have been limited during all the refineries lives and because technical decisions have not taken into account for many years the needed competition and the requirements of the processing plants control.

In the Salina Cruz Refinery, both field and control room instrumentation at the power plant station are mainly activated pneumatically and the various utilities are operated from the control room or manually.

Field instrumentation and control equipment are also operated manually. Additional on-off switching facilities are available but no remote control has been provided for shutoff valves; so they are manually operated by a hand wheel at their respective location. Field instrumentation at the processing plants is outdated, but is now being reviewed, looking for technical up-to-dateness. A resume about the current instrumentation at the refinery is as follows:

1_/ "Advanced Process Control Handbook VI. Computer Integrated Processing. Reference 43
2_/ "Dartt s.r. " Asses today's options in distributed process control". Reference 82
3_/ " Funk J.C: " Controlling continous processes with DCS. Refence 83

1. 13 Processing plants have electronic instrumentation and 5 have a distributed control.
2. In the power station half the turbogenerators have pneumatic control and half have electronic control.
3. Most boilers also have pneumatic control (90%)
4. Blow down control has electronic instrumentation and residual effluents control is based on electronic instruments.
5. Products movement control instrumentation is mostly electronic in polyducts, pipelines, tanks and product to sale line.

INSTRUMENTATION MAINTENANCE

There is no an effective maintenance system for the instrumentation of the refinery. It was detected, during an inspection, that the steam flow meter on the main turbines TG1 y TG2 were out of order and the transmitters of the measured values were not replaced by new ones.

After a plant inspection, a repair and the maintenance programme were defined its cost would be from 12,000 to 18,000 Dls including the replacement of transmitters.

Regarding the whole refinery, it is possible to save on costs in electrical installations, instrumentation and control, improving the installation of transmitters, all this to help assure the installed control and monitoring equipment remain operative.

The instrumentation and control of the process units are designed for measurement and registration to establish the process flows and levels. It is necessary to improve the instrumentation to obtain a short time response, allow a prompt revision and increase both plant efficiency and production.

ALTERNATIVES FOR INSTRUMENTATION IMPROVEMENT

ALTERNATIVE 1A CODE D69-P15-E10 phase 1

Instrumentation improvement at refinery border

Instrumentation improvement at power station
Instrumentation improvement at processing plants

ALTERNATIVE 2   CODE D70-P15-E-10   phase 2

Instrumentation improvement towards distributed process

ALTERNATIVE 3   CODE 71-P15-E10   phase 3

Instrumentation improvement towards advanced control

The characteristics of the instrumentation after adopting recommended modifications will be: integral, uniform and up to dated. it will be possible to have a reliable measurement at the refinery border, in processing plants and product movement area.

INVESTMENT PROGRAMME AND ECONOMIC BENEFITS 1_/
TABLE 5.8.j
MM DLS

	PHASE 1 1995	PHASE 2 1996	PHASE 3 1998	TOTAL
BORDER REFINERY				4.0
POWER STATION	8.0	6.0	3.0	17.0
PROCESSING PLANTS				7.6
- ATM. DISTILLATION			2.0	
- FCC		1.2		
- REFORMING		1.4		
- OTHER PROCESSES		1.5	1.5	
PROD. MOVEMENT	4.0	3.0		7.0
TOTAL	16.0	13.1	6.5	35.6
BENEFITS	12.0	21.0	6.0	39.0

INVESTMENT VS BENEFITS

It is possible to show by a graph the relation between capital costs, expressed in percentage, vs the potential benefits from adopting a higher level of control technology. The Salina Cruz Refinery is not a very old refinery, so the investment needed to improve instrumentation is lower in respect to older refineries such as Madero or Salamanca.

1_/ Data from technical studies carried out in PEMEX about advanced control project

On the other hand, the following presents technical information on the investment needed to change the technological level of instrumentation:

TABLE 5.8.k

INVESTMENT FOR IMPROVING INSTRUMENTATION IN PROCESSING PLANTS (MM DLS)

	KIND OF PLANT	
	SIMPLE	**COMPLEX**
LOOPS	150-180	250-320
FROM PNEUMATIC TO DISTRIBUTED	1.00	2.00
FROM ELECTRONIC TO DISTRIBUTED	0.35	0.60
FROM DISTRIBUTED TO ADVANCED CONTROL	0.25	0.40

1_/ Dronoff A., Hamman M. "Improve return on advanced controls". pp 112-113. Reference 84

SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY
PHASE 3 PART B
PROJECT 11

REDESIGN THE WASTE HEAT BOILER OF FCC UNIT

Code : D72 - P07 - E09

The refinery is going to be enlarged with an FCC new plant during the next years. A waste heat boiler is projected for the new FCC section, according to the particular situation. It is recommended to be designed at temperature of 485 °c to generate 19 bar steam.

There is a bad experience about it since a boiler of this type exists for the current FCC unit. It should be replaced. the future advantage of this project will be the flexibility in operation and the benefit from the back pressure power generation in the high pressure part of the steam turbines.

Required investment=0.89 MM/Dls
Saving revenues=0.287 MM Dls/yr
Payout time=3.1 Yr.

SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY
PHASE 3 PART B
PROJECT 12

EXPORT OF POWER

CODE : D73 - P14 - E08

The present gas turbine should be rehabilitated up to full power generation and converted to fuel with refinery gas. To complete the cogeneration system one 55 Ton/hr waste heat boiler should also be implemented to utilize the heat which is contained in the exhaust gas of the gas turbine set. The waste heat boiler is connected to the 60 bar steam.

The costs of energy internally generated in the refinery are between 0.025 and 0.030 Dls/kwh, the CFE selling price is 6.5 Dls/ kwh in average. Although government is reviewing the rules to be applied in case of cogeneration, the difference between the two figures makes export power to the CFE grid attractive.1_/

1_/ Wilson W. B. and Kovacik J.M. "Electricity: Generate or buy". pp 75-78. Reference 85

Provided that each steam turbine sets load to aproximately 220 Ton/hr to 240 Ton/hr of life steam, some 75 MW of power might be generated.

After the rehabilitation of turbine, it would be possible to export 37.0 MW to CFE, and revenues would be 10.5 million Dls/yr. This export estimate takes into account the future demand for the refinery, 58 MW, which includes the conversion of drives to electric motors.

If one steam turbine is out of operation, the power plant is still capable to generating an electric output of 50 MW. The existing control and instrumentation should be rehabilitated and modified.

No investment is required for implementing this measure. The revenues from exporting power is 4.7 MM Dls /yr

Required investment=0
Saving revenues=4.7 MMDls/yr.
Payout time=0

PHASE 3 PART B
PROJECT 13
REPLACING SOME WATER COOLERS BY AIR COOLERS

CODE :D74-P15-E05

There is interest in reducing the cooling water circulation to improve thermal efficiency. After studying process flow diagrams for all existing units, reviewing the heat and material balance data and design specification sheets on water and air coolers, it was determined where energy contained in process streams could be gainfully recovered. 1_/.

In **annex** 7 the general design data of process coolers. Are included. In order to upgrade the overall plant cooling system, the substitution by direct air cooling when the process temperatures are high enough to make air cooling an economically attractive alternative, have been proposed.

1_/ Flemming J. Duckham H. and Styslmer J. "Recover energy with exchangers". Hydrocarbon Processing. July 1976. pp 101-104. Reference 38

After selecting the potential candidates the following list was defined. Further studies should be done to have the economic data for analyzing the needed investment and its profitability. To implement the programme, it is supposed that the coolers can be classified according to their economic parameters, specifically their payout time:

a) Less than 2 years
b) From 2 to 4 years
c) More than 4 years

TABLE 5.8. m

COOLER SYSTEM DUTIES EXISTING SITUATION

	DUTY OF WATER COOLERS MW	DUTY OF WATER COOLERS MW
CRUDE AND VACUUM UNIT 1	161.7	44.1
CRUDE AND VACUUM UNIT 2	154.5	65.5
FLUID. CAT. CRACKING NAPHTA	121.8	13.1
DESULPH.	23.1	---
NAPHTA REFORMER	4.8	18.6
FRAC. AND TREATING	13.2	---
INT. DIST.		
DESULPH.	26.3	---
" (800)	26.3	---
TOTAL		
REVAMP		
FCC	64.8	28.0
NAPHTHA DESULPHUR	33.8	---
NAPHTHA REFORMER.	22.4	23.0
FRAC. AND TREAT.	34.0	---
INT. DIST.DESUL	26.4	---
" . "	26.4	---
VISBREAKER	35.8	4.7
TOTAL	775.3	197.0

SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY
PHASE 3 PART B
PROJECT 14

LOAD MANAGEMENT

CODE: D75-P15-E07

This project concerns with the necessary modifications in electrical and control systems as a result of the several measures related to the power station and their integration.

INTRODUCTION

The existing power station has four fired steam generators with capacity of 200 Ton/hr. One CO boiler of 180 Ton/hr capacity is part of the steam generating cycle.

Power generation is made by four turbogenerators: TG1 and TG2 with 32 MVA of nominal rating and TG3 and TG4 with 40 MVA. TG4 is under construction. The power demand ranges in average.

Power supply is ensured in three voltage levels: 13.8 KV, main distribution frame in the central power plant, 4.16 KV level and 480 V level.

The generators feed three separate main distributors: TPD1 (bus a), TDP 2 (bus b), TDP 3 (bus a) and TDP 7 on the 13.7 Kv levels. These generators are synchronizing through a circuit TBS. Power feed from the public CFE grid can be supplied to the TBS synchronizing circuit.

The instrumentation in the power station for the electric energy generation consists of analog instrumentation. The generator output is manually adjusted. Both field and control room instrumentation for the power plant section are actuated pneumatically.

Some 5% of losses are created by the reactors in the synchronizing bus. Load distribution and power factor are adjusted manually in the plant.

MEASURE:

Power should be generated where power is needed and power transfer via synchronizing bus avoided whenever possible. Power should be generated in the steam turbine individually, according to the demand in the distribution bus.

Required investment = 0
Saving revenues = 0.57 MM Dls/yr
Payout time=0

SPECIFIC PROJECT FOR REDESIGNING THE REFINERY
PROJECT 15

TO APPLY THE EXERGIA METHOD FOR DETERMINING THE MAXIMUM POTENTIAL OF ENERGY RECOVERY IN THE SALINA CRUZ REFINERY 1_/

CODE: D76 P15 E10

INTRODUCTION:

To modify or enlarge a refinery to improve its energy usage productivity, determining the maximum energy recovery potential and identifyng the modifications to be made are necessary.

In Mexico, refineries have more or less the same processing plants, so the same method can be applied. This project consists in studying the refinery by means of the exergia method in a process simulator.

METHOD :

The activities to be executed are :

To elaborate material and energy balances
To diagnose the energy potential saving
To select the highest potential areas
To analyze instrumental and operational conditions
To define modifications according to technical and economic evaluation

---

1_/ Seminar about measures to save energy. pp 57-64. Reference 40.

Processing plants to be analyzed

P 01 Distillation unit

P 02 Vacuum distillation unit

P 03 Hydrodesulphurizing naphtha unit

P 04 Naphtha reforming unit

P 05 Hydrocarbon treating

P 06 Intermediate distillate products hydr desulphurating unit

P 07 Catalytic cracking unit

P 08 Sulphur recovery unit

P 09 Boilers

P 10 Facilities area

P 11 Effluent treatment

P 12 Cooling towers

P 13 Product movement area

P 14 Turbogenerators

This project requires 50 000 men-hours. The total cost is estimated in 1.65 M Dls. and the time required for the study is one year.

ENERGY SAVING

It is difficult to estimate the possible energy saving by this project. When the study is finished, the needed modifications for optimizing energy consumption will be clear. According to similar experiences in other refineries it is known that it is possible to save 10-12 % of the current energy consumed. At the present time, once the refinery modifications are defined, it is necessary to evaluate and invest on the select refinery redesigning modifications.

Required initial investment= 1.650 MM Dls
Required additional investments=not defined
Saving revenues=15.90 MM Dls/yr
Payout time=0.10 yr

SPECIFIC PROJECT FOR REDESIGNING THE REFINERY PROCESS
PHASE 3 PART B
PROJECT 16

EVALUATION OF UTILIZATION OF A SET POINT COMPUTER PACKAGE FOR OPTIMIZING ENERGY USAGE IN THE POWER STATION 1_/

CODE : D77-P09-E10

INTRODUCTION

The utility energy optimization applications incorporate modelling and advanced controls to provide a modular overall plant energy system approach which optimizes energy costs by providing the energy demands at the least cost alternatives.

A plant energy model is a model of the plant energy system that includes engineering calculations. It takes into account the electric contract and determines cost of power, boiler load. The allocation model is designed to distribute the total steam demand among boilers. The generator load allocation module provides optimum production of cogenerated power by considering the cost of the steam or fuel, the incremental cost of purchased power and the performance efficiency of the generator. The model includes other modules for: Optimization with control constraints, steam generation, advanced regulatory control and off-line optimization.

METHOD

To analyze the computer package

To review each module

To apply the package to a Mexican refinery

To evaluate the results

1_/ Advance Process Control Handbook VI. Reference 43

RESULTS

It is estimated that the package can help to reduce energy costs in 5%.

Licensor: Setpoint inc, Houston Texas.

Required investment=15000 Dls
Saving revenues=6.6 MM Dls/yr
Payout time=0.0022=0

SPECIFIC PROJECT FOR REDESIGNING THE REFINERY PROCESS
PHASE 3 PART B
PROJECT 17

EVALUATION OF THE ENERGY MANAGEMENT SYSTEM (EMS) PACKAGE 1_/

CODE: D78-P15-E10

INTRODUCTION

This package was designed to manage and control the generation and distribution of energy for industrial process.

The objective is to provide steam and power at minimum cost and reduce the downtime of the utility plant by introducing optimal and advanced control strategy and a continuous monitoring system. Its functions are: Optimization, energy forecast, steam and power balance, coordination of steam and power generation control, adapatative and predictive control, advanced regulatory control, performance monitoring, management information and operator interface.

The independent or interactive functions are:

- Global level optimization of the power and steam balance and tie - line control.
- Unit level optimization for boiler load and power generation
- Component level optimization of combustion control, condenser pressure, turbine, compressor operation optimization.

1_/ Advances Process Control Handbook VI. Reference 43

The modules are:

- Fuel optimization. Control system to reduce the gas loading by increasing usage in power generation
- Steam generation optimization. Calculates boiler efficiency using on-line data and generates a boiler load characteristic curve for economic load despatch
- Power generation control. Optimal level of power generation, economic load dispatch, condenser pressure
- Electrical load control. To control the economic electrical demand as well as emergency load shedding of the plant.
- What if energy management simulator.

METHOD

To analyze the package
To review functionality and performance of each module
To apply the package to a specific case of a Mexican refinery and evaluate results

ECONOMIC RESULT

It is estimated that this package can help to reduce energy costs by 7 %.

Licensor: APP SIMCON, INC, Houston Texas

Required investment=18,000 Dls
Saving revenues=4.64 MM Dls/yr
Payout time=0.0038 Yr=0

SPECIFIC PROJECT FOR REDESIGNING REFINERY PROCESS OR EQUIPMENT

PHASE 3 PART B
PROJECT 18

EVALUATION OF THE UTILIZATION OF THE KBC UTOPIA COMPUTER STEAM AND POWER PACKAGE 1_/

CODE: D79- P15 E10

INTRODUCTION

This package has two elements: an advanced control system and a model based on facility for optimizing the efficiency of the utility plant.

The advanced control system maximizes the performance of the individual items. The control strategy is implemented to minimize the fuel consumption. The second element in the control package utopia uses a model of the utility system in conjunction with economic information and process data to determine the set points.

The advanced control element reduces fuel consumption by 1%, the annual non investment benefits in the range of 1.0 M Dls to 3.5 million dls for an average 5 MT/ yr oil refining.

Required investment=50,000 Dls
Saving revenues=1.32 MM Dls/yr
Payout time=0.36 yr =0.0

Licensor: KBC Process Technology

1_/ Advances Process control Handbook VI. Reference 43

SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY
PROJECT 19

EVALUATION OF UTILIZATION OF A MDC COMPUTER PACKAGE FOR UTILITIES OPTIMIZATION 1_/

CODE: D-80-P-15-E10

This technology is based on software products mod-estim, optim and estim and provides the requirements for an on line optimization of the operation of utilities area.

The control strategy utilizes an accurate plant model consisting of fit-for purpose process equipment models. Each unit model has its own data base and user-friendly interface. The unit models are configured with manufacturer's data. The units are connected together by the executive wich controls the solution process

The standard library contains all the typical units such as boilers, gas turbines, waste head recovery boilers and a whole plant/site model may be constructed without programming.

The keypoint is the application of a plant model which is configurable in terms of setpoints, cost functions and constraints. The optimizer uses inter programming methods. The models are automatically up dated to relect changes in efficiency using real plant data and ignore instrument errors or bad data .

The whole system is operated via an advance window-based used interface, to make easy for the user the configuration of his own screens.

Benefits depend on the degree to which the plant responds to changes. Energy savings are normally 2% to 5%.

MDC is used in the steel, refinery, chemicals and pharmaceutical industries

Licensor MDC LTD, Middles Brough, Cleveland UK

Required investment=15000 Dls
Saving revenues=3.97 MMDls/yr
Payout Time=0.0038 yr=0

1_/ Advances Process Control Handbook VI. Reference 43

SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY
PHASE 3 PART B
PROJECT 20

EVALUATION OF THE UTILIZATION OF PLUTO II, A SOFTWARE FOR UTILITIES OPTIMIZATION

CODE: D81-P15-E10

INTRODUCTION:

Pluto II (plant utility optimizer) is a software package for analyzing and optimizing total utility systems. Using ranges from daily operations to analyzing the impact of a major plant modification on the utility system, pluto II finds the utility condition that satisfies the utility demands at a minimum total cost for purchased fuel, electric power and water. Optimization is focused on turbogenerator loading, extraction turbines, driver spare operations, boiler loadings and cogeneration operation. It is possible to support "On-line " optimization through the autotune function which was developed to use minimal input data. Advantages of this function are: attention focusing on adjustable. System elements whose operating condition can be changed by system operators to improve efficiency and reduce costs; reducing input data, to allow automatic data entry from most existing plant information system; and trial and error procedures.

ECONOMICS

Savings ranging from $180,000 to $3500,000 per year have been shown in PLUTO studies of proposed utilities system modifications. Benefits from PLUTO vary from plant to plant. Improvements in day to day operation fall in the range of 50-100 $ per hour.

Required invesment=$50,000 dls
Saving revenues=250,000 dls/yr.
Payout time=0.20yr

1_/ Advanced Process Control Handbook VI. Reference 43

SPECIIFIC PROJECT FOR REDESIGNING REFINERY PROCESS OR EQUIPMENT
PHASE 3 PART B
PROJECT 21

KRAFTANLAGEN SIMULATOR FOR ENERGY MANAGEMENT DESIGNED FOR PEMEX

CODE: D82 P15-E10

INTRODUCTION

There are several computer packages for energy management in the market. All of them have been generalized to be used in any enterprise. Nevertheless, the size of PEMEX, the structure of its six refineries, its mix of processes and subprocesses makes it desirable to have its own specific designed package

Kraftanlagen has proposed to build a computer simulator to plan the optimum energy input in a frame of a generalized policy of rational use of energy. The final objective is improving energy usage efficiency in new designs as well as in existing plants.

The simulation of energy usage consists in achieving the best use of energy by changing the structure of the installation and its operating condition. The objective is to solve the trade between energy savings and capital investment.

The software will provide the enthalpy-temperature curves for indicating the opportunities of energy recovery. Besides it is possible to analyze a high number of possibilities and minimum cost criteria instead of minimum of energy.

In refineries, energy is generated and distributed in the form of steam and electricity. The energy input required is determined by the specifics processes and the plant production rate. The major energy consumers are: Process steam demand, heating of input crude, steam drives in the process, turbines for power generation and electric drives.

ENERGY MANAGEMENT

Energy management is based on the simulation of energy input for a planned production. It can help for achieving an optimum energy utilization. 1_/

For saving energy it is necessary to determine the proper demand on the 60 bar, 19 bar and 3 bar steam line. The 19 bar line has a guiding function, for having no excess energy on the 3 and 19 bar. The objective is getting the optimal characteristics of the power plant.

The simulation model can help to achieve the best equilibrium between the generated and exported electric energy. When more electrical energy is to be generated, excess energy on the 19 bar line is deliberately produced, such excess energy can be controlled via the simulation programme according to technical and economical aspects.

PARTIAL OBJECTIVES OF THE SIMULATOR SOFTWARE

- Determination of the energy consumers for energy consumption optimization
- Determination of the function of the energy consumer in dependence on the plant's production rate
- Determination of the measuring points for the main parameters (pressure 3 bar line and flow rate steam reducer station)
- Energy generation program as a function of the energy request
- Performance specifications

PROGRAMSTRUCTURE

- Determination of scope data to be measured
- Logging (automatic, continuous or intermittent)
- Selection of computer

1_/ Taylor Robert. Refiners can save energy, too. Reference 37

SCOPE OF SERVICES

- Fact finding mission
- Evaluation of requirements for the software and hardware
- Evaluation of input and output parameters and flexibility
- Consideration of energy generation, distribution and consumption in the power station as well as in the processing units

Cost of the conceptual design of the simulator 394 120 Dollars

Required investment=392,000 Dls
Additional required investment=400,000 Dls
Saving revenues=4 64 MM Dls/yr
Payout time=0.17 Yr

SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY
PHASE 3 PART B
PROJECT 22

DESIGN AND DEVELOPMENT OF A WASHING MACHINE FOR HEAT EXCHANGERS 1_/

CODE D83 P15-E06

INTRODUCTION

It has been observed at the Salina Cruz Refinery that part of the inefficiency in energy usage is due to the fact that heat exchanger equipment does not have a good performance and should be thoroughly cleaned. As there are so many heat exchanger equipments, it is very difficult to keep up an effective maintenance to assure an efficient heat transmission.

The solution is having a mechanical, fast and efficient procedure for cleaning tubes and shells of heat exchangers. Each plant shutting requires to clean about 40 heat exchangers. The traditional cleaning method is not effective enough so, the equipments are dirty in three or four months.

1_/ Seminar About Feasible Measures To Save Energy. Reference 40. pp 31, 51

The design, development and construction of a dynamic simulator to studying the performance, problems and solutions linked to a typical heat exchanger has been proposed in order to design the needed machine for cleaning it. After that, this machine would be constructed in the refinery shops. Once the prototype machine is obtained it will be possible to produce as many as needed in the different refineries.

To produce the machines, human, material and financial resources for the project have to be assigned. The following activities are needed:

Engineering
Material and equipment selection
Shop manufacturing
Prove the prototype
Transportation of the machine
Quality control
Installation
Final adjustments
Delivery to operators
Cleaning shop design

WASHING MACHINE ADVANTAGES

1. Diminishing maintenance and operation costs
2. Saving time in the external and internal cleaning
3. Minimizing shutting plant time
4. Diminishing investment costs in heat exchangers
5. Keeping in operation for longer time the heat exchanger equipment and saving energy

PHASES FOR CONSTRUCTING THE MODEL FOR SIMULATION

Problem identification
Data gathering
Technical analysis
Conceptual design
Analysis
Model validation
Design options
Detailed design
Construction

INVESTMENT COSTS

Required investment=0.565 Mm Pesos 1986
Saving revenues=0.330 MM Dls/yr
Payout time=1.7 yr

SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY PROCESS
PHASE 3 PART B
PROJECT 23

ADDITION OF AN ENERGY ECONOMIZER FOR RECOVERING HEAT FROM THE COMBUSTION GASES TO CHIMNEY

CODE: D 84 -P15-E02

As direct fired process furnaces typically represent the largest consumers of fuel in a refinery, they are the area where largest savings can be made. In the Salina Cruz Refinery there are 30 furnaces for different services and duties.

Regarding to furnaces three different measures are analyzed in the research: 1_/

- Addition of process coil surface
- Addition of combustion air preheat systems
- Addition of 60 bar steam waste heat boilers

The first measure is analyzed in Project 1, the second one in Project 2, and the third one in this project.

It is possible to conclude from the energy balance of the Salina Cruz Refinery that 90% of the fresh energy consumed is used in heaters and furnaces. From this energy, 80% is lost in the gases escaped through chimeney.

1_/ Reed D R. "Recover energy from furnance staks." Reference 29

Then it can be profitable to design economizers for recovering heat from each heater. As examples, the proposed measures are related to heaters of the atmospheric and vacuum units

It is necessary to establish the long term normal operating capacity of each process unit and the furnace efficiencies, in order to establish the individual furnace duties.

Addition of waste heat boilers is suitable for all furnaces. Although the present fuel costs indicate that 60 bar steam can be more economically generated by alternative energy conservation schemes.

This system would consist in the following: flue gases are ducted from below a new damper installed in the existing furnace stacks down to grade. The fuel gases then pass through a supplementary fired waste heat boiler and finally discharged to a new stack. This supplementary firing is required in the boiler to achieve the desired steam superheat temperature.

The new stack dampers act as high efficiency by-pass dampers when the flue gases are being ducted to the waste heat boiler.

METHOD

THE ACTIVITIES TO BE CARRIED OUT ARE:

- To gather basic information
- To review original designs
- To make energy balances at the two plants
- To define modifications according with technical and economic evaluations
- To present final report and recommendations

Each heater requires its own specific study to define the cost-benefit parameter. While all the studies are made, a typical example is used to illustrate this measure,

Required investment = 2.1 MM Dls
Saving revenues= 0.77 MM Dls/yr
Payout time= 2.7 years

SPECIFIC PROJECTS FOR REDESIGNING THE REFINERY PROCESS
PHASE 3 PART B
PROJECT 24

INSTALLATION OF CONTINUOUS ANALYZERS IN HEATERS AND BOILERS 1_/

CODE: D85 - P15 - EO2

Boiler's gas combustion has been analyzed in PEMEX for many years. Although most furnaces have not been subjected to the same policy. Technology has had considerably advance in this kind of analyzers.

It is important to install analyzers in the furnaces of the refinery to control the air excess in the combustion to a minimum, according to each design and used fuel.

When the air excess is kept at 40%, it is lost 3.65% of the heat power. A heater normally consumes 100% of its acquisition cost as fuel.

To evaluate the economic result of a continuous analyzer it was considered that this system allow us to control from 30% to 15%. the saved heat costs 9 148.6 Dls/yr.

A finding mission visited the Salina Cruz Refinery and observed the furnances,the duties and conclusions about the furnances are pressented in annex :

Required investment= 1 285.7 Dls
Saving revenues = 9 148.6 Dls/yr
Payout time = 2 months

1_/ Seminar About Feasible Measures To Save Energy. Reference 40

SPECIFIC PROCESSES FOR REDESIGNING THE REFINERY PROCESS
PHASE 3 PART B
PROJECT 25

APPLICATION OF PINCH TECHNOLOGY 1_/ 2_/

CODE: D-86-P15E-07'

INTRODUCTION

This technology is applied to determine which are the opportunities for saving energy in the refinery.According to other experiences 1_/ 20% of the utility operating cost can be saved by correcting the existing problems of heat transfer.

The project incremental economies trend to diminish the consumed energy as the method lets us to approach the minimum.

The relationship between investment, saving and payback can be explored for retrofit projects at the targeting stage.

Pinch technology concepts for energy recovery has been used extensively in refining and petrochemical industries with outstanding results. It is a novel energy conservation tool into a powerful methodology, to fully realize the practical potential of a process. It reduces both capital and operating costs for retrofits designs.

The process complexity involves multiple utilities, both generated and imported, heat and power integration within the process, furnaces, cooling water towers, multiple level refrigeration systems and, in general, a complex heat recovery in the overall process.

Excess heat must cascade down across multiple pinches and ultimately be offset by reduced input at lower temperatures or excess cold utilities.

1_/ Linnot B. And Witherell W.D., "Pinch Tecnology Guides To Retrofit". Reference 21

2_/ Fleming J. Duckhamh. Styslinger J. Recover Energy From Exchangers. Reference 38

In a new design, pinch technology usually identifies optimized minimum energy designs with reduced capital spending. A retrofit design requires capital to correct existing problems.

One of the most important aspects of pinch technology is its ability to set cost trade offs for different scenarios working from the targets.

Every study has different requirements, relevant only to that particular location: Different utilities, different pressure levels and different operability requirements. Every study is different. Individual results should not be directly applied to other similar processes.

Studies involving multiple utilities, both imported and exported are difficult. Many ideas for energy conservation may appear to offer favorable project economics. The question is whether or not an idea is compatible with the concept of overall optimization. Pinch technology answers this question and represents a thermodynamically rigorous support for process integration.

This technology has not been applied yet to the Salina Cruz Refinery. Nevertheless, it is supposed that it could be very useful to integrate different solutions to improve the energy usage productivity of the refinery.

According to experience the economic advantage of the implementation of an overall programme would be attractive and justifies this first part of the analysis. However, it is difficult to determine which part of the result can be taken for the economic analysis of each measure.

Required investment= 1,02 MM Dls
Saving revenues= 12.9 MM Dls
Payout time=0.079 YR = 1 month

5.9.0 PROJECT EVALUATION MODEL APPLICATION

Figure 4.6.a shows a framework for redesigning a refinery to improve energy usage productivity. To improve this parameter it is necessary to take into account that the system to be studied is the same refinery to be improved in terms of energy usage productivity. Other condition for the analysis is the refinery as a dynamic system so new plants are going to be added in each period.

According to the figure 4.6.a there are several analysis to be carried out before doing the modifications included in the redesign of the refinery so,.these analysis are carried out based on different models. Among them the economic project evaluation integrates the results of the previous models giving to the economic factor the major importance. To implement these models several parameters have been selected to evaluate different aspects of the design:

PD Performance design

Functional model. Refinery configuration

Capability model. Processing plants capacity

The functional model is related to the refinery configuration and represents the different processes that the refinery carries out. Three different moments have been selected for the analysis: Jan 1,1991, Jan 1, 1992 and Jan 1,1995.

1991 CONFIGURATION (JAN 1)

Primary, vacuum and stabilization units 1 and 2

Naphtha HDS units 1

Reformer units 1

FCC unit num 1

Int. dist. Hds units 1 and 2

Merox and sweetening treatment

Treating and fractionating num 1

Sulphur recovery

1992 CONFIGURATION (JAN 1)

Primary, vacuum and stabilization units 1 and 2

Naphtha HDS units 1 and 2

Reformer units 1 and 2

FCC unit num 1

Int. Dist. HDS units 1, 2, 3 and 4

Merox and sweetening treatment

Treating and fractionating num 1

Sulphur recovery

1995 CONFIGURATION (JAN 1)

Primary, vacuum and stabilization units 1 and 2

Naphtha HDS units 1 and 2

Reformer units 1 and 2

FCC unit num 1 and 2

Int. dist. HDS units 1, 2, 3 and 4

Merox and sweetening treatment

Treating and fractionating num 1

Sulphur recovery

Visbreaking unit

The capability model is represented by the total crude oil capacity of the whole refinery and the capacity of each processing plant.

1991 AND 1992 CAPACITIES

Total pemex-ref 1 524 000 B/D Salina Cruz 155 000 B/D

1995 refining CAPACITY

Total PEMEX- 1 809 000 B/D Salina Cruz 250 000 B/D

HRD heat recovery design

Project definition

Project selection

According to experience, studies carried out and technical literature in heat recovery design, there are 8 main group of technical possibilities to be considered in this section 1_/

1 Air preheating to heaters
2 Increasing area in preheating of charge
3 Installation of waste heat reboiler
4 Optimization of steam production and distribution
5 Optimization of electricity generation, distribution and exportation
6 Hydrocarbon gas recovery from blowdown
7 Optimization air coolers versus water coolers

8 Energy economizer in furnaces and boilers
9 Better control and information

SP Support design
L Logistic subsystem
M Maintenance process
IP Information process
IC Information control

OP Operational scenario
Operational cost model
Capital cost model
Life cost model

Integrating cost - offs

Economic project evaluation

Parameter evaluation
Project selection

5.10.0 CONCLUSIONS FROM THE MODEL APPLICATION

This first model application had no significant differences in terms of results as a consequence of the performance design, capability and operational scenario, when it was applied to different system structures to modify the original design.

Only three differences seemed to be important from the analysis:

a) Amount of energy saved through each project
b) Productivity of the investment measured through proper parameters
c) Time period when each measure can be applied or when it is feasible or convenient for the saving programme effectiveness.

The Salina Cruz Refinery is 8 years old in average, one of the youngest of the Mexican system, but it is hard for PEMEX-REFINACION to decide to make deep modifications in the current installations in order to improve energy productivity, because it is now one of the more important supports for the whole production. The refinery is going to grow when a new train is added, but this revamp is going to be built closely but separately from the current refinery.

On the other hand, the investments for several modifications that improve energy usage to have better energy productivity are considerable such as those for the new train. Due to this, each project had to be evaluated; after that many measures had to be discarded since they had no acceptable return on investment.

CONCLUSION ABOUT OIL SAVINGS

	TON / YR
NON COST MODIFICATIONS	66 626
LOW INVESTMENT MEASURES	15 126
MIDDLE INVESTMENT MEASURES	165 040
EXPORT POWER EQUIVALENCE	7 000 e
LOAD MANAGEMENT EQUIVALENCE	45 000 e
TOTAL	298 792

5.11 ENERGY SAVING PROGRAMME

5.11.1 CONSIDERATIONS FOR STRUCTURING THE PROGRAMME

The proposed energy saving programme is the result of considering a decision tree for mutual exclusive projects, in which the parameters obtained from the economic project evaluation are taken into account.

So, the variables considered are:

a) Time
b) Investment profitability parameters
c) Potential improvement of the energy consumption productivity parameters versus investment
d) Difficulties for shutting down the refinery for implementing the measures
e) Amount of financial resources for investment

The general energy saving programme considers three actions:

1. Improving operation conditions- PHASE 1
2. Corrective maintenance- PHASE 2
3. Redesigning the refinery- PHASE 3

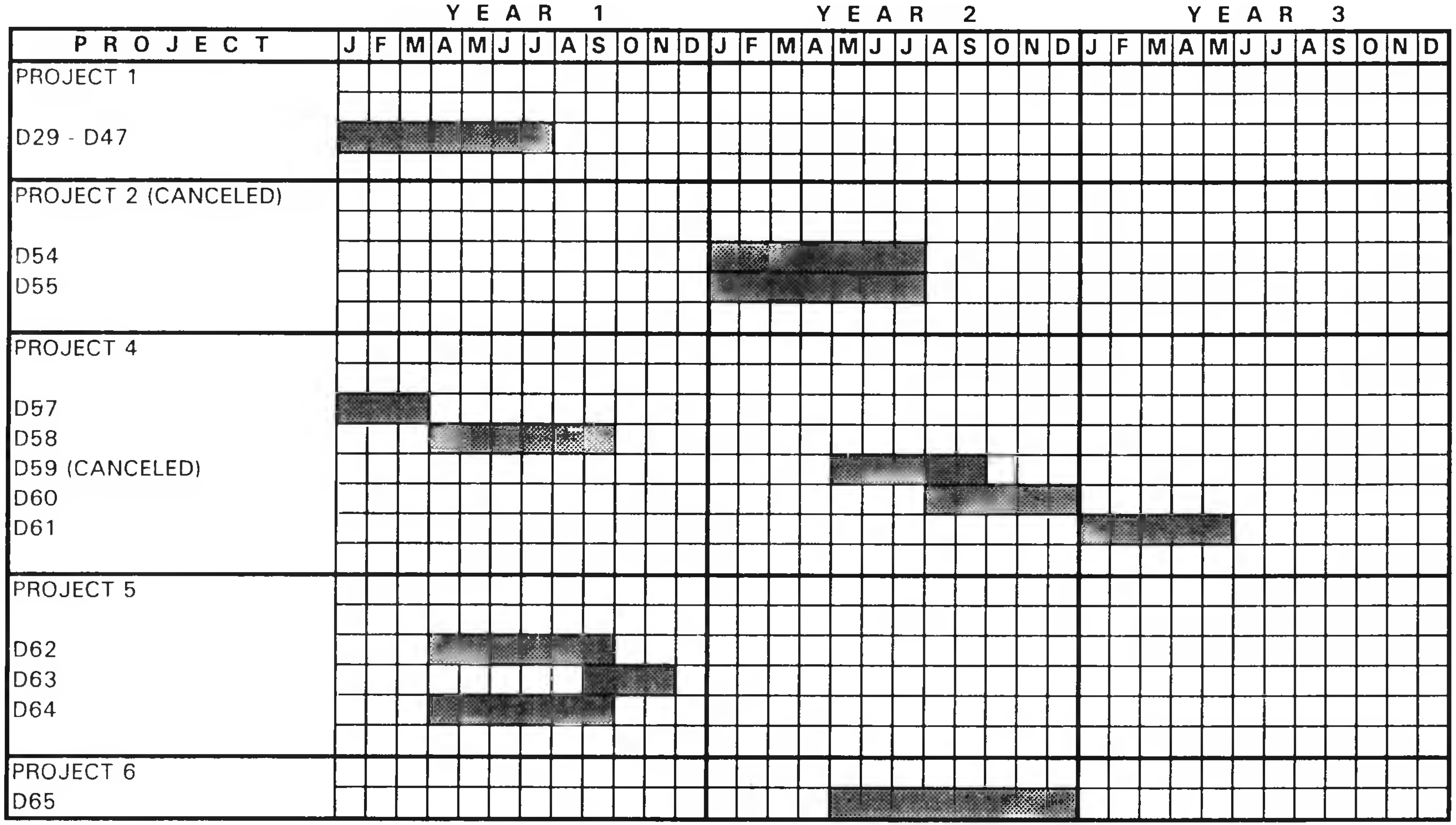
There are many actions to save energy and the refinery has to determin a detailed programme. For the first two phases, in this study, a summary of measures to improve operation and maintenance was presented in chapter V, section 5.b, pages 190-200. According to the research work objectives, emphasis is mainly put on the main actions related to projects for redesigning the refinery. Through the analysis of all the identified opportunities, it was made a selection of a set of feasible measures then, the proposed model for economic evaluation was applied taking advantage of the excell computer package support , after that, once the economic parameters were calculated, an analysis about the time or sequence constraints was carreied out. The results of these steps are presented in following pages.

1) Calculation of economic parameters
2) Proposed energy programme

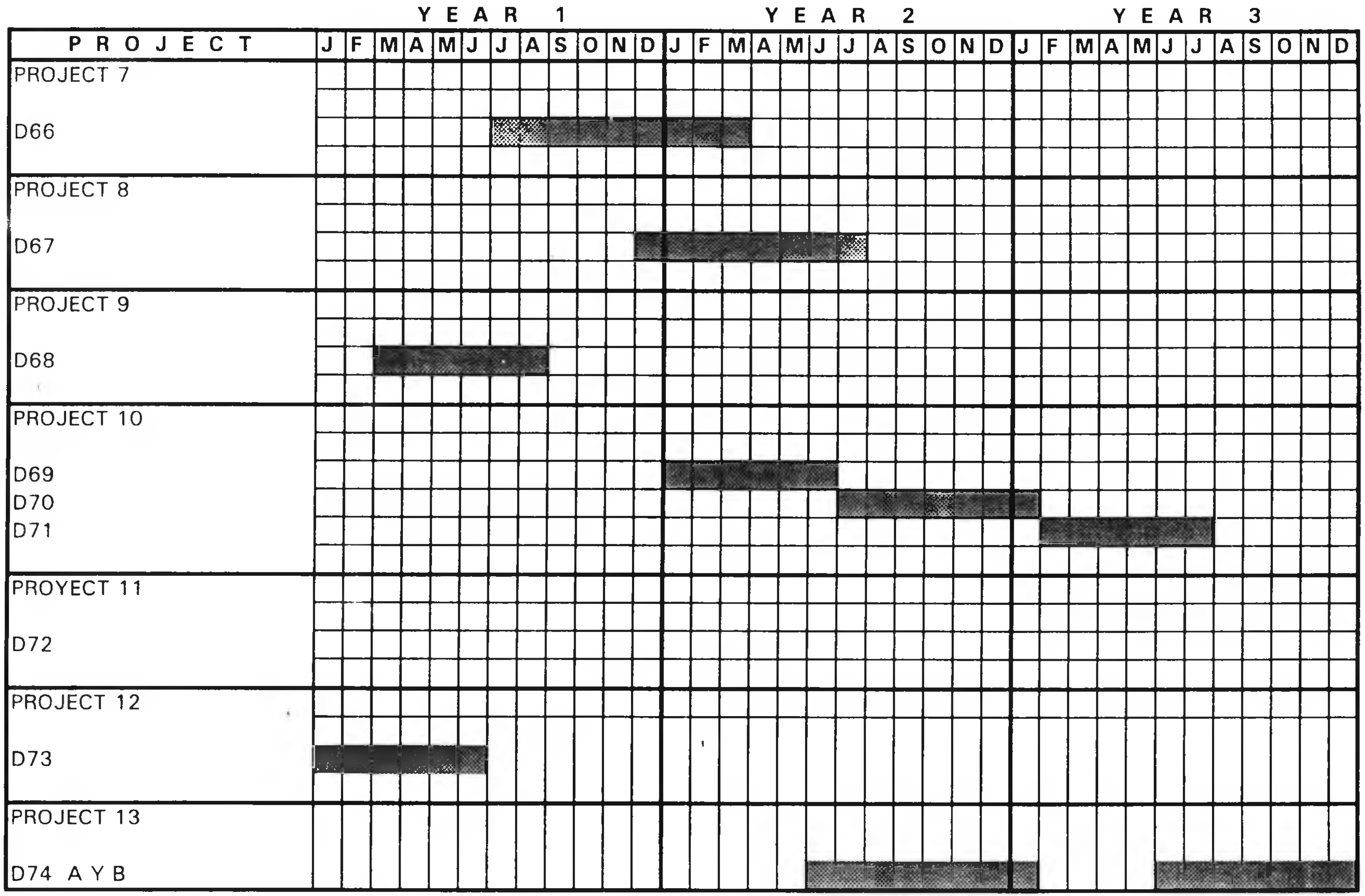
The general strategy for implementing the energy saving programme is to implement first of all, those measures whose investment is zero or very low. This strategy makes it possible to have high profitability of the investment and to diminish the needed financial resources. So, the economic feasibility is related to three levels: Non cost, low investment and middle investment

From the study of the whole measures, those which are feasible and acceptable in terms of profitability were selected first of all. The selected set of measures was the result of several analysis carried out by teams of engineers. For saving energy controling energy losses and improving energy usage productivity through implementing specific projects. This analysis was based on the energy auditing achieved in order to have a good balance between the energy generation capacity and the energy usages.

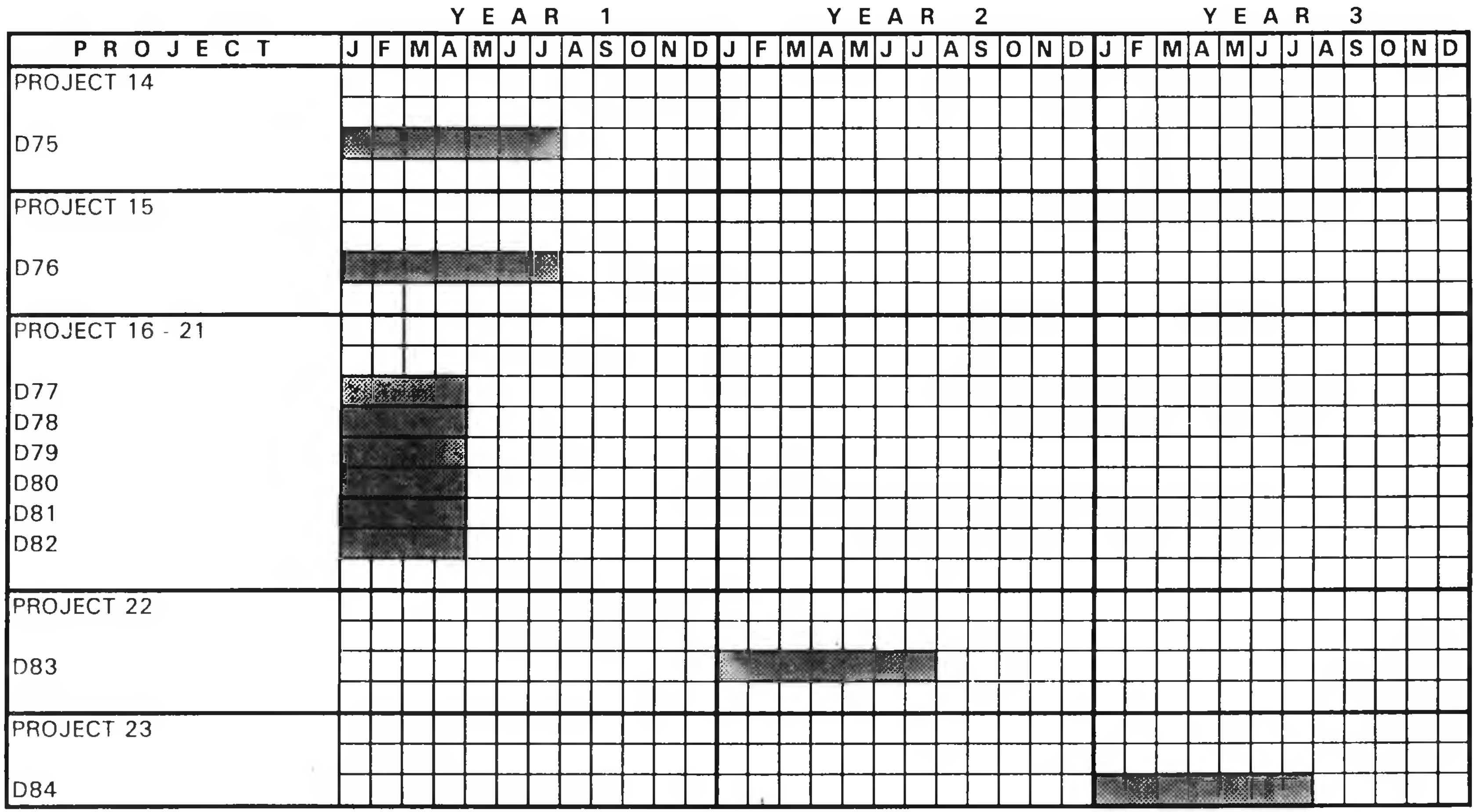
PROPOSED ENERGY SAVING PROGRAMME FOR THE SALINA CRUZ REFINERY



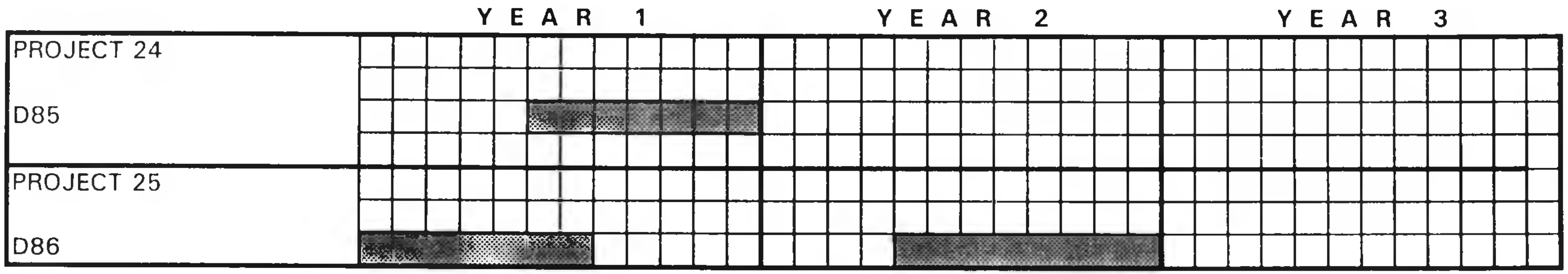
PROPOSED ENERGY SAVING PROGRAMME FOR THE SALINA CRUZ REFINERY



PROPOSED ENERGY SAVING PROGRAMME FOR THE SALINA CRUZ REFINERY



PROPOSED ENERGY SAVING PROGRAMME FOR THE SALINA CRUZ REFINERY



CALCULATION OF PARAMETERS OF MODEL 1

REDESIGNING A REFINERY TO IMPROVE ITS ENERGY USAGE PRODUCTIVITY

PROJECT	ACTION NUM	F.C. (*)	INV MMDL	RETURN YEAR1	RETURN YEAR2	RETURN YEAR3	RETURN YEAR4	RETURN YEAR5	RETURN YEAR6	RETURN YEAR7	RETURN YEAR8	RETURN YEAR9	RETURN YEAR10	RETURN AVERAGE	ROI	PT	NPV	IRR
PROJECT 1. ENERGY ANALYSIS OF FURNACES AND BOILERS																		
1	29	0 14	-17 21	589 5	589 5	589 5	589 5	589 5	589 5	589 5	589 5	589 5	589 5	589 5	34 25	0 03	3074 90	34 25
1	30	0 14	-5 97	206 6	206 6	206 6	206 6	206 6	206 6	206 6	206 6	206 6	206 6	206 6	34 61	0 03	1077 65	34 61
1	31	0 14	-9 91	343 5	343 5	343 5	343 5	343 5	343 5	343 5	343 5	343 5	343 5	343 5	34 66	0 03	1791 74	34 66
1	32	0 14	-3 56	123 0	123 0	123 0	123 0	123 0	123 0	123 0	123 0	123 0	123 0	123 0	34 55	0 03	641 58	34 55
1	34	0 14	-0 91	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	33 19	0 03	157 53	33 19
1	35	0 14	-3 33	116 0	116 0	116 0	116 0	116 0	116 0	116 0	116 0	116 0	116 0	116 0	34 83	0 03	605 07	34 83
1	36	0 14	-0 77	25 5	25 5	25 5	25 5	25 5	25 5	25 5	25 5	25 5	25 5	25 5	33 12	0 03	133 01	33 12
1	37	0 14	-4 87	169 4	169 4	169 4	169 4	169 4	169 4	169 4	169 4	169 4	169 4	169 4	34 78	0 03	883 61	34 78
1	38	0 14	-0 53	18 6	18 6	18 6	18 6	18 6	18 6	18 6	18 6	18 6	18 6	18 6	35 09	0 03	97 02	35 09
1	39	0 14	-0 91	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	33 19	0 03	157 53	33 19
1	40	0 14	-0 87	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	34 71	0 03	157 53	34 71
1	41	0 14	-0 91	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	33 19	0 03	157 53	33 19
1	42	0 14	-0 87	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	30 2	34 71	0 03	157 53	34 71
1	43	0 14	-8 27	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	34 80	0 03	1501 20	34 80
1	44	0 14	-8 27	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	34 80	0 03	1501 20	34 80
1	45	0 14	-8 27	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	34 80	0 03	1501 20	34 80
1	46	0 14	-8 27	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	287 8	34 80	0 03	1501 20	34 80
1	47	0 14	-9 13	320 3	320 3	320 3	320 3	320 3	320 3	320 3	320 3	320 3	320 3	320 3	35 08	0 03	1670 72	35 08
PROJECT 2. AIR PREHEATING TO HEATERS																		
2	48	0 14	-6 38	2 393	2 393	2 393	2 393	2 393	2 393	2 393	2 393	2 393	2 393	2 393	0 38	2 67	12 48	0 36
2	49	0 14	-4 39	0 831	0 831	0 831	0 831	0 831	0 831	0 831	0 831	0 831	0 831	0 831	0 19	5 28	4 33	0 14
2	50	0 14	-6 49	1 379	1 379	1 379	1 379	1 379	1 379	1 379	1 379	1 379	1 379	1 379	0 21	4 71	7 19	0 17
2	51	0 14	-4 62	0 499	0 499	0 499	0 499	0 499	0 499	0 499	0 499	0 499	0 499	0 499	0 11	9 26	2 60	0 01
2	52	0 14	-4 5	0 466	0 466	0 466	0 466	0 466	0 466	0 466	0 466	0 466	0 466	0 466	0 10	9 66	2 43	0 01
2	53	0 14	-5 2	0 682	0 682	0 682	0 682	0 682	0 682	0 682	0 682	0 682	0 682	0 682	0 13	7 62	3 56	0 05
PROJECT 3. INCREASING AREA IN PREHEATING OF CHARGE																		
3	54	0 14	-0 923	0 529	0 529	0 529	0 529	0 529	0 529	0 529	0 529	0 529	0 529	0 529	0 57	1 74	2 76	0 57
3	55	0 14	-0 265	0 129	0 129	0 129	0 129	0 129	0 129	0 129	0 129	0 129	0 129	0 129	0 49	2 05	0 67	0 48
3	56	0 14	-0 459	0 094	0 094	0 094	0 094	0 094	0 094	0 094	0 094	0 094	0 094	0 094	0 20	4 88	0 49	0 16
PROJECT 4. REHABILITATION OF GAS TURBINE AND RECOVERY OF THE HEAT CONTAINED IN THE EXHAUST GAS FLOW																		
4	58	0 14	0 00	5 87	5 87	5 87	5 87	5 87	5 87	5 87	5 87	5 87	5 87	5 87	0 00	0 00	30 62	0 00
4	59	0 14	-6 53	8 29	8 29	8 29	8 29	8 29	8 29	8 29	8 29	8 29	8 29	8 29	1 27	0 79	43 24	1 27
4	60	0 14	-6 40	4 00	4 00	4 00	4 00	4 00	4 00	4 00	4 00	4 00	4 00	4 00	0 63	1 60	20 86	0 62
4	61	0 14	-15 92	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	0 31	3 18	26 08	0 29

(*) CONVERGENCE FACTOR

CALCULATION OF PARAMETERS OF MODEL 1

REDESIGNING A REFINERY TO IMPROVE ITS ENERGY USAGE PRODUCTIVITY

PROJECT NUMBER	ACTION NUMBER	F.C. (*)	INV MMDL	RETURN YEAR1	RETURN YEAR2	RETURN YEAR3	RETURN YEAR4	RETURN YEAR5	RETURN YEAR6	RETURN YEAR7	RETURN YEAR8	RETURN YEAR9	RETURN YEAR10	RETURN AVERAGE	ROI	PT	NPV	IRR
PROJECT 5	STEAM PRODUCTION AND DISTRIBUTION OPTIMIZATION																	
5	62	0 14	-0 20	2 09	2 09	2 09	2 09	2 09	2 09	2 09	2 09	2 089	2 09	2 09	10 45	0 10	10 90	10 44
5	63	0 14	0 00	1 69	1 69	1 69	1 69	1 69	1 69	1 69	1 69	1 69	1 69	1 69		0 00	8 82	
5	64	0 14	-1 50	0 80	0 80	0 8	0 8	0 8	0 8	0 80	0 80	0 8	0 80	0 8	0 53	1 88	4 17	0 53
PROJECT 6	REDESIGNING A PROCESSING PLANT CASE: NAPHTHA HYDRODESULPHURIZATION UNIT																	
6	65	0 14	-6 18	4 56	4 56	4 57	4 57	4 57	4 57	4 57	4 57	4 566	4 57	4 57	0 74	1 35	23 80	0 73
PROJECT 7	HYDROCARBON GAS RECOVERY FROM BLOWDOWN																	
7	66	0 14	-2 17	7 36	7 36	7 36	7 36	7 36	7 36	7 36	7 36	7 36	7 36	7 36	3 39	0 29	38 36	3 39
PROJECT 8	REDESIGNING ATMOSPHERIC AND VACUUM UNITS IN A UNIT																	
8	67	0 14	-10 65	39 70	39 7	39 7	39 7	39 7	39 7	39 70	39 70	39 7	39 70	39 7	3 73	0 27	207 08	3 73
PROJECT 9	DEAERATOR PRESSURE MODIFICATION																	
9	68	0 14	0 00	1 55	1 55	1 55	1 55	1 55	1 55	1 55	1 55	1 55	1 55	1 55		0 00	8 08	
PROJECT 10	IMPROVING PLANT INSTRUMENTATION																	
10	69	0 14	-16 00	12 00	12 00	12 0	12 0	12 0	12 0						0 00	0 00	46 66	0 72
10	70	0 14	-13 00	21 00	21 00	21 00	21 00	21 00	21 00	21 00	21 00	21 00	21 00	21 00	1 62	0 62	109 54	1 62
10	71	0 14	-6 50	6 00	6 00	6 00	6 00	6 00	6 00	6 00	6 00	6 00	6 00	6 00	0 92	1 08	31 30	0 92
PROJECT 11																		
11	72 0	0 14	-0 89	0 29	0 3	0 3	0 3	0 3	0 3	0 3	0 3	0 3	0 3	0 3	0 32	3 10	1 50	0 30
PROJECT 12	EXPORT OF POWER																	
12	75	0 14	0 00	4 70	4 7	4 7	4 7	4 7	4 7	4 7	4 7	4 7	4 7	4 7		0 00	24 52	
PROJECT 13	REPLACING WATER COOLERS BY AIR COOLERS (1)																	
13	76																	
PREJECT 14	LOAD MANAGEMENT																	
14	54	0 14	0 00	0 57	0 57	0 57	0 57	0 57	0 57	0 57	0 57	0 57	0 57	0 57		0 00	2 97	
PROJECT 15	APPLYING ENERGIA METHOD																	
15	57	0 14	-1 65	15 90	15 90	15 90	15 90	15 90	15 90	15 90	15 90	15 90	15 90	15 90	9 64	0 10	82 94	9 64

(*) CONVERGENCE FACTOR
(1) DEEP STUDIES ARE NEEDED

CALCULATION OF PARAMETERS OF MODEL 1

REDESIGNING A REFINERY TO IMPROVE ITS ENERGY USAGE PRODUCTIVITY

PROJECT NUMBER	ACTION NUMBER	F.C. (*)	INV MMDL	RETURN YEAR1	RETURN YEAR2	RETURN YEAR3	RETURN YEAR4	RETURN YEAR5	RETURN YEAR6	RETURN YEAR7	RETURN YEAR8	RETURN YEAR9	RETURN YEAR10	RETURN AVERAGE	ROI	PT	NPV	IRR
PROJECT 16	EVALUATION OF UTILIZATION OF A SETPOINT COMPUTER PACKAGE																	
16	77	0.14	-0.02	6.60	6.60	6.60	6.60	6.60	6.60	6.60	6.60	6.60	6.60	6.60	440.00	0.00	34.43	440.00
PROJECT 17	EVALUATION OF THE ENERGY MANAGEMENT SYSTEM EMS PACKAGE																	
17	78	0.14	-0.02	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	257.78	0.00	24.20	257.78
PROJECT 18	EVALUATION OF THE UTILIZATION ON OF THE ICBC UTOPIA COMPUTER PACKAGE																	
18	79	0.14	-0.05	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	26.40	0.04	6.89	26.40
PROJECT 19	EVALUATION OF THE UTILIZATION ON OF A MDC COMPUTER PACKAGE FOR UTILITIES																	
19	80	0.14	-0.02	3.97	3.97	3.97	3.97	3.97	3.97	3.97	3.97	3.97	3.97	3.97	264.67	0.00	20.71	264.67
PROJECT 20	EVALUATION OF THE UTILIZATION OF PLUTO II FOR UTILITIES OPTIMIZATION																	
20	81	0.14	-0.05	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	5.00	0.20	1.30	5.00
PROJECT 21	EVALUATION OF KRAFTANLAGEN SIMULATOR FOR ENERGY MANAGEMENT																	
21	82	0.14	-0.39	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	11.84	0.08	24.20	11.84
PROJECT 22	DESIGN AND DEVELOPMENT OF A WASHING MACHINE FOR HEAT EXCHANGERS																	
22	83	0.14	-0.57	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.58	1.71	1.72	0.58
PROJECT 23	ADDITION OF AN ENERGY ECONOMIZER FOR RECOVERING HEAT FROM THE COMBUSTION GASES																	
23	84	0.14	-2.1	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.37	2.73	4.02	0.35
PROJECT 24	INSTALLATION OF CONTINUOUS ANALYZERS IN HEATERS AND BOILERS																	
24	85	0.14	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	9.00	0.11	0.05	9.00
PROJECT 25	APPLICATION OF PINCH TECHNOLOGY																	
25	86	0.14	-1.02	12.90	12.90	12.90	12.90	12.90	12.90	12.90	12.90	12.9	12.90	12.9	12.65	0.08	67.29	12.65

(*) CONVERGENCE FACTOR

6.0.0 DESIGNING A NEW REFINERY IMPROVING ITS ENERGY USAGE PRODUCTIVITY

6.1.0 SYSTEM DESCRIPTION

In section 4.2.0, a system structure for the four major activities of the Petroleum Industry, for its wider systems, as well as for its subsystems, were defined.

Several ways for defining the refinery's structure have already been proposed. The following are three possible definitions:

a) Processing plants, maintenance and facilities
b) Processing plants; power station, boilers and facilities; instrumentation, control and information systems.
c) Operation system, control system, information system and support system

In order to describe the system, the second structure is more appropriate. Therefore, as defined in section 5.1.0, to analyze the problem of designing a new refinery to improve its energy usage productivity, the whole system is a typical refinery, which is the result of the integration of three main subsystems:

a) Processing plants
b) Power station, boilers and facilities
c) Instrumentation, control and information

The processing plants that should integrate a typical refinery can be determined by means of a refinery configuration study. In a specific refinery, the type and number of process units that are included depend on the kind of crude oil to be processed, product requirements and economic factors that affect the result, such as crude cost product values and prices and availability of capital for investment.

Refineries are classified as simple, complex or very complex. The simple refineries have only crude distillation, hydrotreating of middle distillates and reforming of naphtha. A complex refinery includes, as well, a cat cracker, alkylation plant and gas processing. A very complex refinery also includes either an olefins unit or a residual reduction unit such as a coker

Other common classification is: Crude topping refinery (1 or 2 complexity); hydroskimming refinery (3 to 5 complexity) and conversion refinery (5 +complexity)

6.1.1 SUBSYSTEM PROCESSING PLANTS

The processes included in a typical refinery are:

- Atmospheric distillation
- Vacuum destillation
- Catalytic cracking
- Catalytic reforming
- Catalytic hydrocracking
- Alkylation
- Aromatics isomerization
- Hydrorefining
- Hydrotreating
- Residue and heavy gas oil hydrorefining

The selected processes and subprocesses mix depend on the specific demand served, the enterprise structure, the utilized mix of crudes, the adopted technology and the policies in commercial and production aspects.

For the definition of this part, it is assumed that there is a basic design for the refinery, obtained as the result of the evaluation of alternatives for different capacities, processes and subprocesses

Then the main matter to solve at this point, is how energy usage productivity can be improved in a new refinery design when a basic design is available. The premises are:

a) The mix of processes are previously defined

b) The technological choices on performance, demand satisfaction and pollution have also been previously taken

c) The whole and partial capacities are also defined

6.1.2 POWER STATION, BOILERS AND FACILITIES

It is necessary to structure and formulate each component of this subsystem:

a) Number and specification for each boiler

b) Number and specification for each turbogenerator

c) Facilities area specification

6.2.0 SYSTEM ANALYSIS

When a new refinery design is needed and the objective of improving energy usage productivity is stated, the analysis should focus on the answer how energy usage productivity can be improved, provided that a specific configuration is adopted.

The solution includes the design of the processing plants section, power station, boilers and facilities and the definition of heat transfer and heat recovery of the whole process. The design of this part depends on the requirements of the processing plants and the general energy balance of the refinery.

In this case, system analysis has the same three major applications and the same concepts as those in section 5.1.0:

a) Problem solving
b) Policy setting
c) Decision making

Partial systems are processing plants; power station, boiler and facilities; instrumentation, control and information systems. Each processing plant has its own characteristics in term of heat consumption, process temperature and capacity.

Therefore, the subprocess mix, technology and heat recovery level determine energy consumption. The methodology and economic project evaluation model can be the same as in the first problem, which was analyzed in chapter III.

The most important difference in respect to that problem, is how methodology and model are applied. In this case, it is necessary to have a basic design in order to apply and analyze the optional solutions. Diagram 6. 2. a. shows the methodological scheme to achieve the best solution. Each option needs to be evaluated from the technical and economic point of view. Performance, cost, return on investment, reliability, time and serviceability are the main factors to consider.

If a good basic design is available, it means that performance, reliability and serviceability have been analyzed and reasonably optimized. Then, cost, return on investment and time analysis are required.

System engineering has a number of different criteria that the design must meet. In considering system designs engineers traditionally place more emphasis on performance than on cost. But, in this case, the methodology is mainly focused on energy usage productivity, so the parameters to be analyzed are:

a) Potential energy saving of each project
b) Total system cost and additional costs per project
c) Profitability of the investment of each project
   - Return on investment
   - Payout time
   - Net present value
   - Net return rate
   - Internal rate of return
d) Time

The proposed system engineering methodology recognizes the refinery as an integrated whole, composed of diverse, specialized structures and subfunctions. It further recognizes that any system has a number of objectives and the balance between them may differ widely from system to system. The specialized structures and subfunctions are the ones that correspond to each processing, service or facility plant. The proposed method is intended to optimize the overall energy usage productivity in the system.

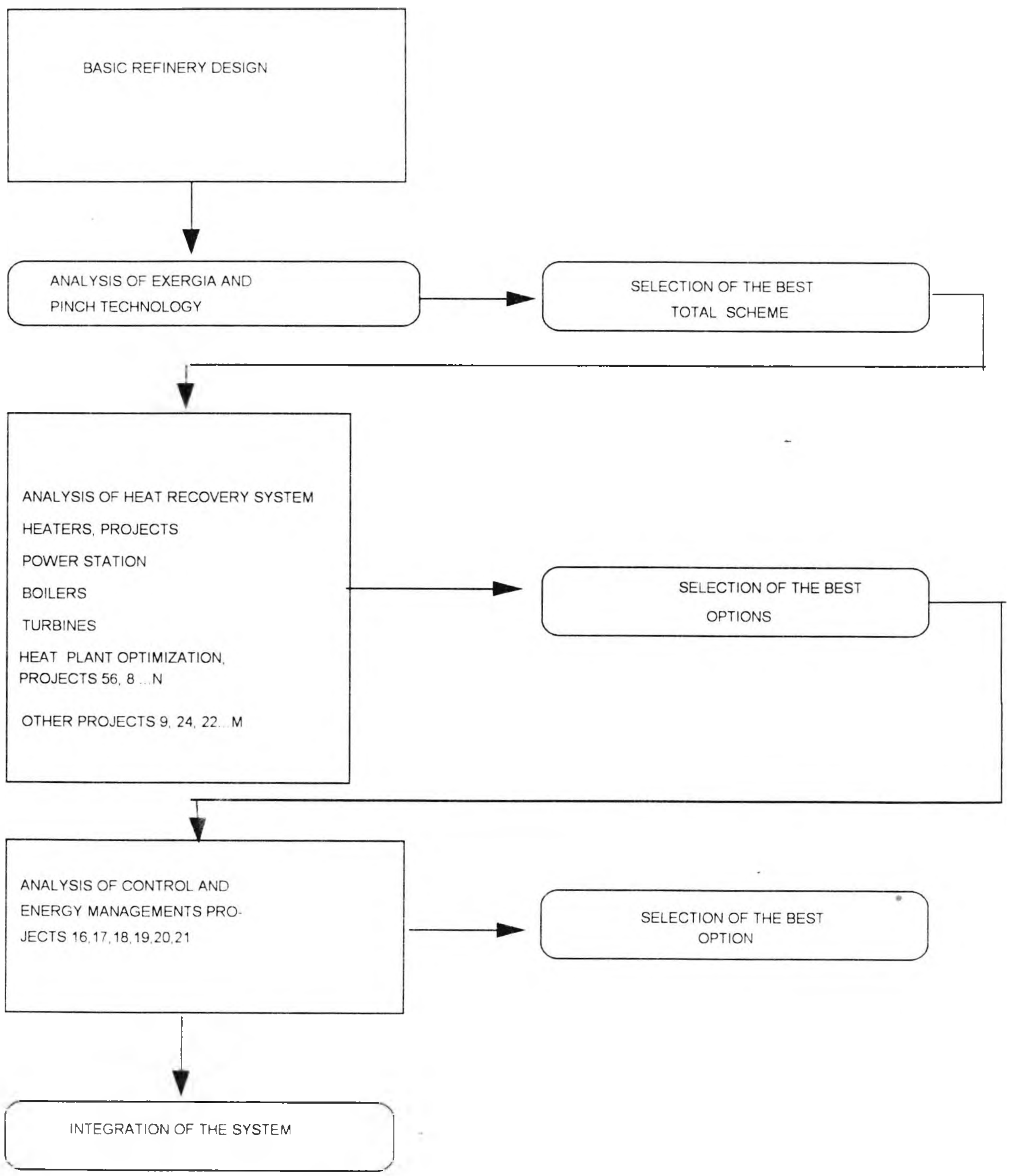
This is not the primary objective of the system, so it represents a conceptual problem. Therefore, the system is made up of subsystems which achieve the main objective and the problem is how to use these parts most effectively in conjunction with new portions, to determine the best additional equipment to save energy.

Two steps are considered: The first, to achieve a good system structure in terms of satisfaction of the demand requirements and achievement of a good system performance; and second, to review the system structure to optimize its energy usage productivity.

When these two steps are considered together and the problem is analyzed in terms of cost-effectiveness, the methodology is the one proposed in section 7.0.

DIAGRAM 6.2.a

ANALYSIS OF THE OPTIONAL SOLUTIONS TO IMPROVE ENERGY USAGE PRODUCTIVITY



Specialized structures and subfunctions are chosen in such a way as to make the overall operation possible and to contribute to the success of the whole system from the point of view of energy usage productivity

6.3.0 ENERGY MANAGEMENT CONTROL SYSTEM

There is a very wide range of energy saving technologies which allow project and design engineers to have many different possibilities to design and redesign processes. A very important aspect to be considered in a refinery design is the energy management control system, particulary when energy usage productivity is the major objective.

There is a strong correlation between the level of control technology, the needed capital costs and the potential benefits of the system in terms of energy saving.

Figure 6.3.a. shows the total energy management process. According with advanced application technology in the specific case of a refinery, energy management should achieve the following partial objetives 1_/

- Boiler control optimization and control
- Soot blowing optimization and control
- Turbogenerator extraction and load optimization and control
- Power demand control
- Chilled water control

1_/ "Energy management concepts". Bulletin 4.008 Fisher. April 1993 . U.S.A. Reference 82

6.4.0 PROJECT EVALUATION MODEL

Provided that the proposed framework for an integrated refinery design is the same as that presented in figure 4.7.a, it is necessary to have an integrated model composed by several parts to analyze different aspects of the system design:

The functional model, the capability model and the availability model are important to analyze performance, heat recovery and support. This analysis must be carried out before the economic project evaluation.

The model for this evaluation has four main parts: 1_/

a) A cost model

This model defines capital cost as well as operational costs related to each design option and makes clear how every additional modification increases a basic total system cost.

b) An energy usage efficiency model

This model analyzes how energy usage efficiency is modified when each proposed modification of heat recovery or up grading of energy management control systems are adopted.

c) A time analysis model

This part is focused on analyzing the feasibility of each action on the time scale taking into account the refinery building programme and the interactions between different projects.

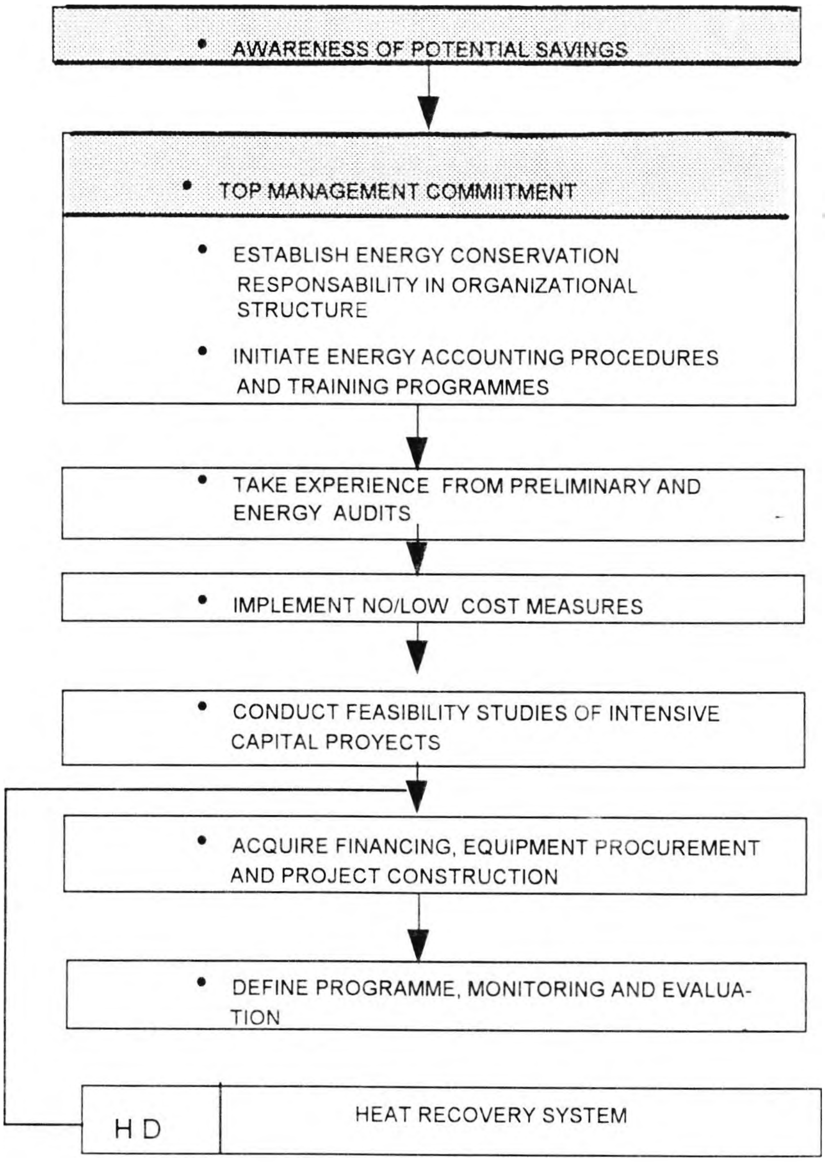
d) An economic project evaluation model

This evaluation is based on an investment profitability analysis model, which analyzes the economic result of each project or measure through the determination of the following parameters: Return on investment **(ROI)**, payout time **(PT)**, net present value **(NPV)** and internal rate of return **(IRR)**

1_/ This proposed model is a simplification of the cost effectiveness model but enough structured to achieve the objective.

FIGURE 6.3.a

THE TOTAL ENERGY MANAGEMENT PROCESS TO SUPPORT THE HEAT RECOVERY DESIGN 1_/



1_/ Streicher A. "Economic and Technological Implications of Energetic Conservation Programs at the National and Enterprise Levels". Reference 22

6.5.0 DESIGNING A NEW REFINERY IMPROVING ITS ENERGY USAGE PRODUCTIVITY

Provided the main objective is to design a new refinery, the formal process to achieve it is structuring the system by defining the refinery´s configuration, synthetizising the system, then starting from a basic design and taking advantage of it optimizing the system by means of the application of different techniques, mainly of heat recovery optimization.

The optimization of the overall system functions, according to the weighed objectives is based on :

1.) Measures performance and compare it to the stated objectives

2.) Project identification

3.) Project selection

4.) Integration of the best alternative for the whole system

From the point of view of system engineering, figure 6.5.a shows the main steps to design a new system.

Figure 6.5.b takes the "Framework for an integrated refinery design to improve energy usage productivity", according with figure 4.7.a, to confirm the essence of the integration between different kind of designs, starting from the system configuration design. Its final result is the project selection for a whole system design.

This framework is similar to that one represented in Figure 4.8.b. When a cost-effectiveness analysis and a life cost model are both added to the above mentioned methodological structure, the result is the framework considered in Figure 4.8.a.

DIAGRAM 6.5.a

DESIGNING A NEW SYSTEM

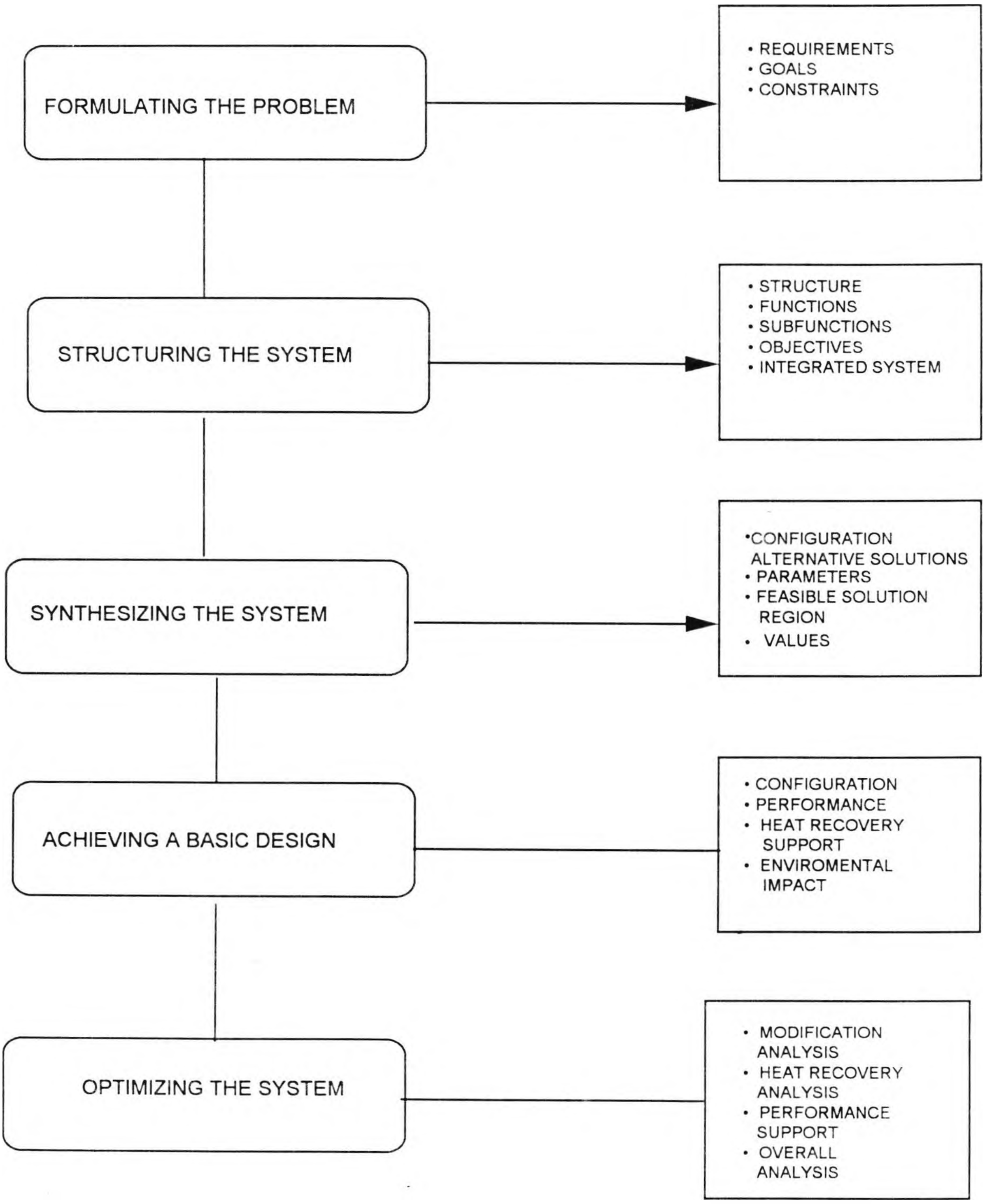
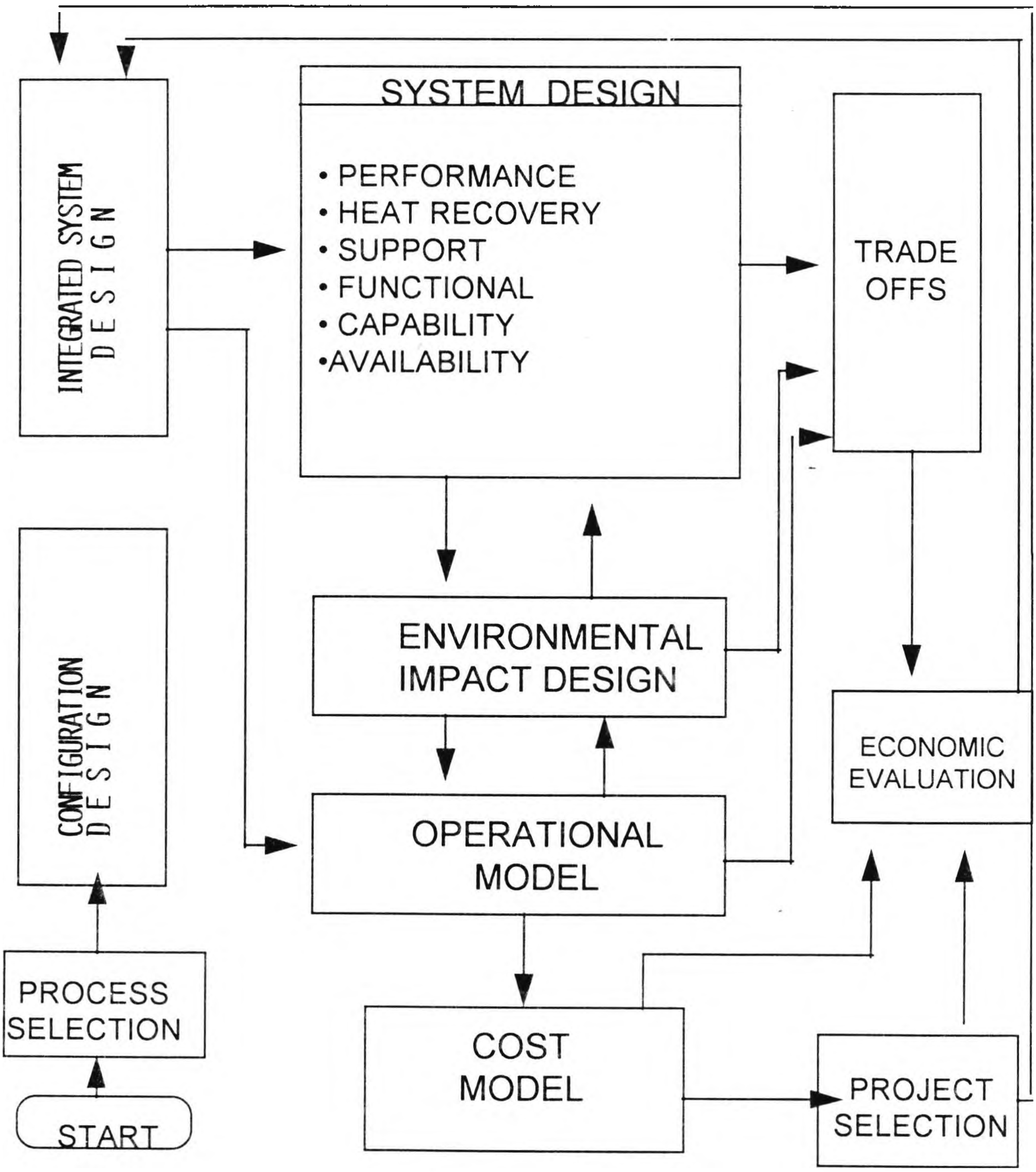


FIG. 6.5.b

FRAMEWORK TO INTEGRATE A REFINERY DESIGN IMPROVING ITS ENERGY USAGE PRODUCTIVY



7.0.0 IMPROVING COST-EFFECTIVENESS RATIO IN A NEW REFINERY DESIGN

7.1.0 COST-EFFECTIVENESS CONCEPTS

Effectiveness can be defined as the probability that a designed operational system will satisfy a stated performance or mission requirements under stated operational environments during the stated system's life-time period.

Cost is the present value of the whole life ownership cost of a system. It normally includes capital, operational, support, maintenance and environmental impact costs.

When a redesign problem is being considered, there is a practical solution that takes in account only the incremental capital needed for the system modification, so it is possible to analyze the incremental performance to evaluate the new increased effectiveness.

When a new design for a refinery is being considered, it can be started from a minimum refinery model, constituted by the processes that are undoubtedly necessary. Cost-effectiveness of this model of refinery is analyzed as a reference for evaluating the alternatives of different mixtures of subprocesses.

7.1.1 SYSTEM COST-EFFECTIVENESS MODEL

This model will be adapted to the measurement of the expected values of total system effectiveness in cost-effectiveness analysis. It should faithfully represent the effectiveness analog of all the elements of the system. The definition of the system's elements depends on the level of use which fixes the effectiveness level and the costing level so, it is necessary to have two models : _1/

A) A cost model

B) An effectiveness model

The related factors of particular significance in system cost-effectiveness analysis are :

1_/ Seiler K. "Introduction To Systems Cost Effectiveness", pp 5 . Reference 2

A) Level of use

B) Inheritance

C) Research and development

D) Input and output

E) Time

F) Performance

G) Geographical location

LEVEL OF USE

Level of use in the organizational hierarchy determines the costing level, hence the depth of cost coverage in the program breakdown structure. In relation to the level of use, it may be well to point out that the higher the level, the greater the tendency for the lower cost levels not to be detailed. 1_/

Trying to clarify the concept of level of use, following the example of the air preheating for saving energy in the Salina Cruz Refinery is analyzed as follows:

TABLE 7.1.a LEVEL OF USE

LEVEL OF USE	DESCRIPTOR
SERVICE	MEXICAN PETROLEUM INDUSTRY
COMMAND	REFINING CORPORATION
SYSTEM	ATMOSPHERIC DISTILLATION UNIT
SUBSYSTEM	HEATERS
MODULE	AIR PREHEATING
COMPONENT	PREHEATERS

1_/ Seiler K. "Introduction to systemx Cost-Effectiveness" pp 6. Reference 2

INHERITANCE

There is a degree of inheritance available when a new system is built. In the above example, the air preheating area can make use of all the existing installations, communication facilities, processing data and control system.

The concept of inheritance leads directly to the concept of incremental cost, which means that only the requirement beyond those that can be inherited are charged to the new system.

Total system cost - Inheritance = Incremental system cost

RESEARCH AND DEVELOPMENT

Research and development is an important phase in system cycle life so, three definitions should be made: **basic research** is the research in which primary result is a complete knowledge or understanding of the subject under study. **Applied research** is directed toward the practical application of knowledge and covers research projects which have specific commercial objectives with respect to products or services.

Development is the systematic use of scientific knowledge directed toward the production of useful materials, devices, systems, methods, prototypes and processes.

INPUTS AND OUTPUTS

The total cost of a system can be measured in terms of the identified inputs to the production unit. This is the conventional cost-accounting approach based on market values. These cost elements are material, labor and capital. Besides which, there is a pro rata provision for the recovery of the costs of administration, distribution and a return of capital.

Costs may be categorized in terms of the sensitivity to changes in output. Costs that change with output will also be changing with time, but costs that change with time do not necessarily result in a change in output.

In the long run all costs are variable, but cost-effectiveness analysis are predominantly short run. The components of total systems costs **c** are classified in terms of sensitivity to output as follows: 1_/

1_/ Seiler K. " Introduction To System Cost Effectiveness" pp 10. Reference 2

Total system cost = C, dC/dQ > 0, < ∞

Total fixed cost =F , dF/dQ = 0,

Total variable cost = V, dV/dQ > 0, < ∞

Average system cost = $\bar{C}$, , d$\bar{C}$/dQ > 0, < ∞

Average fixed cost = $\bar{F}$, d$\bar{F}$/dQ > 0, < ∞

Average variable cost = $\bar{V}$, d$\bar{V}$/dQ, > c < ∞

These cost components are related as follows:

$$C = F + V = \sum_{i=i}^{m} F_i + \sum_{i=i}^{n} V_i$$

Where i = cost of the i-th component

The yield of an activity should, if possible, be expanded only as long as the marginal benefit exceeds the marginal cost. The expansion should be stopped at the point at which the marginal net yield is zero.

BREAKEVEN POINT 1_/

The analysis of cost as a function of output of the intersection of the cumulative effectiveness or revenue curve and the cumulative cost curve; is known as the breakeven point. This analysis is of particular importance in cost-effectiveness analysis when the ratios of the fixed cost to the variable cost are widely different among the competing alternatives.

One example clarifies this point. If we have two systems that have the same revenue or effectiveness curve and also have the same total system cost, the only difference is the ratio of fixed to variable cost. the conclusions are presented in the following table:

TABLE 7.1.b

	1	2
DOMINANT COST	FIXED COST	VARIABLE COST
BREAKEVENPOINT	LATER. HIGHER	EARLIER. LOWER
NET EFFECTIVENESS	SMALLER	LARGER
AREA	LARGER	SMALLER

1_/ Seiler K. "Introduction To Systems Cost Effectiveness". pp. 14. Reference 2.

The first one consists principally in a series of summations and the second one in a series of multiplications.

The initial phase in system effectiveness model development, is the assembly of the appropriate elements of effectiveness.

E(E) = E = Expected effectiveness of the system

E(P) = P = Expected performance of the system

Cp = Statistical confidence of performance

E(A) = A = Expected availability of the system

E(R) = R = Expected reliability of the system

E(S) = S = Expected survivability of the system

E(E) = [E (P) Cp] [E(A) Ca] [E(R) Cr E(S) Cs]s

The basic performance variable E(P) represents the expected value of a distribution of possible performance variables that would fall within given statistical confidence limits.

The statistical confidence level is a measure of the expectancy that a simple interval will contain the true value of the population parameter.

It is most common for a system to be characterized by more than one basic performance parameter and the expected value of p may have to represent an index of a combination of expected basic performances of various subsystems.

PERFORMANCE

1. Performance
   1 A. Demand suitability
   1 B Products yield
   1 C Efficiency
   1 D Used energy
2. Availability
3. Reliability

4. Survivability
5. Cost- worth
6. Environmental adaptation

7.1.2 REFINERY TECHNOLOGY AND EFFECTIVENESS

Refinery performance, energy usage and pollution, from the point of view of technology, are determined mainly by process and design engineering attached to industrial projects. It is technically difficult to improve in a short time the used technology because it is highly demanding of financial resources and because at a given time, there is a mix of processes corresponding to technology of previous decades in existing plants.

Particularly, third world countries are dependent on industrialized nations in this respect. They do not have the capacity of developing technological solutions to improve performance, energy usage productivity and environmental effects. Their current technology is the same as what was available in other countries many years ago, since know-how is transferred by licensed processes and technological papers.

The first Mexican refineries were built in the 1920's, but most plants were built in the 60's and 70's. Each refinery has had its own development whereby several processing plants were incorporated during the last four decades.

A refinery is a system that has several processing plants with different technological ages, so the refinery performance, energy efficiency and pollution result from the combination of the specific mix of processes and subprocesses, each of them with their own attributes.

The main idea for analyzing cost- effectiveness is considering the plant as a man-machine system requiring proper coordination and optimization of its several interdependent parts, throughout the plant's life cycle. system engineering has the privilege of defining the best design by harmonizing the conflicting view points at the design stage, so the plant satisfies the cost, performance and ecological requirements to achieve a high cost - effectiveness ratio during the whole cycle life.

7.1.3 IMPROVING COST - EFFECTIVENESS

Long term gains in energy saving, waste minimization and improved performance can be achieved selecting new processes and operations, when technology is being defined by means of planning of the following aspects:

Market suitability objectives

Energy usage minimization

Waste minimization

Operating costs and capital cost investment minimization

These four partial objectives may be achieved through partial analysis and a final integrated evaluation, which consider cost and effectiveness levels

PERFORMANCE

- Operativeness
- Product performance
- Energy usage productivity
- Operating costs
- Capital costs
- Energy costs
- Availability
- Reliability

COST

- Fixed cost
- Variable cost

7.2.0 WHOLE SYSTEM ANALYSIS

Based on concepts of systems engineering, problem definition, system analysis methodology, the whole system analysis should consider the following aspects:

7.2.1 SYSTEM STRUCTURE

- Macrosystems
- Systems
- Subsystems
- Environment

7.2.2 SYSTEM LIFE CYCLE

- Realization
- Acquisition
- Operation
- Renovation
- Retirement

7.2.3 WIDER SYSTEMS

- Mexican petroleum industry
- World refining business
- Mexican social, economic and environmental system

7.2.4 COST AND EFFECTIVENESS ANALYSIS

COSTS ANALYSIS

- Fixed cost
- Variable cost
- Operational costs
- Life costs and cost by phases
  - Research and development
  - Engineering design
  - Engineering project
  - Installation and test
  - Operation
  - Retirement

EFFECTIVENESS ANALYSIS

- Performance analysis
  - Operativeness
  - Product performance
  - Energy usage productivity
  - Efficiency
- Availability
- Reliability
- Survivability
- Other aspects
  - Level of use
  - Inheritance
  - Research, development and technology
  - Inputs and outputs
  - Breakeven point
  - Size and vertical integration
  - Refinery configuration
  - Time
  - Geographical location

7.2.5 MANAGERIAL AND FINANCIAL FACTORS

- Human resources
- Investment profitability
- Return on investment
  - Payout
  - Cash margin
  - Change process

7.2.6 ENVIRONMENTAL IMPACT ANALYSIS

- Refinery pollution

  Air emissions

  Waste water

  Product quality (fuel, gas and gasoline)

  Automotive emission

  Whole environmental adaptation

7.2.7 MISSION REQUIREMENTS

- Demand structure
- Demand suitability
- Products yield

7.2.8 GOVERNMENTAL REGULATIONS

- Vertical integration
- Diversification
- Environmental regulation

7.2.9 COST - OFFS

Coupling between various partial designs interactions between **RD**, **MD** and **LD** interactions between performance and availability local optimization vs whole optimization

7.3.0 COST - EFFECTIVENESS MODELS

The integration of this model takes place when the expected values of the system cost and effectiveness are combined into a single common index for each alternative.

These parameters provide a basic framework for a rational cost-effectiveness decision making process. System's cost-effectiveness models are analytical analogs of the physical system that represent, in this case a refinery. The final analysis has only estimates based on fundamental assumptions to predict the future realization of future objectives.

To develop the cost-effectiveness model, it is convenient to make an evaluation of cost and effectiveness. This evaluation will limit the graphical field of system alternatives to a northeast corner "Domain of Feasibility", as shown in figure 7.3.a

7.3.a DOMAIN OF FEASIBILITY

DOMAIN OF FEASIBILITY	EXCESS COST
DEFICIENT EFFECTIVENESS	EXCESS COST AND DEFICIENT EFFECTIVENESS

7.3.1 A SYSTEM COST MODEL

This model is especially adapted to the measurement of the expected value of the total system cost within a cost-effectiveness analysis. It ideally represents the cost of all the elements of a system, from inception to retirement.

The system cost model should not be made too detailed lest it become unmanageable, yet it should not be too general lest it become insensitive to significant parameters.

The arrangement of the cost data is usually represented by a two-dimension matrix where all the significant element costs are organized by phases and modules.

Although it is possible to have a very extensive number of elements, it is better to initially have groupings of several elements to reduce the number of figures to be estimated and to have a more representative approach.

The cost of an element can be determined mathematically by adding up the various components of its costs in each phase

PHASES 1_/

R & D PHASE

$R_{el} = (E_s + E_h + E_r + E_m + E_c + E_e)$

Where

R_{el} = Research and development
E_s = Engineering, systems,
E_h = Engineering, human factors
E_r = Engineering, reliability
E_m = Engineering, mechanical
E_c = Engineering, civil
E_e = Engineering, economics

INVESTMENT PHASE

I el = Ed + Ep + D + T + (M+L) EXP Q + S + F + X + Y + Z,

Where

I_{el} = Investment
E_d = Engineering, design
E_p = Engineering, project
D = Drafting
T = Tooling
M = Material, factory
L = Labor, factory
Q = Learning curve factor
S = Spares
F = Freight
X = Emplacement

1_/ Seiler K. "Introduction To Systems Costs-Effectiveness". Reference 2

Y = Installation

Z = Test

OPERATION PHASE

$O_{el} = (S + W + L + P + C_c)$

Where

O_{el} = Operation

S = Spares

W = Spares incluiding logistic support

L = Labor

P = Power or Fuel

Cc =Communication channels

7.4.0. REFINERY PERFORMANCE MEASUREMENT

Performance measurement is concerned with competitive activities within the individual business segment of each refinery in a competitive environment. In the refining industry performance is related to the following factors:1_/ 2_/

Vertical integration
Diversification
Size
Change process
Goverment regulation
Profitability

Measuring the performance of a refinery is a complex task which each company approaches with different objectives and methods. There are many areas of interest when a refinery's performance is being evaluated and it can be viewed from several perspectives: Economic, political, accounting, regulatory and technical.

1_/ Jelen F.C. "Pitfalls in profitability analysis". Reference 27

2_/ Solomon "Development of comparative refinery performance analysis" Reference 58

It is necessary to build a data base to support this performance measurement task. The most recommended base to have the needed data is a use orientation; since any analysis might be speculative it should be based on abstract theory.

Performance measures should be useful to the refinery management. Although the solution does not involve a simple cost-benefit analysis. Benefits from individual performance measurements cannot always be separated.

As in formal analysis, a process of hypothesis formation is necessary, to define the combination of measures that satisfy use-oriented needs. It is very common to find extreme hypothesis and it is very important to overthrow the null hypothesis and to reduce the potential hypothesis. The analysis of hypothesis implies value judgments. The performance measurement system should then allow a capability for hypothesis revision.

Many people think of maintenance of stable secure markets is the primary objective of oil companies and this objective is mainly achieved by the practice of controlling most of the crude oil and refined products, thereby inhibiting competition.

It is felt that competition in oil industries is intramural for sharing the international market internally regulated by the vertically integrated majors. Interdependency among major firms for a larger share of market prevents entry by independent competitors and keeps the stability of the integrated industry.

Competition within the refinery market affect competitive activity within the marketing sector. Integrated oil companies control the majority of crude and refined petroleum product supplies.

If the supply of crude to them is reduced, the total available supply of refined products declines. These companies must allocate the reduced quantity between company controlled stations and the third party market, shutting off the independent marketers.

Following it is defined the main content of each of the mentioned factors

7.4.1 VERTICAL INTEGRATION

a) Efficiency and control lelvel as a result of vertical integration

b) Future integration

c) Efficiency levels associated with vertical integration

d) Effectiveness of vertical integration to gain market

7.4.2 DIVERSIFICATION

a) Extension of control in various refining areas

b) Diversification patterns and trends

c) Comparison with diversification trends of other firms

d) Development of new technologies to back up diversification

7.4.3. S I Z E

a) Size, profitability, degree of obtained integration

b) Integration level of the main refining centers and divisions

c) Size vs efficiency, and risk reduction

d) Size is a factor to increase market share

e) Size is a a factor to research and development capital formation

7.4.4. CHANGE PROCESS AND FINANCING

a) Company patterns of profitability and development

b) Changes associated with size and profitability

c) Investment and production rates compared with other firms

d) Capital formation

e) Investment financing. market forces influences on investment patterns

f) Market forces influence on development of new technology

7.4.5. GOVERNMENT REGULATION

a) Impact of federal government regulation on competition within particular segments of the industry

b) Economic impact of federal regulation

c) Federal tax policies in different alternative fuel sources

d) Aggregate financial impact of the present system of entitlements of other federal energy regulations

The competition in the petroleum industry is very fierce, since 300 000 firms are responsible for extracting crude oil, refining it into usable products and distributing them.

The four basic functions of the petroleum industry are : Exploration and production, transportation, refining and marketing. The refining sector is a complex and capital intensive industry that transforms the hydrocarbon mix of different crude oils into dozens of products. Firms operating in the petroleum industry are of greatly varying sizes. only 20 of them, such as EXXON, TEXACO, MOBILOIL, standard of california and gulf are major integrated petroleum companies..

7.4.6 THE PERFORMANCE MEASUREMENT PROBLEM

The objective of performance analysis is to present as clear as a picture of the most relevant factors to the manager. The detail level needed for the management decision making is greater than that for external reporting. There are different measurements of performance for planning, control, economies and other functional areas.

Performance measurement in economics is a use-oriented problem, in which the performance of an industry is compared to some ideal state.

7.4.7 PROFITABILITY

Functional profitability of refining has become more important in recent years. For a long time there was less concern resulting in areas largely unprofitable.

The collapse of crude oil prices has brought about new concepts on functional profitability in the refining industry. Most major companies are being structured to have more profits, are placing new emphasis on profit generation.

Now, there is interest in comparative refining efficiency data because of the urgent requirement for generating profits when there is a declining demand for some products and a possible reduction in some prices.

7.4.8 INTERNAL FACTORS OF REFINERY PERFORMANCE

7.4.8.1 A COST-EFFECTIVE PLANT

Common goals when managers are concerned with operation or designing a plant are: In project engineering, to achieve high operational efficiency for a given capital cost; in maintenance engineering, to have high reliability supported by excellent maintenance to minimize downtime; in logistic engineering, to adequate provisioning for minimizing the risk of stock-out; in personnel management, training on-the-job learning to maximize human potential; in finances, having a good financial control for improving the rate of return.

System engineering prefers not having a specific point of view because of its criteria about whole-life-cost, which includes capital cost for building the plant, operating and maintainance cost from commissioning to retirement, the unreliability costs and the marketing costs, among others.

An effective plant has a high probability of being, for different operational environments:

a) Operationally ready at any time

b) Able to complete its objective

c) Able to meet the performance requirements

7.4.8.2 INTERNAL FACTORS OF REFINERY PERFORMANCE

There are many factors which explain an specific refinery performance:

OPERATING CHARACTERISTICS

Refinery utilization

Crude unit utilization

Refinery complexity

Refinery age

Crude API and sulphur content

Operating cost

Maintenance index

Mechanical availability

Energy intensity index

ECONOMIC AND FINANCIAL FACTORS

Capital investment index

Return on investment

Payout

Cash margin

MANAGERIAL FACTORS

Human resources management

Personnel

7.5.0 STRUCTURAL ANALYSIS FOR SAVING ENERGY AND CONTROLLING POLLUTION IN A NEW PETROLEUM REFINERY DESIGN.

Petroleum industry has an energy consumption and an overall pollution profile depending on several structural aspects. The most important are: The subprocess mix of the industry, outputs of each subprocess and facilities utilized.

As much as we try to improve energy usage productivity by means of operational or maintenance actions, when we try to improve a refinery design in order to come to an ideal solution for energy consumption and pollution, it is convenient to collect information about a completely accurate energy profile of the present conditions.

Other questions should as well be answered: What there will be in the future, which the factors contributing to change are, how much energy usage and pollution picture are affected by refinery's size, technology, sources and characteristics of raw materials; are refinery location, of the refinery's processes and combination of waste treatment processes and pollution

An understanding of all these factors for a complex refinery involve a study so comprehensive that the time required makes considering this base as a projection of future conditions impractical.

Petroleum industry pollution is concerned with the integrated industry in general, from crude production to desalting, to refining to product storage and distribution. Nevertheless, in this part the main interest of this research is to analyze the interaction between refineries and their environment. All petroleum activities may be sources of emissions to air. Production and refining may be sources of many types of emissions from the complex equipment and operations involved. 1-/

The four principal environmental problems concerning the oil industry are:

- o Oil spills
- o Sulfur in fuel oil
- o Automotive emissions
- o Effluent and emissions from refineries

This research is concerned only with refining. As a consecuence of its operation several polluting materials are released into the environment. The pollutants which are by - products of the refinery process are:

- o Hydrogen sulfide that is formed in hydroprocessing (catalytic reforming, hidrotreating andhydrocracking) and cracking (catalytic, thermal and coking); sulfur oxides are also formed in the combustion of sulfur containing liquids.

- o Hydrocarbon vapors can escape from tanks containing gasoline or crude oil.
- o Carbon monoxide is a by product of catalytic cracking. Also, some catalyst dust occurs.
- o Substances which create a biological oxygen demand (BOD) in waste water are formed in catalytic and thermal cracking.
- o Waste water from every refinery may contain oil.

There are different processes used to control the emission of these pollutants

1_/ Jones H.R. " Pollution Control in the petroleum industry". Reference 93

7.5 1 REFINERY TECHNOLOGY

7.5.1.1 REFINERY COMPLEXITY

A petroleum refinery is an organized arrangement of processes to provide both physical and chemical change of crude oil into sellable products with the qualities and in the volume demanded by the market. A refining installation includes all necessary facilities: adequate tankage for storing crude oil, intermediate and finished products, a source of electric power, workshops and supplies for maintaining continuous operation 24 hr/day operation

Depending on the process used, refineries can be classified as simple, complex or fully integrated. A simple refinery includes crude oil distillation, catalytic reforming and treating. A more complex refinery requires the following additional process: Vacuum distillation, catalytic cracking with gas recovery, polymerization and alkylation. This installation produces high-octane gasolines. The fully integrated refinery makes a full range of products. The process includes high vacuum fractionation, solvent extraction, desasphalting, dewaxing and treating. Depending on the type of crude oil used, the refinery may have to include one more hydrogen process. If sour crude oil is used and if sulphur can be recovered in profitable volumes, a refinery includes a unit for this purpose.

Processes in Mexican refineries are shown in tables 7.5.a and 7.5.b . The Salina Cruz Refinery can be considered a complex one because it has the following processes: Distillation, vacuum distillation, hydrodesulphurizing naphtha, naphtha reforming, intermediate products distillation, hydrodesulphurating, catalytic cracking and sulphur recovery. Aside from these it also has facility areas with boilers, cooling towers and turbogenerators. Although it cannot be considered a fully integrated refinery because it does not have processes such as alkylation, solvent extraction nor dewaxing.

7.5.1.2 CURRENT PROCESS IN OIL REFINING

Refinery technology is a composite of catalysts process, equipment and control systems. Forecasts for the year 2000 let us see that catalytic reforming, cracking, hydrotreating, hydrocracking and coking will still be key processes. Modernization will bring a pattern of development on unit sizing, equipment reliability and control systems. In control there will be improvements in corrosion control, furnace coking control, rotating equipment monitoring and microprocessor applications to process control. 1_/

1_/ Kane E.D. "Refining will see changes by 2000". Reference 86

The refinery design will be highly integrated to achieve capital and energy savings by eliminating intermediate tankage and minimizing heating-cooling loads

CATALYTIC REFORMING.

In the fifties this process operated at pressures of 500-700 psig, 75-85 octane range and 2 years of catalyst life. Today the new technology will allow 100 octane, a 200 psig operation and 10 year of catalyst life.

From 1965-1975 reformate yields increased from 65 to 75% on fresh feed; the yield forecasted to 2000 is 81%, a 95% approach to reforming perfection. That means nil destruction of feed aromatics, nil naphthene ring loss, selective conversion of paraffins to aromatics and complete conversion of c7 plus paraffins.

Only a minor reduction of pressure was projected, as an economic solution to have a balance between yields and mainly capital costs. Continuous reforming was commercialized in 1970. The future of the reforming process depends upon catalyst developments. Reforming front-runner position is expected to be maintained.

CATALYTIC CRACKING.

This is the key process for gasoline production. Hydrocracking process offered the same competition in the sixties. Now, catalytic cracking has maintained its position thanks to a "learning curve" of equipment development, operation expertise and effective utilization of zeolite cracking catalyst.

Refinery technology has benefited by a conjunction of both processes where in highly aromatic catalytically cracked cycle stock can be charged to hydrocrakers for complete conversion to lighter products.

Current technology optimizing zeolite catalysts riser cracking, feed hydrogen pretreatment and hydrogeneration-recracking of cycle oil was shown to achieve 78% yield. In the near future it is expected to achieve 85%

Regarding to SO_2 emission, it can currently be reduced by treating flue gas or by desulfurizing the feedstock.

Crude and reduced crude cracking will benefit from SO_2 reduction system, catalyst developments and control of metal content feed stocks will come very soon and will include the production of low sulfur synthetic crudes and petrochemical feed. The process is forecast to up grade heavy oil reserves.

HYDROTREATING

Now, hydrotreating is a key process for naphtha pretreatment, catalytic reforming or residue desulfurization, catalysts do specific jobs and their performance can be evaluated through a relative-activity rating. This parameter shows that catalyst activity has improved from 0.6 in 1950, 1.0 in 1955, 2.0 in 1965 and 3.0 in 1975. This means that the same degree of desulfurization can be achieved with a third of the amount of catalyst.

Residue hydrotreating catalyst differs in that it suffers activity loss because of metal contamination and coke deposition. Current processing to produce low sulfur product is still be withdrawn regenerated, selectively demetallized for vanadium and nickel removal and recycled to service.

HYDROCRACKING

This process will continue to fullfill several refining technology needs with its excellent yield pattern, nil sulfur content products and the capability to completely convert polynuclear aromatics. Hydrocracking will lead to lower pressure, lower hydrogen consumption operations and an improved yield maintenance throughout a run.

COKING

It is expected that delayed and fluid coking of residuals will be more efficient, but not so in respect to the control of thermal reactions.

In annex 6 the eviromental control process are shown in detail.

7.5.1.3 FUTURE CHANGES IN REFINERY TECHNOLOGY

Besides the process evolution, refineries are expected to have the following changes:

1 Running heavier crudes

2 Consuming a lot more hydrogen

3 Petrochemical feedstock will continue increasing

4 Future refineries will need more capacity conversion

5 Refineries will continue to reduce the impact of other operations on the environment

6 Refineries will not use substantially fewer people than todasy's, but the people will be better trained

7 Refinery flares will be extinguished and relief systems will be provided with recovery equipment

8 Computers will be used much more than today. Their uses are for: planning, process control, product blending, most control will be on line

9 Product blending will allow to reduce inventories. for this purpose operations will be in line blended to shipments, automatically into customer ordering and invoicing.

10 Marketing will be more complex because it will be a combined operation between exporter refineries in producing countries and domestic refineries.

7.5.1.4 TRENDS IN OIL PROCESSING IN NEXT YEARS 1_/ 2_/

Crude oil distillation capacity has not increased much in last period in the international market. But conversion and treating capacity showed respectable increments. There was a strong demand for gasoline, diesel fuel and other high quality products in last years. The slight increase in crude capacity has kept the industry closely balanced with demand, besides its operating rates and operating margins have kept also high.

In the middle of the 1980's much excess refining capacity in the form of old, inefficient refineries had been idled. Some of that is beginning to restart as the industry enters the 1990's.3_/

1_/ Jones L.R. "What's ahead in 1992. U.S. Refiners will face a year of challenge". Reference 87
2_/ Penick J.E. "Future refinery to have different look." Reference 89
3_/ "Regulation will govern refining processes and operations". International Petroleum Encyclopedia 199. Reference

In the 80's it was observed that refinery operating rates, expressed as crude runs as a percent of crude capacity, have been on the rise in spite crude capacity was more or less the same. A steadily increasing demand has pushed operating rates up. Nevertheless, capacities of key downstream process that produce gasoline and diesel showed good percentage increases in the USA; processes that treat the feeds to these key processes also had high increases because of demand for conversion and light fuel production.

The downstream capacity increases also reflect the response to more critical environmental rules that currently mandate oxygenated gasoline blends in winter and lower gasoline vapor pressure during the summer. These rules could limit the industry's ability to meet demand but could had the positive effect of keeping refining margins healthy.1_/

Fluid catalytic cracking will help to meet some of those proposed environmental rules. Key processes that produce light fuel products such as fluid catalytic cracking, catalytic hydrocracking, alkylation and aromatics-isomerization have scored notable capacity gains during these last years.1_/

In 1989 FCC capacity grew 2.8%, catalytic hydrocracking capacity rose 4.1%, and aromatic isomerization capacity 12%, hydrotreating capacity rose 2.2%. FCC pretreating capacity 3.7% and catalytic naphtha reformer feed treatment and naphtha desulfurization capacity rose 2 %. The biggest increase was in straight run distillate hydrotreating capacity; up 17.9% because of a redefinition of the types of material being hydrotreated.

The residue and gasoil hydrorefining capacity rose 2% indicating a continued need to convert heavier feed stocks into light products. Higher demand for high quality light fuel products has placed more emphasis on increasing the capacity of the processes that produce them. Capacity demand balance has been maintained for the last 4.5 years because the industry has only added the incremental distillation capacity needed to meet demand.

Refined products demand is expected to rise 1% so capacity should remain in close balance with demand, keeping refining margins healthy as the industry progresses into the 90's,. So, Refinery construction activity is expected to be moderate in next years because the current margins, although good, still do not provide enough economic incentive to build modern refineries.2_/

1_/ Dosher J.R. "U.S. Refining industry faces political and economic hurdless". Reference 90
2_/ Masologites G. " Refining Technology to keep on expanding. Reference 88

7.5.2. FUTURE CHANGES IN ENERGY USAGE EFFICIENCY

Crude oil is now being revaluated worldwide, and despite its costs, it has gone up and down in the last decade as a consequence of market variations. It is expected that in the coming years, crude oil will be largely reserved only for production of transportation fuels and petrochemicals. 1_/

As petroleum falls to a short supply and its cost increases, it will be directed to higher-value uses. Residual products will be up-graded to lighter products; motor gasoline production will peak and diesel will have a modest growth. 2_/

In the future, petroleum reserves will be utilized in a much more rational way. Indeed, the energy conservation potential is still considerable for all uses of petroleum.

In industry, energy consumption for main processes, such as manufacturing of cement, steel and glass, is much higher than the theoretical consumption required. The gap is so wide that there is an opportunity for great advances in energy usage efficiency. 3_/

At present time, such advances have been limited because of the economic situation, so only investments corresponding to a payout of preferably less than 3 years are being made.

In other countries, new home heating regulations could result in great improvements; additional savings of about 15% can already be hoped for by improving existing technics and other reductions in consumption should be made possible by technological improvements in new vehicles. 3_/

Aside form all this, a different sort of competition between energies is also expected.in this way, oil can be partially substituted by nuclear or solar energy. Also coal or synthetic fuels, are going to gain market, after a hard competition between them in terms of cost, geographic availability and sulphur content.

1_/ Cleveland Ch. H. "Energy and Conservation". Reference 24.
2_/ Penick J.E. "Future refining to have different look". Reference 89
3_/ Streicher A. "Economic and technological implications on energy connservation programs at the natural and enterprise levels". Reference 22

7.5.3 POLLUTION CONTROL

Governmental actions and policies will determine much of the future structure of the petroleum refining industry. Demand, product quality, environmental controls and capital availability will be the main factors which will determine the refining evolution.1_/

But pollution control is, undoubtedly the new factor that will have a relevant effect on refining. Many petroleum companies have formed an unprecedented alliance with the automobile industry to develop cleaner burning gasolines. Refiners have included new reformulated gasolines and diesels.1_/

The problem is that the amount of reformulated gasoline that can be made in existing refineries is limited. There isn't much flexibility within refineries to change gasoline specifications. Only if refinery industry is faced with investments of billions of dollars it will be possible to make major process changes. For controlling pollution, the strategy is to reduce the aromatics and olefin contents of gasoline and substitute oxygenates which reduce carbon monoxide emission and boost octane.

Regulation in all countries will be stricter in the long term and will have an impact on refining. The first stage will require refineries to make reformulated gasolines. Operations should be adjusted to have lower vapor pressure, lower aromatics and benzene content, to increase using of oxygenates and detergents to keep engines clean. In a second stage, emissions are going to be reduced drastically to one fifth. That means a combination of inherently clean fuels and advanced emissions-control technology will be necessary, so oil and auto industries have to work together to meet new standards.2_/

Refinery technology has many factors of which catalysts, processes, equipment and control systems are the most important future technology will change in several aspects, but remain the same in other:

1. In plan sizing there is no expectation for increasing unit size, but perhaps there will be parallel trains of units.
2. Refinery design will consider highly integrated operations as meshing of crude fractionation system with downstream process unit for saving capital and energy.

1_/ OECD "Energy efficiency and enviroment". Reference 26
2_/ JONES H.R. "Pollution control in the petroleum industry" Reference 93

3. Most equipment will improve, but key factors will be monitoring of rotation equipment, corrosion control and furnance coking control

4. Control systems will progress considerably. They will be based on sensors plus reliable continuous analysis and microprocessor applications.

5. It is necessary to have flexibility to handle any raw material in the refinery, various combinations of heavy oils, sour asphaltic and high metal crude. Then, quality of raw materials will determine the prerefining degree.

6. Basic process will remain: Distillation, catalytic reforming, catalytic cracking, hydrotreating, hydrocracking and coking. Although each process will have changes and improvements as explained in the following section.

7.6.0 TRENDS TOWARDS A SYSTEM INTEGRATED DESIGN

7.6.1 OBJECTIVE AND GOALS

The system design process has two main objectives:

a) To establish overall system performance requirements and to ensure that the system candidate satisfies whole-system, whole-life cost effectiveness criteria.

b) To ensure that all aspects of detail design, development and production during the acquisition phase are so planned and integrated that the assembled and operated system does in fact the specified performance.

c) The close monitoring of all stages during acquisition to ensure that the operating system will achieve the specified performance.

These functions are becoming known as systems assurance and support the ideas towards integrated system design (**ISD**) 1_/

System assurance has two parts: **Design assurance** and **Quality assurance**.

1_/ M'Pherson P.K.: " A framework for system engineering design". Reference 17 the first one includes :

- o Definition of operational and performance requirements
- o Integrated system design to meet requirements
- o Optimal allocation of requirements
- o Audit of design
- o Design assessment with whole-system whole-life criteria
- o Optimal system design

Quality assurance takes place in the acquisition phase and includes:

- o Definition of the design assurance requirements through systems hierarchy from subsystems down to elements
- o Control to satisfy quality assurance
- o Integration of system hierarchy from elements up to subsystems to meet quality assurance requirements
- o Integration of subsystems to provide a system that meets design assurance requirements

According to a modern approach, design is not a matter of only achieving a stated performance specification but all the consideration necessary to ensure that the system not only meets its functional requirements but also continues in a satisfactory working state and is not degraded by any malfunctions.

7.6.2 PARTIAL DESIGNS AND PHASES FOR INTEGRAL DESIGN

Applied system analysis for system design provides:

- o Problem definition
- o Objective setting and criterion design
- o Research
- o Scenario generation

- o Overall assessment of system worth
- o Integrated system design includes several partial designs
- o Performance design
- o Reliability design
- o Support design
- o Integration through mutual trade-offs
- o Optimization through cost-effectiveness analysis

There are multiple objectives for any non-trivial design problem: Technical, social and environmental. Some of these objectives are easily quantifiable, and others are more difficult to define. There are also interactions between the objectives, some reinforce each other and others conflict with each other.

The objectives should result from the costumers's requirements in terms of

- o Satisfaction of basic need, resource procurement, survival avoidance of undesirabilities, obtained from need analysis
- o Identification of opportunities in technological, market and political aspects, obtained from opportunity analysis
- o Identification of threats from the competition, obtained from threat analysis

7.7.0 DECISION TREE DIAGRAM FOR AN INTEGRATED DESIGN

A framework for systems engineering design must therefore be comprehensive, otherwise it cannot support the systems engineer's tasks for the whole system problem, overall the specialist dimensions and over the future operational life.

Fig. 4.8.a from chapter iv defined the proposed framework for an integrated refinery design through a cost-effectiveness analysis. According to this figure, the sequence of activities to achieve the integrated design is:

STEP 1

To structure the system by means of a process selection. Several design candidates are proposed as options of configuration.

STEP 2

After defining optional configurations, preliminary partial designs are completed: **PD** PERFORMANCE DESIGN, **RD** Reliability Design, **SD** Support Design and eid environmental impact design

STEP 3

The capital and operational models. These costs are discounted to their net present value for the ce cost-effectiveness analysis.

STEP 4

To compare the partial goals for each design to the requirements. Goal coordination is necessary in the different levels of the design hierarchy. fig 4.8.b.

STEP 5

Cost-effectiveness analysis application for each system candidate.

Provided the problem complexity of a refinery's design it is necessary to define a preliminary phase for structuring the system.

7.7.1 STRUCTURING THE SYSTEM

The kind of hardware inside different refineries has profound effects on product prices, crude processing, demand satisfaction and profitability. Since the 1980's the interest was not in expansion but in operations.

Regarding their structure, refineries are classified as simple, complex or very complex. The simple refinery includes crude distillation, hydrotreating of middle distillates, and naphtha reforming, and has 1 to 2 complexity.

The complex refinery is a simple one plus a cat cracker, alkylation plant and gas processing unit. The very complex refinery adds either an olefin unit, a residual reduction unit such a coker or other processing plants. More complex refineries make high quality products from low quality crudes, have minimal fuel oil yield and are very capital intensive. These refineries have facilities to produce the high value-added products

Structuring the system means in this case to define the type and number of process units in a given refinery. It depends upon the type of crude oil to be processed, product requirements and economic factors such as crude cost, product values, availability and cost of utilities and equipment. This definition is the starting point for having an integrated refinery design.

7.7.2 FORMULATING THE SYSTEM

The formulation of the system is a task that requires a lot of work of project engineering. Each processing plant, each part of the utilities area and the power station require deep specification. Fortunately, there is a lot of experience for this task in Pemex, so all the branches of engineering share the whole technical responsibility.

Perhaps the weakest point in the company respect to this part is the integration of the whole design and the lack of optimization of each part and of the entire project. Up to now the design has always been defined adding the different part of each specialists without trying achieve a true optimization of the whole.

This is the main contribution of system engineering, and of this research, through the proposed framework. In chapter iv it was discussed how to formulate the system, but the practical task is how to modify the design candidate to improve its performance and cost-effectiveness.

The starting point is to find several system configurations whose worth range is feasible and meets the main and partial requirements. Many partial technical/economic decisions have been taken to have the best integrated design searching the best candidate design to fulfil stated objectives.

One of the first decisions to be taken is how much to take into account the experience of old designs and how much to take the risk of new technologies or new solutions. This problem can be seen in figure 7.7.a " decision tree diagram". 1_/

The formal sequence of activities to improve the system design in a systemic way is presented in annex 8. This sequence is based on a mathematical point of view.

1_/ Chesnut H. "System Engineering Methods", pp 141. Reference 61

7.7.3 EVALUATING THE SYSTEM

Evaluating the system means not only to evaluate its various subsystems, parts and designs, but the whole system. Local optimization arrived at independently for performance, reliability, maintenance and logistics do not necessarily mean that the whole system has been optimized.

The subsystems designs cannot be optimal independently. Consequently the trade-offs have be done at a superior level in the design hierarchy. Trade-offs can often be entertained between performance and availability. For example, it is possible to pay to lower the standard of functional performance and use the consequent capital reduction to increase reliability. Which means a more cost-effective system overall, but a non-minimum cost system with respect to purchase price.

The evaluation of every design cycle is an assessment of the design achievement with respect to the specified objectives of the system. To answer how good the system is it is necessary to analyze several aspects:

- o Whole-life cost-effectiveness
- o Commercial attractiveness
- o Social benefit
- o Environmental impact
- o Safety level

The first two aspects are commonly present in most engineering projects assessments. But the remainder are more largely in public utilities and high technology. A system design may be examined for its contributions to the value attributes. The overall aggregate of the contributions will be called worth.

Fig. 7.7.b shows the general tree structure for technological system objectives. It shows also a general structure for the value attributes of a system.

Fig. 7.7.c shows another sight of the general value criterion with which asses the overall worth of a system.

DECISION TREE DIAGRAM 7.7.a

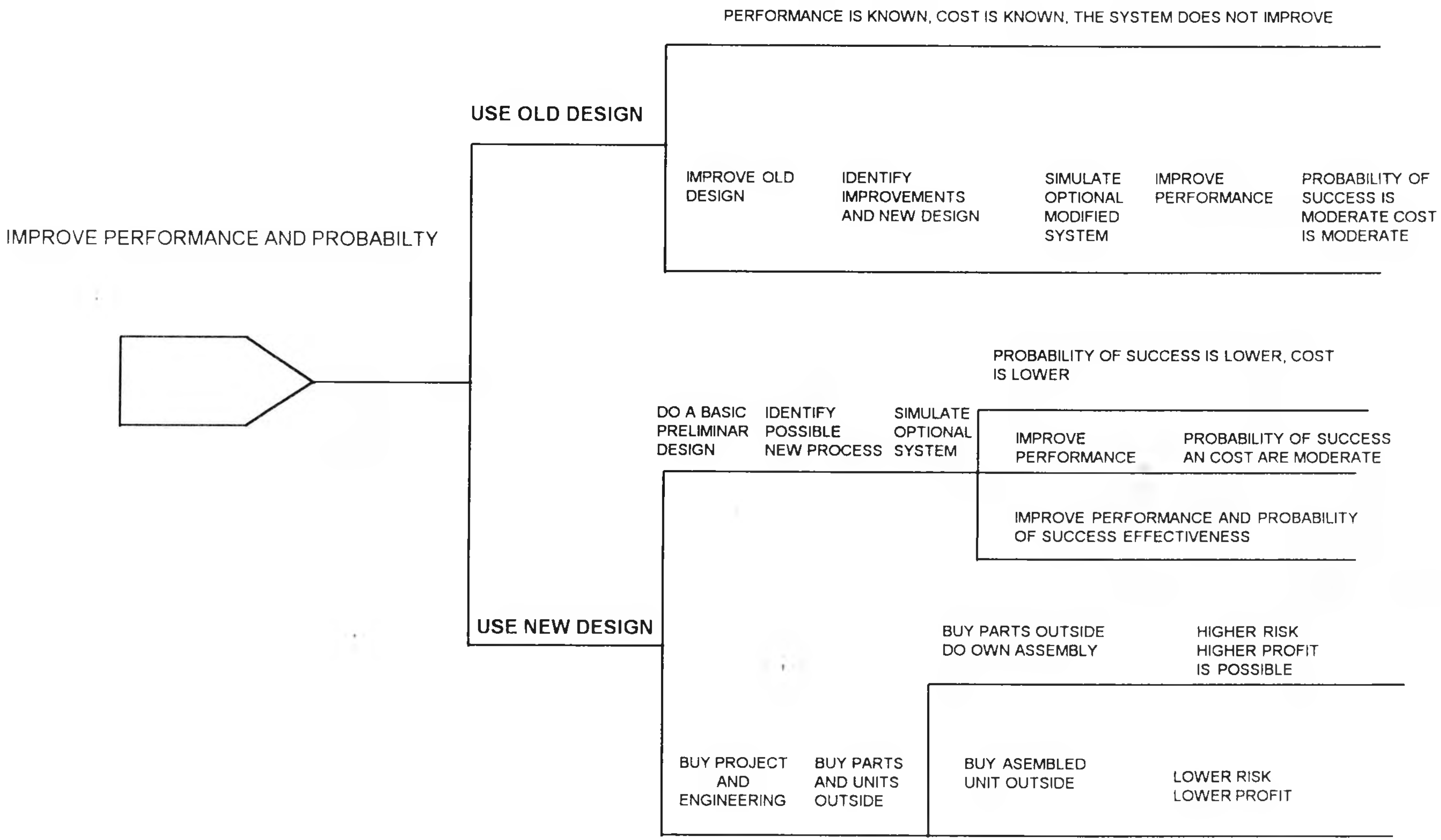


DIAGRAM 7.7.b

COST - EFFECTIVENESS ANALYSIS FOR A REFINERY DESIGN

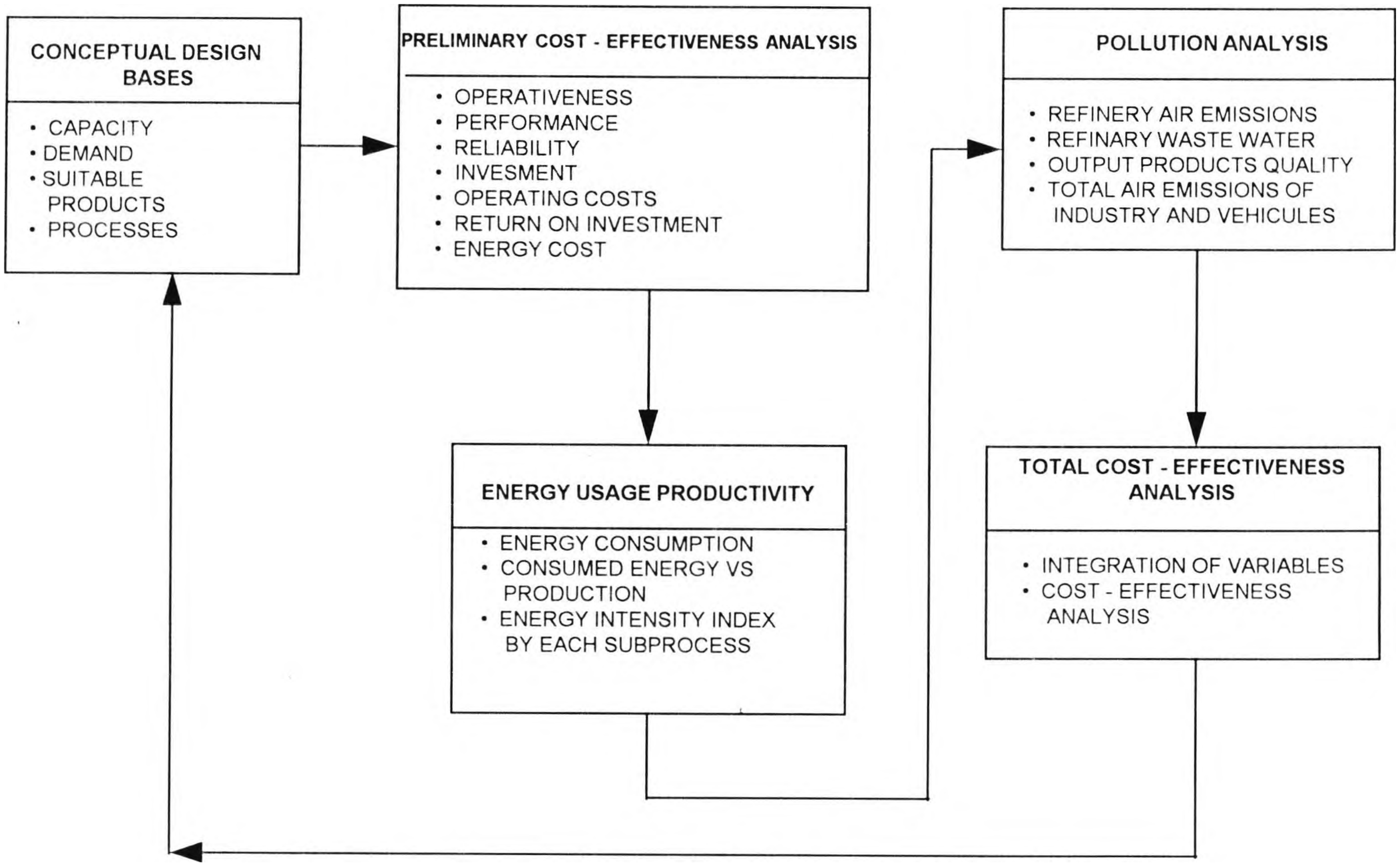
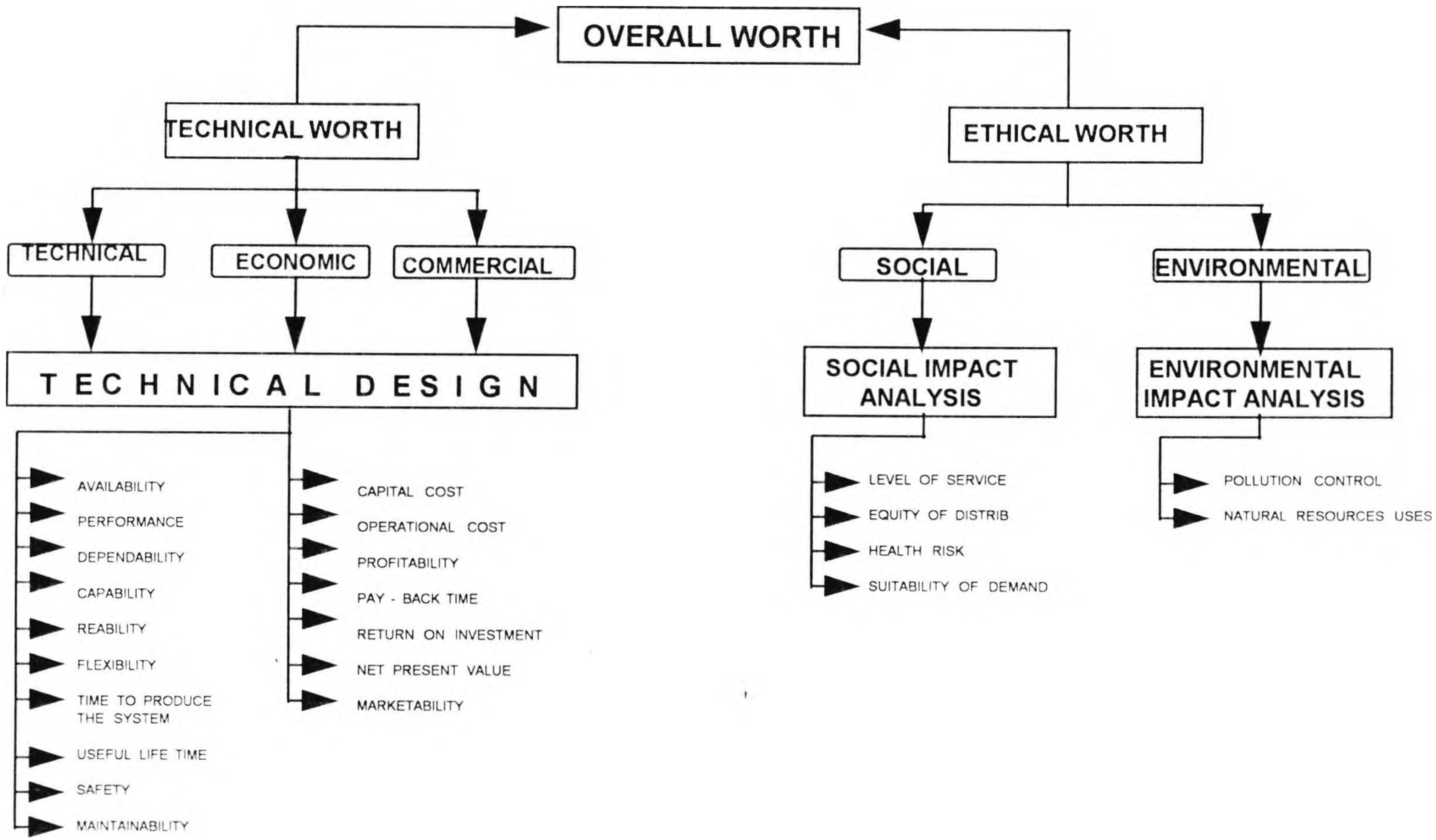


DIAGRAM 7.7.c

SYSTEM WORTH



7.8.0 EVALUATION MODEL FOR COST EFFECTIVENESS ANALYSIS IN A NEW REFINERY DESIGN

System engineering should provide two frameworks: One for the system design process itself and another for the evaluation of systems designs. The system design framework considers five partial designs and eight different models :

DESIGN	MODELS
Performance design	Functional model
Reliability design	Capability model
Support design	Availability model
Integrated system design	Operational cost model
Environmental impact design	Capital cost model
	Life cost model
	System effectiveness model

Operational scenario
Cost-effectiveness analysis
Environmental impact analysis

7.8.1 EVALUATING OPERATIONAL ENVIRONMENTS

Once all the system's alternative are defined, the design candidates evaluations are made through cost-effectiveness analysis. The effectiveness indicator provides a comprehensive figure of technical merit that integrates the various attributes of performance, reliability, maintenance and support design,. as they influence the system's performance in prescribed operational environments.

A certain amount of mathematical modeling followed by sufficient computers runs using quite a powerful machine to evaluate the life-time effectiveness is needed. It is used only as the final over-all system optimization to refine the suboptimal designs.

The cost model has two parts: A capital cost model and an operational cost model, that is an integration of the system whole-life costs.

In the refinery business the turn-key contracts are being used as a normal way for which the main contractor has responsibility for the entire project. So the design, development, deployment, procurement of the main operational parts together with the related and supporting parts are in the responsibility field of the same contractor.

For the customer, it is important to follow the different steps of the macroproject with enough knowledge, control and effective management to assure the success of the whole system.

It was common, three decades ago, to think of a refinery design as a problem of an assemblage of independently processing plants with the customer attempting to put them together. This concept is now out and has been replaced by a total concept.

Efficient performance at this level gives an advantage to larger scale project with advanced technologies teams

The customer has often little understanding of all the technical detail about the project, so they want fully integrated projects right down the unit level, e.g. machine tool centers, integrated condition monitoring aid alarm systems, integrated high technology design an increasingly require advance demonstration that the proposed system will not only meet their performance specification but will continue to be cost-effective over its whole operational life.

The evaluation of the system should be made at different stages: First of all in the structuring phase, after that, once the candidate be selected, each main part should also be evaluated.

7.8.2 SYSTEM HIERARCHY.

- In this case the system is too complex for any designer/decision maker to comprehend it as a whole, hence separations into manageable systems.
- Subsystems designer/decision makers (**sdms**) have limited but expert information and attend primarily to local goals.
- To achieve the task at the same time the **sdms** should work in parallel

- It is required a superior control of the SDM'S, so goal coordination od the sdms is necessary
- **SDMs** Require constant intercommunication to integrate the consequences of **SDM** activity at a whole system level

The system-wide concept of design and project management has introduced a new layer of design and management between the over all project manager and the specialist subsystems design teams and the detail designers. The customer should also adopt himself to this organizational team modification. This new layer provides the system engineering task of the system-wide integration and coordination between and within the phases of system realization and operation

7.8.3 MODEL IMPLEMENTATION

The proposed cost-effectiveness model requires the participation of many different specialities. Its implementation requires a permanent attention to the factors which define effectiveness: Availability, dependability, capability, performance, reliability, maintenance and support.

Effectiveness is the probability that an operational system will satisfy its objectives under stated operating conditions throughout a given period. The role of system engineers is to evaluate the system worth, integrating technical worths, economic worths and ethical worths.

Many partial problems are under study. To conduct a proper analysis of the whole system whole-life operations and advise the responsible decision-makers appropriately is the main objective.

The quality of the redesign or new design will depend on the quality and comprehensiveness of the value criterion, and this depend on a clear statement of all the objectives relevant to the problem. Needs, opportunity and threats analysis should be obtained from a detailed survey of the customers desires.

Following, several recommendations to implement the cost-effectiveness model are proposed:

1• To take the decision-makers preferences into account in relation to risky decisions, the variable loading of attributes, subjective impacts on social or environmental attributes.

2• To integrate the design and planning activities so that all the aspects of the system's future operations are conceived in a balanced and coherent manner

3• To have available two frameworks: One for the system design process itself and another for the evaluation of system designs candidates

4• To optimize the over-all system functions according to the weighed objectives. The success of the system, rather than whether each part function in an optimum fashion is the primary objective

5• To try to obtain improved solutions for the system is the only way to improve the design process, so it requires an iterative process. System engineering methods can help to implement the model.

6• System assurance is the main role of system engineers.

7• To establish a proper information system which supports the model implementation, monitoring and evaluation.

8• To carry out a close monitoring of all the stages during acquisition to ensure that the operating system will achieve the specified performance

8.0.0 CONCLUSIONS

The objectives of this research work were achieved as follows:

a) A complete analysis of energy consumption at global, national, hydrocarbon sector, petroleum industry and refining levels is now available.

b) Two different methodological frameworks were proposed to tackle the problem of redesigning an existing refinery, and designing a new one, both to improve its energy usage productivity. A third one was defined for achieving an integrated design through cost-effectiveness analysis.

c) A system approach and system engineering tools were important elements to get successful results. A system definition was included as key point for carrying out the analysis.

d) The energy usage in the Salina Cruz Refinery was as a case studied to understand how energy flows and to identify its energy saving opportunities. From this analysis, twenty four projects were proposed to be evaluated and if it is convenient be considered to integrate the energy saving programme of the refinery.

e) It was also proposed an evaluation model to analyze the projects to improve energy efficiency within the refinery's redesign.

f) The set three hypothesis defined at the beginning of the research work were proved, but it was hard to define which of them were the most determinant for explaining the low energy usage efficiency in Mexican refineries.

Following, several additional conclusions are shown:

8.1 OECD countries have reduced their energy intensity parameters between 25-30% over the past 20 years. In the same period Mexico has not had a positive change in this matter. Pemex's refineries have not had a clear energy efficiency improvement over the last 15 years in which several energy programmes have been attempted unsuccessfully.

8.2 In an open economy, for Mexican refineries, an energy conservation programme increases the chances for survival, because the competition of operational costs makes necessary to bring them in line with those of international competitors.

8.3 Priorities have not been clearly defined in Mexican refineries to save energy in spite of the rate of return on investment is greater than the other alternatives.

8.4 The first reason that Mexican petroleum industry does not invest in energy conservation measures is that decision makers are not aware of their plants' energy costs. Only few technical analysis areas recently know operational cost comparisons against other foreign companies.

8.5 A simple way for Mexico and for the Mexican petroleum industry to gain advantages in international markets is to adopt seriously energy efficiency programmes, respectively at national level and within refineries.

8.6 According to engineering estimates, the possible energy savings in the Mexican refinery Industry is 7.5 million tons of crude equivalent or 90 million US Dollars per year.

8.7 It is very important to adopt the total energy management process to save energy in any industrial plant and specifically in a refinery. This process would include: awareness of potential savings; top management commitment; preliminary and detailed energy audits; implementation of no/low cost measures; conduction of feasibility studies of capital intensive projects; acquire financing; implementing projects, and monitoring and evaluation of their energy saving programmes.

8.8 The most important role top management should play in energy saving plan is giving a high level strategy and a high priority for this programme; to define a policy and investment climate for energy conservation; and let energy prices reflect real economic costs. So, an important factor to be considered in the saving programmes is the commodity prices.

8.9 To be successful in the saving programme it is necessary to give technical and financial assistance to the top management. Financing is important in the second stage of the conserving programme, once the no/low cost measures have been adopted.

8.10 International energy efficiency standards have been established for boiler, furnaces and electric power factors and other industrial equipment. Top management should promote a proper reviewing of this information to begin taking actions.

8.11 One important criteria is to consider that a better plant design saves energy. It is better to include capital-intensive projects in the initial conception of macroprojects than to aggregate them once the macroprojects are built, because economic feasibility is easier to achieve in the first stage.

8.12 Designing a new refinery or redesigning an existing one are both very complex problems, which require a systems approach and to use modern technology. Besides all the support of the engineering branches for achieving the technical objectives in the detailed design, it is necessary to structure a refinery after a whole and deep system analysis has been performed. Cost-effectiveness analysis has enough power to cover all facets and to achieve good results.

8.13 Regarding the three models under study in this research, it was clear that they are useful for different problems. Nevertheless, from the systems engineering point of view the only one that fulfills the requirements of a system approach is the cost-effectiveness model, since it is allows decision makers to have a whole system analysis, considering all the system's life cycle .

8.14 The "Project Evaluation Model" for redesigning an existing refinery is very practical to support decisions on the best projects to improve energy efficiency. Although, it requires a lot of information about the economic aspect of each project: Costs, potential energy saving and saving revenues. In this case the economic value is the only one considered.

8.15 The second model, proposed for designing a new refinery to improve energy efficiency, is useful to solve this partial problem, but, it is no recommended from the point of view of system engineering, since it separates this problem without to solve the interactions with other important aspects of the system performance and the system impact on its environmental space.

8.16 "The Cost-Effectiveness Model" is the best tool to generalize the analysis of a large scale system. Its disadvantages are that it requires a lot of technical and economic resources and a heavy organization for carrying it out. Each part of the organization for developing each macrosystem, system and subsystem should make its part in complete coordination to the others.

8.17 It is necessary to include a position in the organization, which takes all the responsibilities of the system analysis, because there are interests in conflict and then a wide vision is needed.

8.18 A complete technological platform composed by computers, microprocessors, automatic control systems, mathematical models and in general new technologies are necessary to support the energy saving programme as well as a complete cost-effectiveness analysis to design a new refinery.

8.19 Most capital intensive projects in energy saving programmes are not enough profitable, so the correspondent investments are not economically justified, but if cost-effectiveness criteria are adopted it is possible to give higher weights to other factors, such as environmental or social ones.

8.20 Environmental system is an important wider system to be considered as a part of the study on energy usage productivity as well as on the refinery's integrated design. Cost-effectiveness analysis takes the pollution analysis as one important part of the whole analysis. Saving energy besides that saves money is the most effective way to avoid pollution

9.0.0 RECOMMENDATIONS

9.1 POLICIES

It is necessary to adopt in the Mexican petroleum industry a policy oriented to energy usage efficiency. The strategies should be :

a) to adopt two energy saving programmes. The first one, short range and the second one, long-range.

b) To evaluate permanently and accurately the energy usage in the company and the results obtained from both programmes.

c) to modify processes introducing the technological advances to save energy

d) to inform and motivate people about objectives, programmes, goals and results.

9.2 TOP MANAGEMENT COMMITMENT

The most important role top management should play in energy saving is giving a high level strategy and high priority for this programme; define a policy and investment climate for energy conservation; let energy prices reflect real economic costs, so an important factor to be considered in saving programmes is the commodity price.

Management has to provide the direction of the energy saving programme when necessary. communicate the various corporate entities, maintain the management attitude necessary to encourage energy conservation.

9.3 ORGANIZATION

PEMEX can be broken down into four business enterprises Refining business can be further divided into three main areas. Each of them has a number of plants; each should have its coordinator for implementing energy saving programme. So, energy responsibility lies with the local plant management, supported by technical assistance of the corporative level.

Besides of that it is necessary to introduce all the knowledge and responsibilities into the engineering groups in charge of development or revamp projects.

9.4 METHODOLOGY AND MODELS

It is important to reinforce the technical groups in charge of processing, planning and designing tasks with elements with enough knowledge and experience in systems engineering, operational research and cost-effectiveness techniques.

From the three proposed models only two of them should be implemented : the first one, " Project Evaluation Model for Redesigning an Existing Refinery to improve Energy Usage Productivity" should be implemented in each of the existing refineries to support their energy saving programmes, in the short term.

The second model to be implemented is the cost-effectiveness one. This model can be used in a first stage only for designing new refineries or for making important revamps to the existing ones.

As the the experience in this last model grows, it is possible to began building a cost-effectiveness model for the existing refineries, to study the system in a wide way.

9.5 MODEL IMPLEMENTATION

The proposed cost-effectiveness model has involved many different specialities. Its implementation requires a permanent attention to many factors which define effectiveness.

The quality of the redesign or new design depend on the quality and comprehensiveness of the value criterion, and this depend on a clear statement of all the relevant objectives to the problem. It is necessary to analyse needs, opportunities and threats from a survey of the opinion of the engineers, managers and employees.

following some recommendations to implement the cost- effectiveness model are listed:

9.6 TECHNICAL AND ENGINEERING

In order to be effective short-range and long-range programmes should be precisely defined and coordinated. Respect the short-range energy saving programme the quantitative goals have to be defined as precise as possible.

In the short range operational improvements are : Furnace optimization, heat containment, steam system improvements, heat exchanger cleaning, operational changes and small projects for saving energy.

There is a limit to what you can conserve with existing equipment, so it is convenient to begin studying which programme of capital projects we are going to adopt. To define long range capital projects. many of these decisions should be studied with detailed technical and economic analysis. Some of the typical projects in this category are: furnace efficiency, total energy studies, heat containment, improved heat integration and energy recovery modifications.

In this projects the risk is higher, return is lower and the future economic and regulatory climate is uncertain.

Examples of these projects are: both air preheaters and conversion steam packs, extension of the maintenance insulation programme, integration of heat systems for specific plants or for the whole refinery. This mean to reject to cooling systems, putting emphasis on keeping large processes operating in a temperature regime where the heat is rejected at a high temperature level to be useful. This change may push us to some higher pressure operation than we used to do. It will also drive us to more precess integration than in the past.

9.7 PLANT DESIGN

Project Engineers have great opportunities to contribute energy saving measures for new plants. There are at least have hundred measures to improve energy usage productivity through project and construction engineering. These measures can be reduced to the following general categories : process improvements, furnace efficiency, pumps and compressors, energy recovery systems, exchangers, waste-heat energy recovery systems, reactors, fractionators, tanks designs, instruments, insulation and technical data.

9.8 HUMAN RESOURCES

With proper motivation and training of employees it is possible to implement an energy saving programme more effectively. It is necessary that the technical people of the refinery design, operate and maintain processes with minimum energy usage and maximum return on investment

The engineering staff of the refinery can make studies about utility surveys, plant steam balances, fuel balances, cooling water balances, electrical balances and specific studies for optimizing energy usage in each processing plant The more obvious areas for energy saving have been explored. Now more complicated and expensive programmes and projects are needed

Implementation of an effective energy programme requires in terms of motivation the following:

a) Two-way communication

The communication face to face through in-plant energy saving committee, supervisors open to suggestions made by the refinery's personnel and a recording method for those suggestions is a good combination to support the programme.

b) Involvement and Participation

Development of computer programmes for simulating energy intensive processes gives operators hands-on-experience and allow them to make economic analysis about the implication of several operation options and evaluation of the results of operational changes

c) Commitment and Motivation

Commitment will drive a man to a level of performance higher than might be expected from his normal skill level

Men have a feeling of worthlessness when they are given no the opportunity to contribute Its important to design an energy conservation training programme to make full use of motivation

d) Training

Employee awareness is the key to maintaining a viable and permanent energy conservation programme. The recommendation is to place the energy responsibility at each unit management level.

Capital programmes to reduce the consumption per unit are developed at all levels of the corporation including several groups: process, industrial engineering, line personnel and outside consultants.

The training goal is to motivate, to gain attention. The training programme should involve analysis of what is going to be accomplished and who is going to be trained. Energy conservation must be handled on an individual basis, training a basic group of corporative coordinators, who are going to train to the plant coordinators.

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ANNEXES

ANNEX 1

Energy in the World

Annex 1

Energy In The World

Annex 2

Mexican Petroleum Industry

Energy Balance Diagrams

National Energy Balance Consumption In Energetics Sector

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Design Sequence Of Activities From A Mathematical Point Of View

TABLE 1.2 REFINING SURVEY 1/

SURVEY OF OPERATING REFINERIES WORLDWIDE
(capacities as of January 1, 1994)

Country	No. plants	Crude Capacity (b/cd)	Catalytic cracking (b/cd)	Catalytic reforming (b/cd)
Ethiopia	1	18,000	...	2,400
Finland	2	200,000	45,200	42,800
France	14	1,861,430	340,060	264,500
Gabon	1	17,300	...	1,400
Germany	21	2,265,060	281,650	409,503
Ghana	1	26,600	...	4,950
Greece	4	395,500	63,700	50,800
Guatemala	2	20,000	...	3,000
Honduras	1	14,000	...	1,800
Hungary	3	241,500	24,000	29,600
India	12	1,086,371	130,505	28,874
Indonesia	6	860,200	13,000	63,600
Iran	8	1,161,700	40,000	105,400
Iraq	8	347,500	...	43,500
Ireland	1	52,500	...	12,000
Israel	2	208,000	49,500	26,000
Italy	17	2,262,000	295,000	270,086
Ivory Coast	2	62,800	...	10,200
Jamaica	1	35,500	...	3,540
Japan	41	4,810,150	707,750	669,550
Jordan	1	100,000	4,250	8,640
Kenya	1	90,000	...	9,600
Korea N.	1	42,000	...	...
Korea S.	6	1,147,100	...	122,700
Kuwait	3	624,000	28,000	47,000
Lebanon	2	37,500	7,250	7,442

Country	No. plants	Crude Capacity (b/cd)	Catalytic cracking (b/cd)	Catalytic reforming (b/cd)
Somalia	1	10,000	...	...
South Africa	2	364,038	85,113	61,490
Spain	10	1,283,000	177,600	197,500
Srl Lanke	1	50,000	...	3,750
Sudan	1	21,700	...	1,900
Sweden	5	427,500	28,000	73,500
Switzerland	2	132,000	...	26,000
Syria	2	242,140	...	29,239
Taiwan	2	542,500	45,200	56,500
Tanzania	1	17,000	...	2,500
Thailand	3	313,750	10,200	45,450
Trinidad	2	305,000	28,000	31,000
Tunisia	1	34,000	...	3,300
Turkey	5	713,000	39,320	66,210
United Kingdom	15	1,866,640	474,900	392,200
United States	178	15,141,556	5,221,475	3,656,608
Uruguay	1	35,000	5,000	3,000
Venezuela	6	1,167,000	233,900	8,870
Virgin Islands	1	545,000	75,000	125,000
Yemen	2	120,000	...	8,500
Yogoslavia	4	281,781	20,750	42,145
Zaire	1	17,000	...	3,500
Zambia	1	23,750	...	5,320
Total	706	73,168,574	11,309,679	9,337,91[illegible]

1/ International Petroleum Encyclopedia 1994. "Survey of operating refineries worldwide". pp 270. Reference 74.

TABLE 1.1 REFINING SURVEY 1/

SURVEY OF OPERATING REFINERIES WORLDWIDE
(capacities as of January 1, 1994)

Country	No. plants	Crude Capacity (b/cd)	Catalytic cracking (b/cd)	Catalytic reforming (b/cd)
Abu Dhabi	2	192,500		30,100
Albania	3	40,000		
Algeria	6	530,000		74,000
Angola	1	32,100		1,900
Argentina	12	709,485	180,100	41,300
Australia	9	705,000	214,500	171,100
Austria	1	210,000	25,100	33,700
Bahrain	1	250,000	39,000	18,000
Bangladesh	1	31,200		1,650
Barbados	1	3,000		
Belgium	4	607,000	110,000	95,800
Bolivia	3	45,250	...	14,500
Brazil	13	1,252,860	333,104	...
Brunei	1	8,500	...	5,600
Bulgaria	3	300,000	...	...
Cameroon	1	42,000	...	7,000
Canada	25	1,880,100	391,450	359,450
Chile	3	164,615	38,290	10,100
China	23	2,200,000	...	...
Colombia	5	248,850	90,000	...
C.I.S.	47	9,845,939	433,684	54,312
Congo	1	21,000	...	2,000
Costa Rica	1	15,000	...	1,200
Croatia	2	293,472	32,000	37,400
Cuba	4	280,000	...	...
Cyprus	1	22,000	...	5,100
Czech Republic	6	307,250	...	8,570
Denmark	3	183,500	...	31,600
Dominican Republic	2	48,000	...	9,700
Ecuador	4	148,000	16,000	2,300
Egypt	8	532,153	...	33,540
El Salvador	1	18,000	...	2,200
Liberia	1	15,000	...	2,000
Libya	3	348,400	...	14,000
Lithuania	1	263,420	43,692	51,482
Macedonia	1	51,180	...	10,780
Madagascar	1	16,350	...	2,600
Malaysia	4	269,800	...	30,100
Martinique	1	16,000	...	3,000
Mexico	7	1,524,000	243,000	170,800
Morocco	2	154,600	5,600	26,800
Myanmar	2	32,000	...	...
Netherlands	6	1,183,500	136,000	185,100
Netherlands Antilles	2	477,000	49,000	20,000
New Zealand	1	92,500	...	22,000
Nicaragua	1	16,000	...	3,000
Nigeria	4	433,250	82,700	70,070
Norway	3	287,250	41,000	47,100
Oman	1	76,000	...	15,200
Pakistan	3	132,900	...	4,910
Panama	1	100,000	...	8,000
Paraguay	1	7,500	...	...
Peru	5	184,250	23,300	...
Philippines	4	278,750	22,700	29,300
Poland	9	333,000	32,000	35,000
Portugal	3	294,000	10,100	51,000
Puerto Rico	2	127,000	14,200	26,500
Qatar	1	57,500	...	11,500
Romania	10	680,884	113,295	89,752
Saudi Arabia	8	1,614,000	87,541	184,822
Senegal	1	22,600	...	2,500
Sierra Leone	1	10,000	...	...
Singapore	5	1,055,000	28,000	62,700
Slovakia	1	193,400	...	22,270
Slovenia	1	14,700	...	...

1/ International Petroleum Encyclopedia 1994. "Survey of operating refineries worldwide". pp 270. Reference 74.

TABLE 1.2 1_/

PRICE HISTORY, CRUDE OIL, NATURAL GAS AND MOTOR GASOLINE

	ACTUAL CURRENT PRICES					INFLATION ADJUSTES REAL PRICES					
	Crude Oil			Natural Gas		Crude Oil				Natural Gas	
Year	U S average wellhead $/bbl	West Texas intermediate posted $/bbl	Motor * Gasoline pump price $/gal	U S average wellhead $/Mcf	Consumer average $/Mcf	Producer Price Index 1982 100	U S average wellhead $/bbl	West Texas Intermediate posted $/bbl	Motor Gasoline pump price $/gal	U S average wellhead $/Mcf	Consumer average $/Mcf
1925	1 68	1 79	0 222	0 094	0 223	17 8	9 438	10.056	1 247	0 528	1.253
1926	1 88	1 90	0 234	0 095	0 229	17 2	10 930	11.047	1.359	0 552	1 311
1927	1 30	1 28	0 211	0 088	0 220	16 5	7,879	7.758	1.278	0 533	1 333
1928	1 17	1.36	0 209	0 089	0 232	16 7	7.006	8.144	1.254	0 533	1 389
1929	1 27	1.45	0 214	0 082	0 216	16 4	7 744	8 841	1.306	0 500	1 317
1930	1 19	0 95	0.200	0.076	0.214	14 9	7.987	6.376	1.339 _	0 510	1 436
1931	0 65	0 77	0 170	0.070	0 233	12 6	5 159	6 111	1 348	0 556	1.849
1932	0 87	0.69	0 179	0 064	0 247	11.2	7 768	6 161	1 601	0 571	2 205
1933	0 67	1 00	0.178	0 062	0 237	11 4	5 877	8.772	1 563	0 544	2 079
1934	1 00	1 00	0.189	0 060	0.223	12 9	7 752	7.752	1 461	0 465	1 729
1935	0 97	1 00	0 188	0.058	0 224	13 8	7.029	7.246	1 365	0 420	1 623
1936	1 09	1 10	0 195	0 055	0 220	13 9	7.842	7 914	1.399	0 396	1 583
1937	1 18	1.22	0 200	0 051	0.220	14 9	7 919	8.188	1.342	0 342	1 477
1938	1.13	1.07	0.195	0 049	0.218	13 5	8 370	7.556	1 445	0.363	1 615
1939	1 02	1 02	0 188	0 049	0.216	13 3	7 669	7 699	1 410	0.368	1.624
1940	1 07	1 02	0 184	0.045	0.217	13.5	7.556	7 556	1 364	0.333	1.607
1941	1 14	1 17	0 192	0 049	0.221	15 1	7 550	7 748	1.274	0 325	1 464
1942	1 19	1.17	0 204	0 051	0 227	17.0	7.000	6 882	1 202	0 300	1.335
1943	1 20	1 17	0.205	0 052	0 223	17 8	6.742	6 573	1.153	0 292	1 253
1944	1 21	1.17	0 206	0 051	0.215	17 9	6,760	6.536	1.150	0 285	1 201
1945	1.22	1.17	0.205	0 049	0.214	18.2	6.703	6 429	1.126	0 269	1 176
1946	1 41	1 36	0 208	0 053	0 220	20 8	6.779	6.524	0 999	0.255	1 058
1947	1 93	1 84	0.231	0.060	0 232	25.6	7.539	7 188	0.903	0 234	0 906
1948	2 60	2 57	0 259	0 065	0.241	27 7	9 386	9 278	0.934	0 235	0 870
1949	2 54	2 57	0 268	0 063	0.254	26 3	9 658	9 772	1 019	0 240	0 966
1950	2 51	2 57	0 268	0 065	0 266	27.3	9 194	9 414	0 980	0 238	0 974
1951	2 53	2 57	0 272	0 073	0 298	30.4	8 322	8 454	0 893	0 240	0 980
1952	2 53	2 57	0 276	0 078	0 332	29 6	8 547	8 682	0 931	0 264	1 122
1953	2 68	2 72	0 287	0 092	0 355	29 2	9 178	9 298	0 983	0 315	1 216
1954	2 78	2 82	0.290	0 101	0.381	29 3	9 488	9 625	0 991	0 345	1 300
1955	2 77	2 82	0 291	0 104	0 400	29 3	9 454	9 625	0 992	0 355	1 365
1956	2 79	2 82	0.299	0 108	0 415	30 3	9 208	9 307	0 988	0 356	1 370
1957	3 09	3 04	0 310	0 113	0 431	31 2	9 904	9 753	0 992	0 362	1 381
1958	3 01	3 06	0 304	0 119	0 462	31 6	9 525	9 677	0 961	0 377	1 462
1959	2 90	2 98	0 305	0 129	0 477	31 7	9 148	9 385	0 962	0 407	1 505
1960	2 88	2 97	0 311	0 140	0 500	31 7	9 085	9 369	0 992	0 442	1 577

1_/ International Petroleum Encyclopedia. 1994. " Price History, crude oil, natural gas and motor gasoline". pp 257. Reference 74.

TABLE 1.2 1_/

PRICE HISTORY, CRUDE OIL, NATURAL GAS AND MOTOR GASOLINE

	ACTUAL CURRENT PRICES						INFLATION ADJUSTES REAL PRICES				
	Crude Oil		Natural Gas			Crude Oil			Natural Gas		
Year	U.S. average wellhead $/bbl	West Texas intermediate posted $/bbl	Motor* Gasoline pump price $/gal	U.S. average wellhead $/Mcf	Consumer average $/Mcf	Producer Price Index 1982 100	U.S. average wellhead $/bbl	West Texas Intermediate posted $/bbl	Motor Gasoline pump price $/gal	U.S. average wellhead $/Mcf	Consumer average $/Mcf
1961	2.89	2.97	0.308	0.151	0.510	31.6	9.146	9.399	0.973	0.478	1.614
1962	2.90	2.97	0.306	0.155	0.514	31.7	9.148	9.369	0.967	0.489	1.621
1063	2.89	2.97	0.304	0.158	0.512	31.6	9.146	9.399	0.963	0.500	1.620
1964	2.88	2.95	0.304	0.154	0.519	31.6	9.114	9.320	0.962	0.487	1.642
1965	2.86	2.92	0.312	0.156	0.522	32.3	8.854	9.040	0.966	0.483	1.616
1966	2.88	2.94	0.321	0.157	0.523	33.3	8.649	8.817	0.964	0.471	1.571
1967	2.92	3.03	0.332	0.160	0.520	33.4	8.743	9.060	0.994	0.479	1.557
1968	2.94	3.07	0.337	0.164	0.504	34.2	8.596	8.977	0.985	0.480	1.474
1969	3.09	3.30	0.348	0.167	0.515	35.6	8.680	9.256	0.978	0.469	1.447
1970	3.18	3.35	0.357	0.171	0.550	36.9	8.618	9.079	0.967	0.463	1.491
1971	3.39	3.56	0.364	0.182	0.590	38.0	8.921	9.368	0.958	0.479	1.553
1972	3.39	3.56	0.361	0.186	0.630	39.8	8.518	8.945	0.907	0.467	1.583
1973	3.89	3.87	0.388	0.216	0.680	45.0	8.644	8.604	0.862	0.480	1.511
1974	6.74	10.37	0.532	0.304	0.840	53.5	12.598	19.383	0.994	0.568	1.570
1975	7.56	11.16	0.567	0.445	1.120	58.4	12.945	19.110	0.971	0.762	1.918
1976	8.14	12.65	0.590	0.580	1.370	61.1	13.322	20.704	0.966	0.949	2.242
1977	8.57	14.30	0.622	0.790	1.660	64.9	13.205	22.034	0.958	1.217	2.558
1978	8.96	14.85	0.626	0.905	1.850	69.9	12.818	21.245	0.896	1.295	2.647
1979	12.51	22.40	0.857	1.178	2.210	78.7	15.896	28.463	1.089	1.497	2.808
1980	21.59	37.37	1.191	1.590	2.800	89.7	24.069	41.661	1.328	1.773	3.122
1981	31.77	36.67	1.311	1.980	3.390	98.0	32.418	37.418	1.338	2.020	3.459
1982	28.52	32.75	1.296	2.460	4.150	100.0	28.520	32.750	1.296	2.460	4.150
1983	26.19	30.25	1.241	2.590	4.820	101.2	25.879	29.891	1.226	2.559	4.763
1984	25.88	29.83	1.212	2.660	4.850	103.6	24.981	28.793	1.170	2.568	4.681
1985	24.09	28.08	1.202	2.510	4.720	103.1	23.366	27.236	1.166	2.435	4.578
1986	12.51	16.44	0.927	1.940	4.130	100.1	12.498	16.421	0.926	1.938	4.046
1987	15.40	18.21	0.948	1.670	4.050	102.8	14.981	17.714	0.922	1.625	3.940
1988	12.58	15.52	0.946	1.690	4.090	106.9	11.768	14.518	0.885	1.581	3.826
1989	15.86	18.29	1.021	1.690	4.220	112.2	14.135	16.301	0.910	1.506	3.761
1990	20.03	23.17	1.164	1.710	4.190	116.3	17.223	19.923	1.001	1.470	3.603
1991	16.54	20.42	1.140	1.640	4.071	116.5	14.197	17.528	0.979	1.408	3.494
1992	15.99	19.67	1.127	1.740	4.173	117.2	13.643	16.783	0.962	1.485	3.561

*Leaded gasoline price prior to 1982, unleaded gasoline price beginning in 1982
From: Oil & Gas Journal Energy Database
Source: U.S. Department of Energy

1_/ International Petroleum Encyclopedia 1994. " Price history, crude oil, natural gas and motor gasoline". pp 287. Reference 74.

TABLE 1.3 CRUDE OIL PRICES 1_/

$/bbl

	U.S. REFINER ACQUISITION COST			U.S. LANDED COST OF IMPORTS SELECTED COUNTRIES							AVERAGE EXPORT PRICES		
Year	Domes-tic	Impor-ted	Compo-site	Total	Canada	Mexico	United Kingdom	Nigeria	Saudi Arabia	Vene-zuela	World- wide	OPEC	Non-OPEC
1976	8.84	13.48	10.89	13.32	13.36	12.64	NA	13.81	13.06	11.89	NA	NA	NA
1977	9.55	14.53	11.96	14.36	14.13	13.82	14.83	15.29	13.69	13.11	NA	NA	NA
1978	10.61	14.57	12.46	14.35	14.41	13.56	14.53	14.88	13.94	12.84	NA	NA	NA
1979	14.27	21.67	17.72	21.45	20.22	20.77	22.97	22.97	18.95	17.65	NA	NA	NA
1980	24.29	33.89	28.07	33.67	30.11	31.77	35.68	37.15	29.80	25.92	NA	NA	NA
1981	34.93	37.05	35.24	36.47	32.32	33.70	37.29	39.66	34.20	29.91	34.81	34 42	36.16
1982	31.22	33.55	31.87	33.18	27.15	28.63	34.25	36.16	34.99	24.93	33.33	33.71	32.30
1983	28.87	29.30	28.99	28.93	25.63	25.78	30.87	30.85	29.27	22.94	29.66	29.89	29.13
1984	28.53	28.88	28.63	28.54	26.56	26.85	29.45	30.36	29.20	25.19	28.60	28.61	28.60
1985	26.66	26.99	25.75	26.67	25.71	25.63	28.36	28.96	24.72	24.43	27.60	28.00	26.98
1986	14.82	14.00	14.55	13.49	13.43	12.17	14.63	15.29	12.84	11.52	14.98	15.45	14.21
1987	17.76	18.13	17.90	17.65	17.04	16.69	18.78	19.32	16.81	15.76	17.41	17.31	17.57
1988	14.74	14.56	14.67	14.08	13.50	12.58	15.82	15.88	13.37	13.66	13.79	13.67	14.04
1989	17.87	18.08	17.97	17.68	16.81	16.35	18.74	19.19	17.34	16.78	16.65	16 40	17.11
1990	22.59	21.76	22.22	21.13	20.48	19.64	22.65	23.33	21.82	20.31	21.35	20.98	22 07
1991	19.33	18.70	19.06	18.02	17.16	15.89	21.37	21.39	17.22	15.92	17.82	17.36	18.52
1992	18.63	18.20	18.43	17.75	17.04	15.60	20.63	20.78	17.48	15.13	17.95	17.65	18.51

From: Oil & Gas Journal Energy Database
Source: U:S: Department of Energy

1_/ International Petroleum Encyclopedia 1994. " Crude oil prices " pp 286. Reference 74

TABLE 1.4 REFINERY THROUGHPUT/HISTORICAL RESERVES 1_/

Refinery throughput

(Thousand barrels por calendar day)

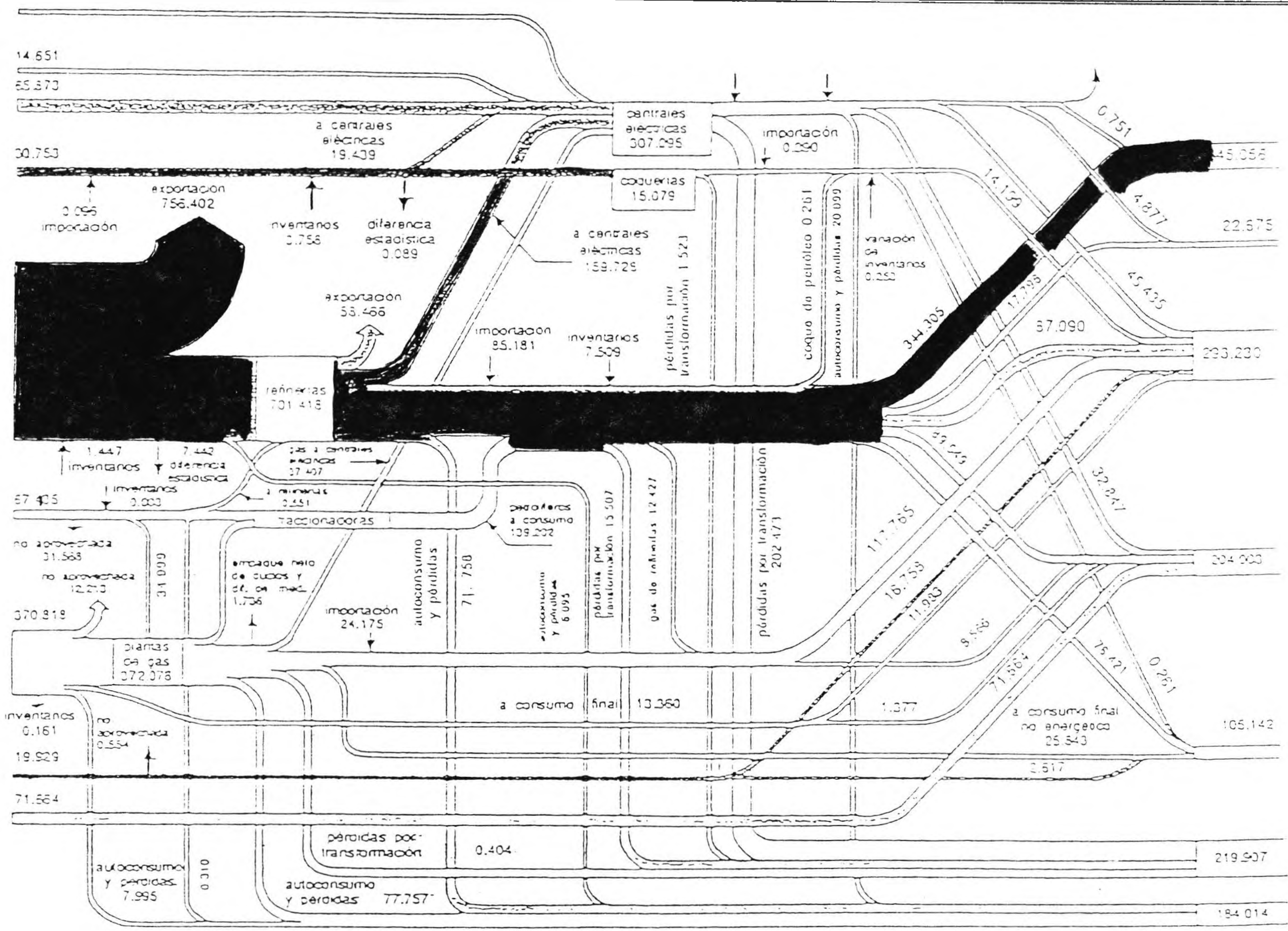
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
U.S.	11,685	12,045	12,000	12,715	12,855	13,245	13,400	13,410	13,300	13,410
Canada	1,455	1,460	1,430	1,395	1,460	1,535	1,555	1,590	1,490	1,450
Latin America	5,955	5,845	5,585	5,615	5,765	6,000	6,165	6,290	6,175	6,260
OECD Europe	10,165	10,255	9,950	10,510	10,380	10,725	11,600	11,895	12,525	12,895
Non-OECD Europe	12,255	12,005	11,725	11,990	12,030	12,070	11,950	11,235	10,065	8,460
Middle East	3,080	3,320	3,665	3,765	3,935	4,265	4,350	4,340	3,800	4,150
Africa	1,700	1,795	1,850	1,920	2,000	2,100	2,185	2,355	2,360	2,375
China	1,600	1,765	1,785	1,865	1,950	2,035	2,110	2,155	2,280	2,430
Japan	3,255	3,355	3,120	2,990	2,910	2,990	3,175	3,435	3,655	3,880
South Asia	880	885	1,020	1,120	1,150	1,150	1,230	1,235	1,215	1,280
Other Asia	2,410	2,485	2,685	2,800	2,785	3,155	3,370	3,580	4,100	4,535
Australasia	605	615	580	580	645	680	700	715	745	745
Total World	55,045	55,830	55,395	57,265	57,865	59,950	61,790	62,235	61,710	61,870
Of which OECD*	27,165	27,730	27,080	28,190	28,250	29,175	30,430	31,045	31,715	32,380
Of which LDCst	15,625	16,095	16,590	17,085	17,585	18,705	19,410	19,955	19,930	21,030

*Organisation for Economic Cooperation and Development.
tLesser developed countries.
Sourse: British Petroleum.

1_/ International Petroleum Encyclopedia 1994. " Crude oil prices " . pp 284. Reference 74

ANNEX 2

Mexican Petroleum Industry

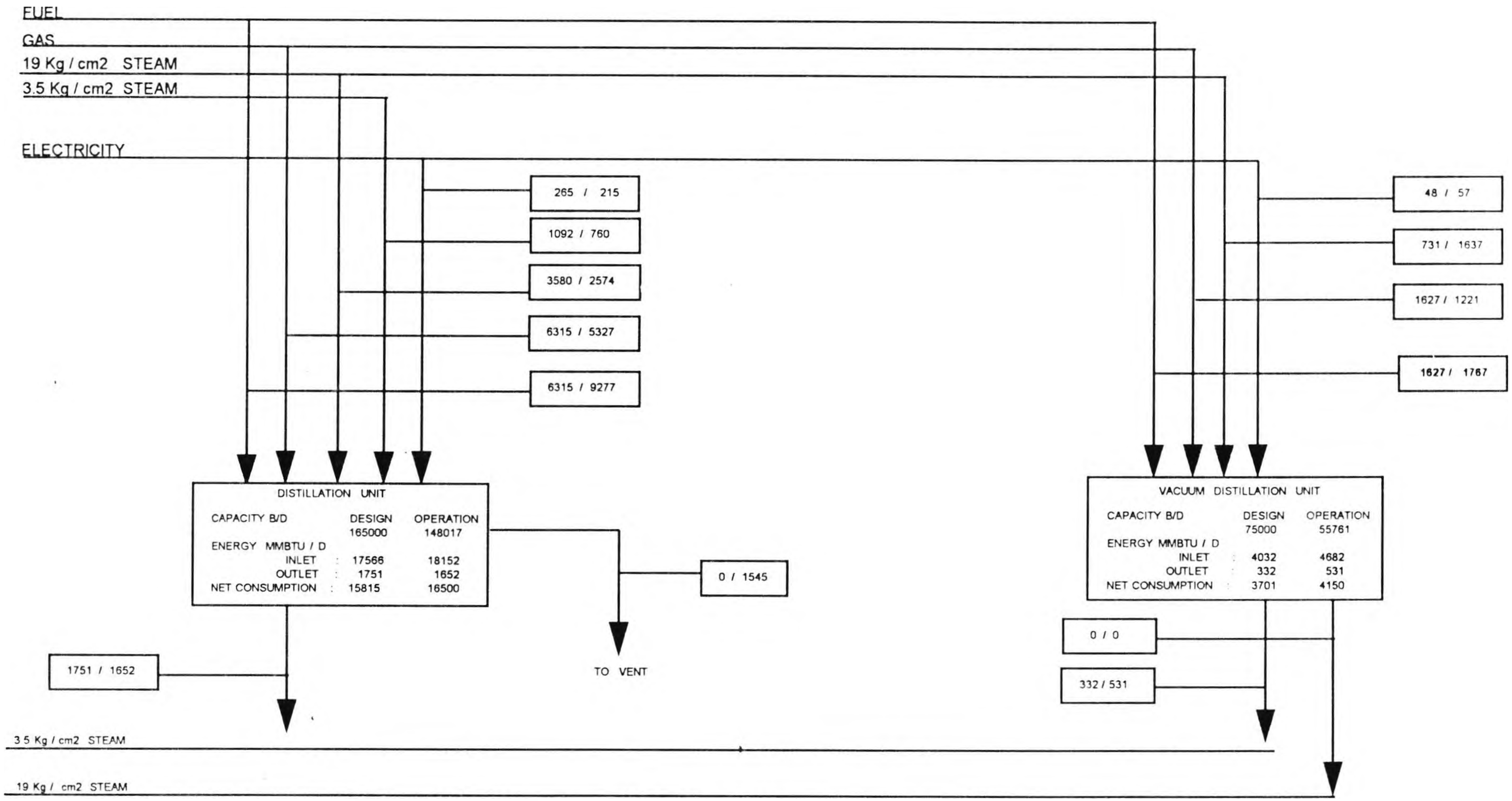


producción		energía no aprovechada		importación		exportación		inventarios		consumo nacional aparente		consumo del sector energético y pérdidas		pérdidas por transformación		diferencia estadística		consumo final
2120.5	−	44.4	+	110.7	−	816.6	+	11.1	=	1381.3	=	184.0	+	219.9	−	-7.3	+	970.1

ANNEX 3

Energy Balances by Plant for the Salina Cruz Refinery

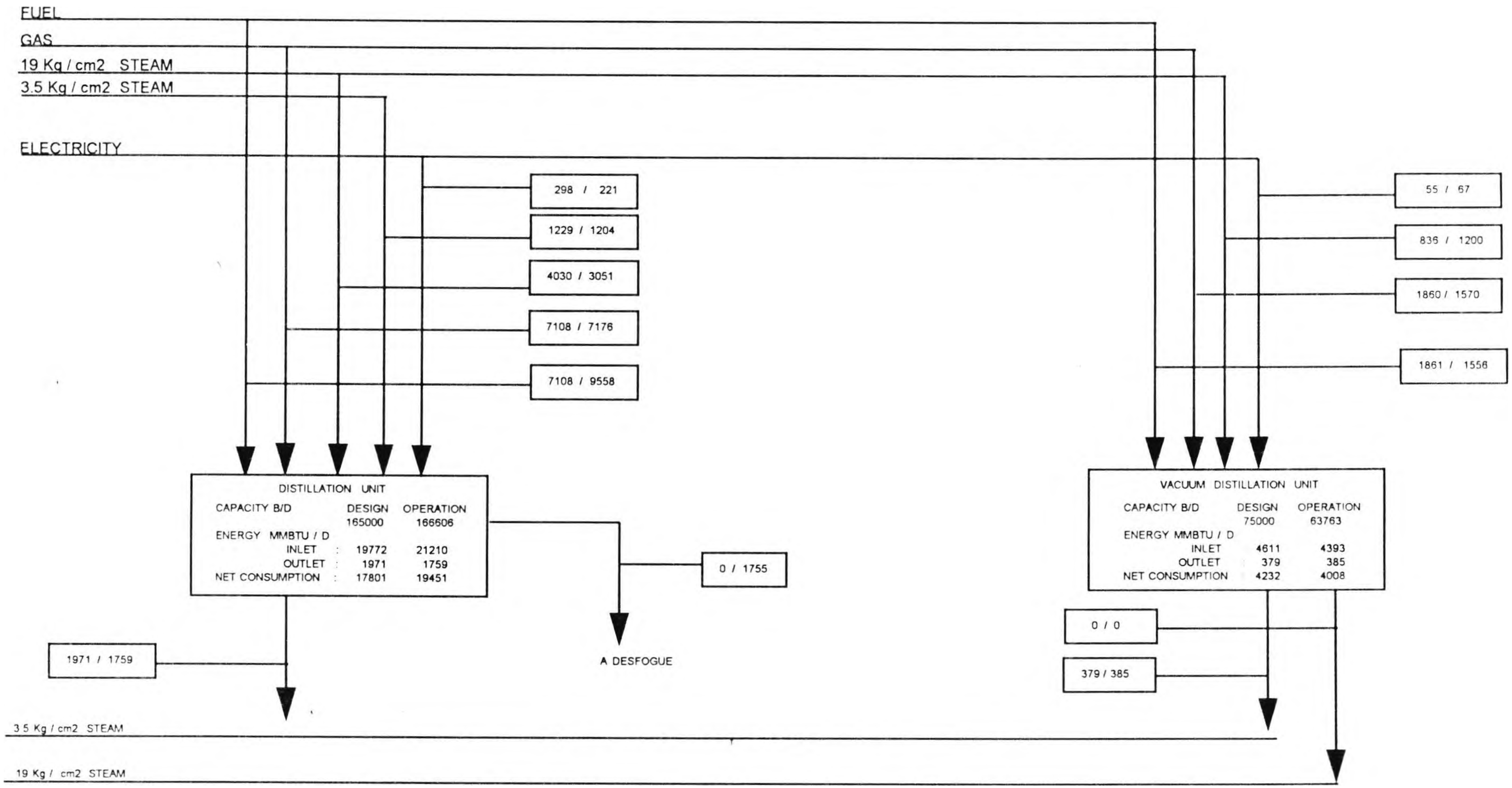
DIAGRAM 3.1.1



NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ, REFINERY
PRIMARY SECTOR
DATA FOR DECEMBER 1987

DIAGRAM 3.1.2



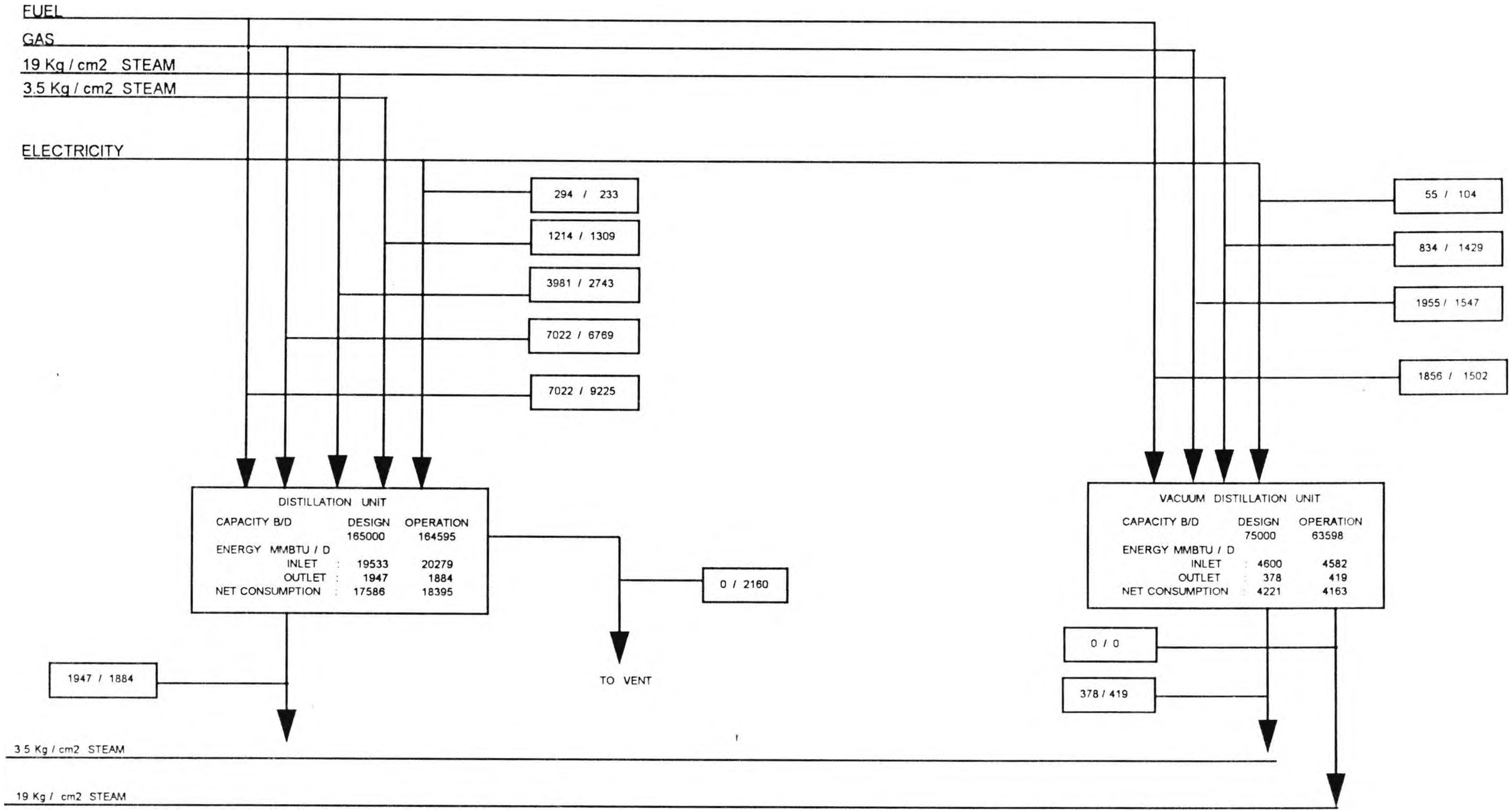
NOTE --THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY

ENERGY PROFILE IN SALINA CRUZ. REFINERY
PRIMARY SECTOR

DATA FOR JANUARY 1988

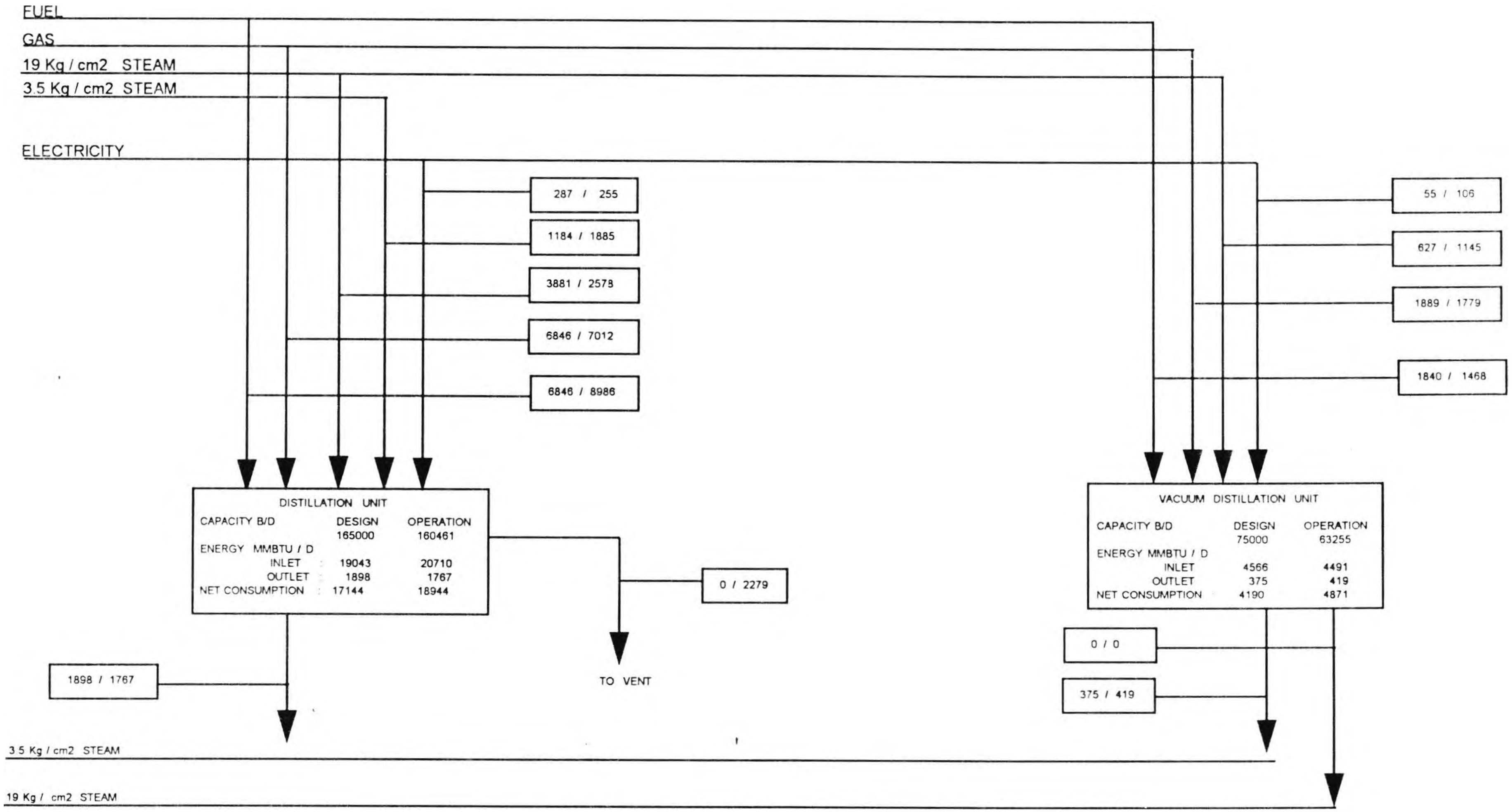
DIAGRAM 3.1.3



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ, REFINERY PRIMARY SECTOR
DATA FOR FEBRUARY 1988

NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

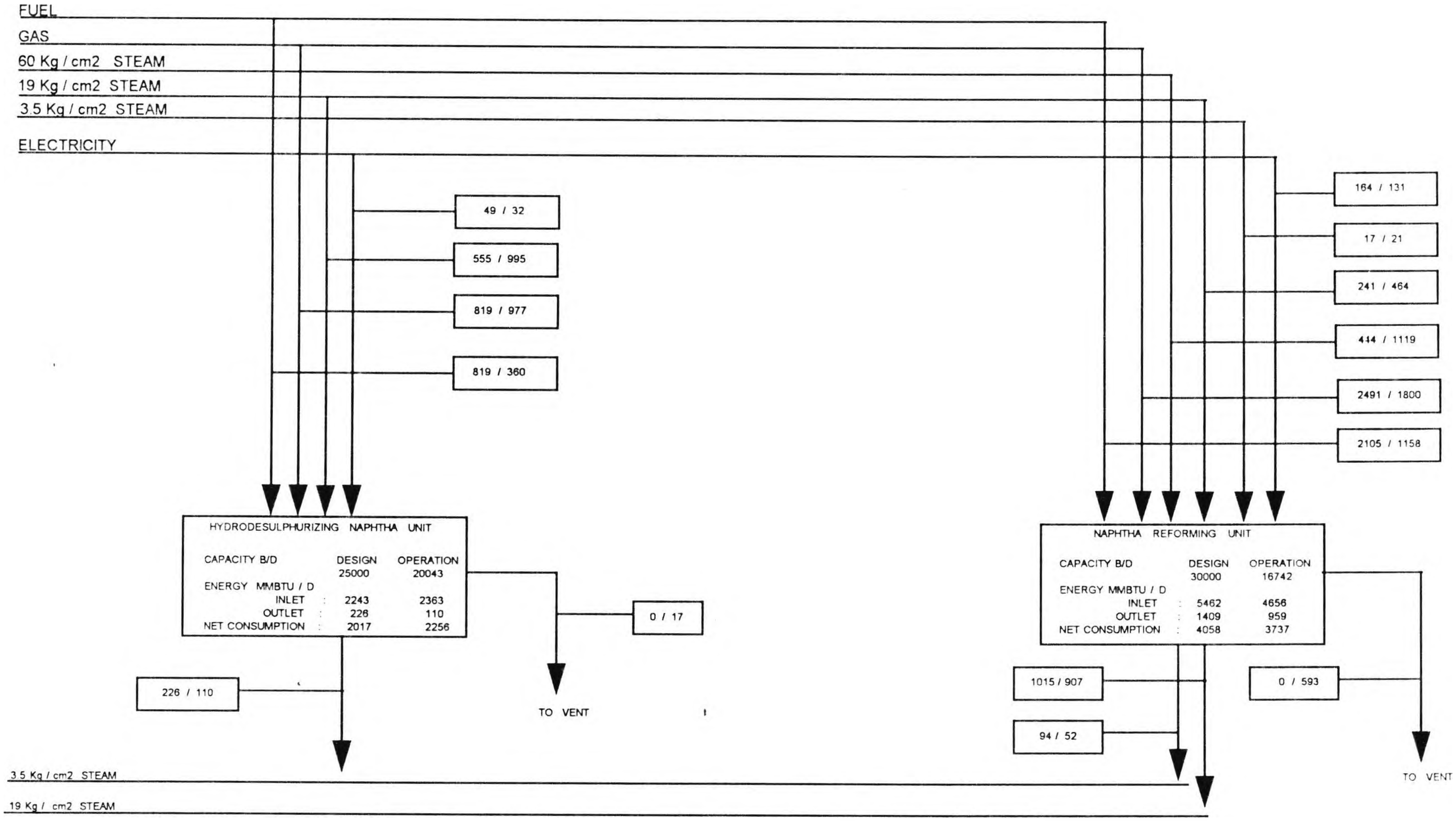
DIAGRAM 3.1.4



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ REFINERY
PRIMARY SECTOR
DATA FOR MARCH 1988

NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

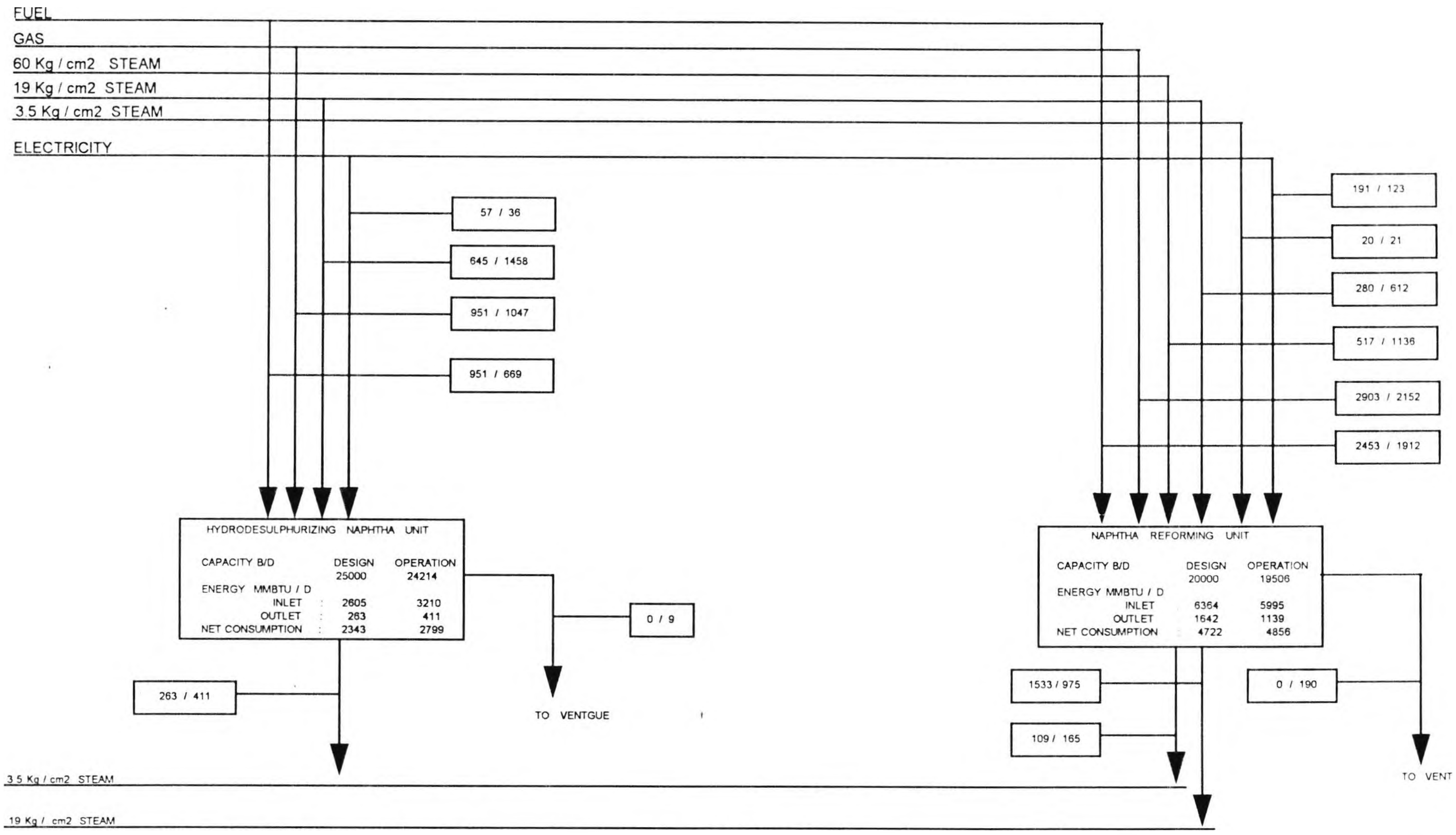
DIAGRAM 3.2.1



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ. REFINERY
HIDRODESUL PHURATION SECTOR
DATA FOR DECEMBER 1987

NOTE — THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

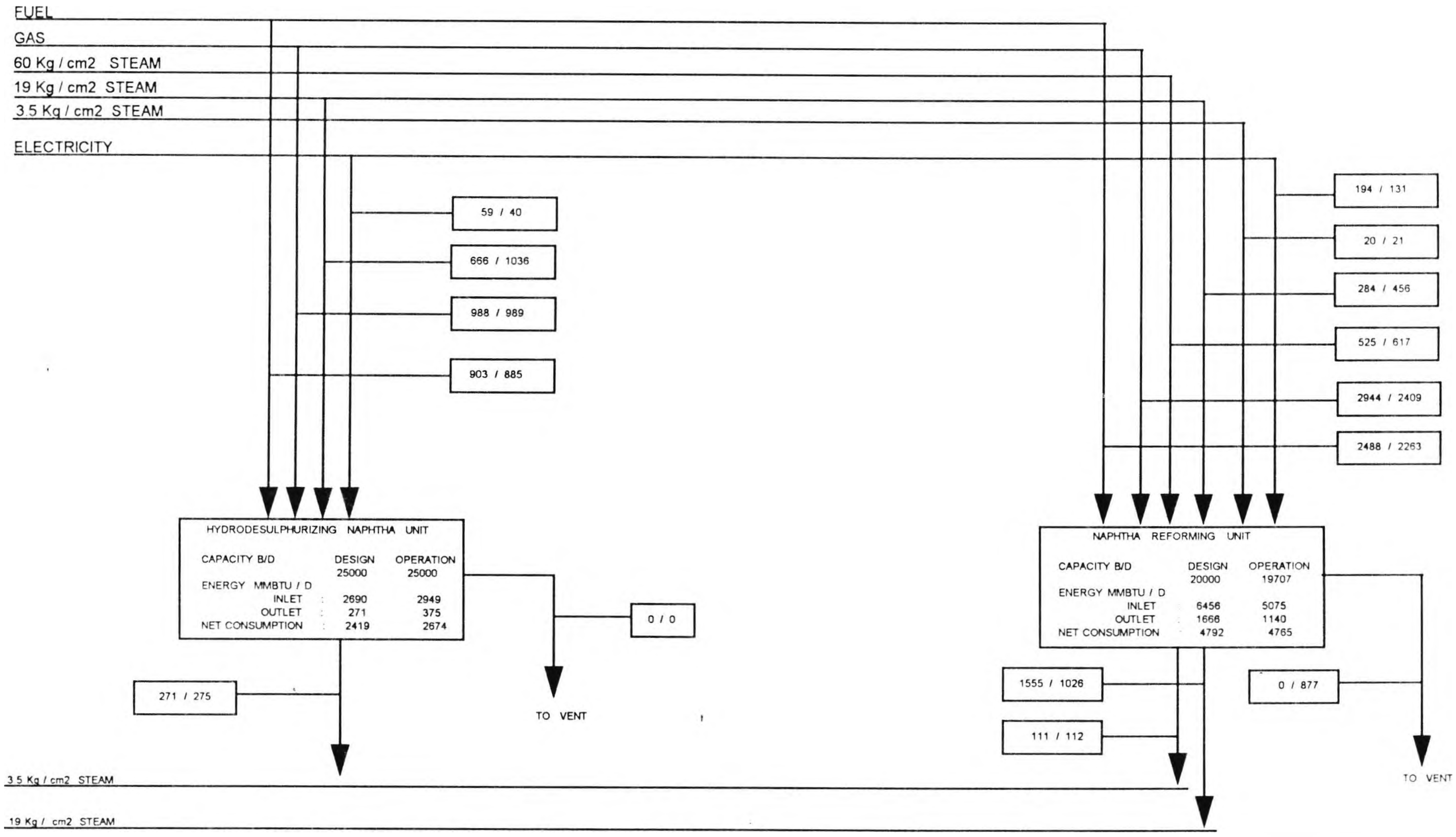
DIAGRAM 3.2.2



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ. REFINERY
HIDRODESULPHURATION SECTOR
DATA FOR DECEMBER 1987

NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

DIAGRAM 3.2.3



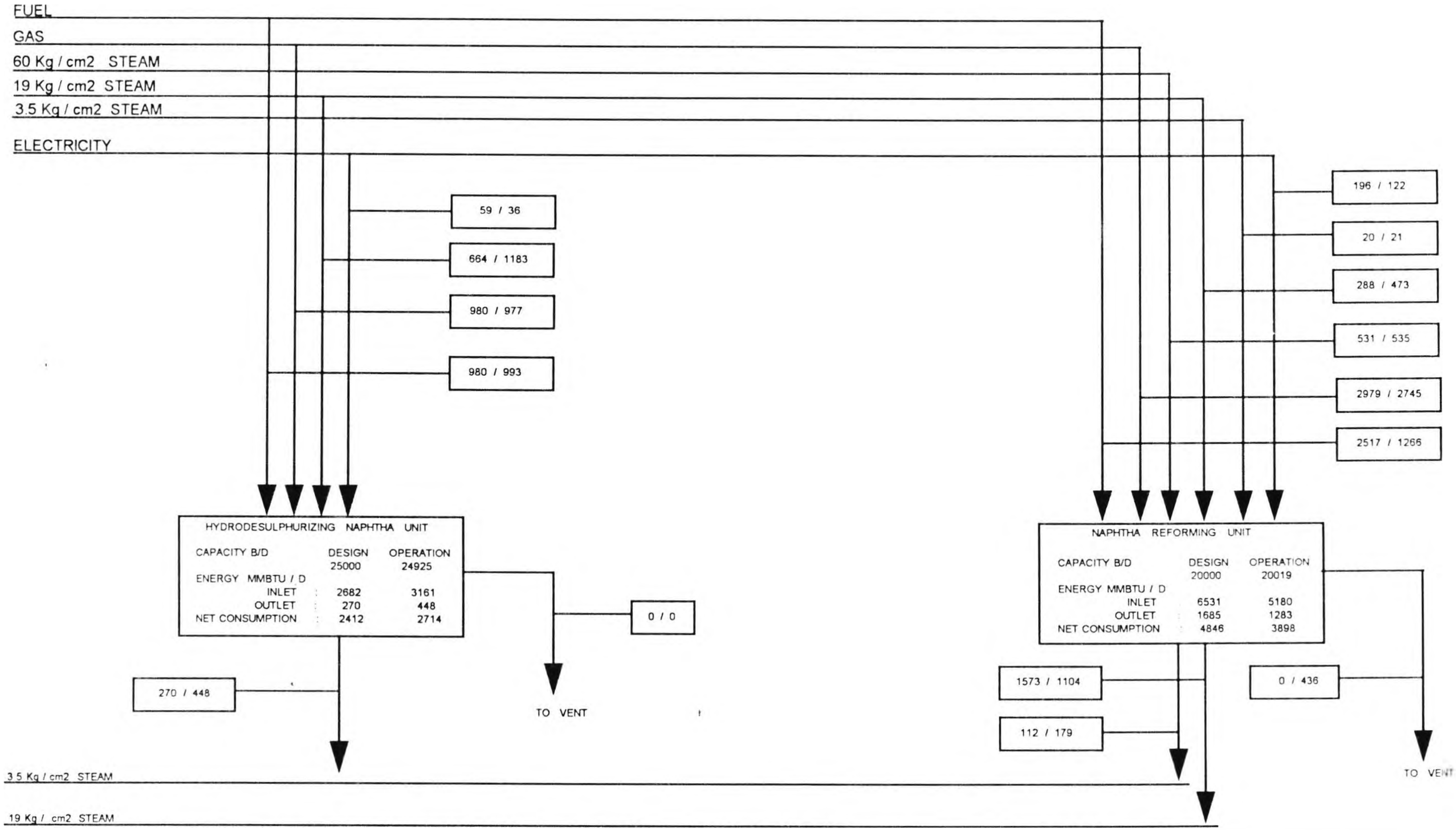
IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY

ENERGY PROFILE IN SALINA CRUZ REFINERY
HIDRODESULPHURATION SECTOR

DATA FOR FEBRUARY 1988

NOTE --THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

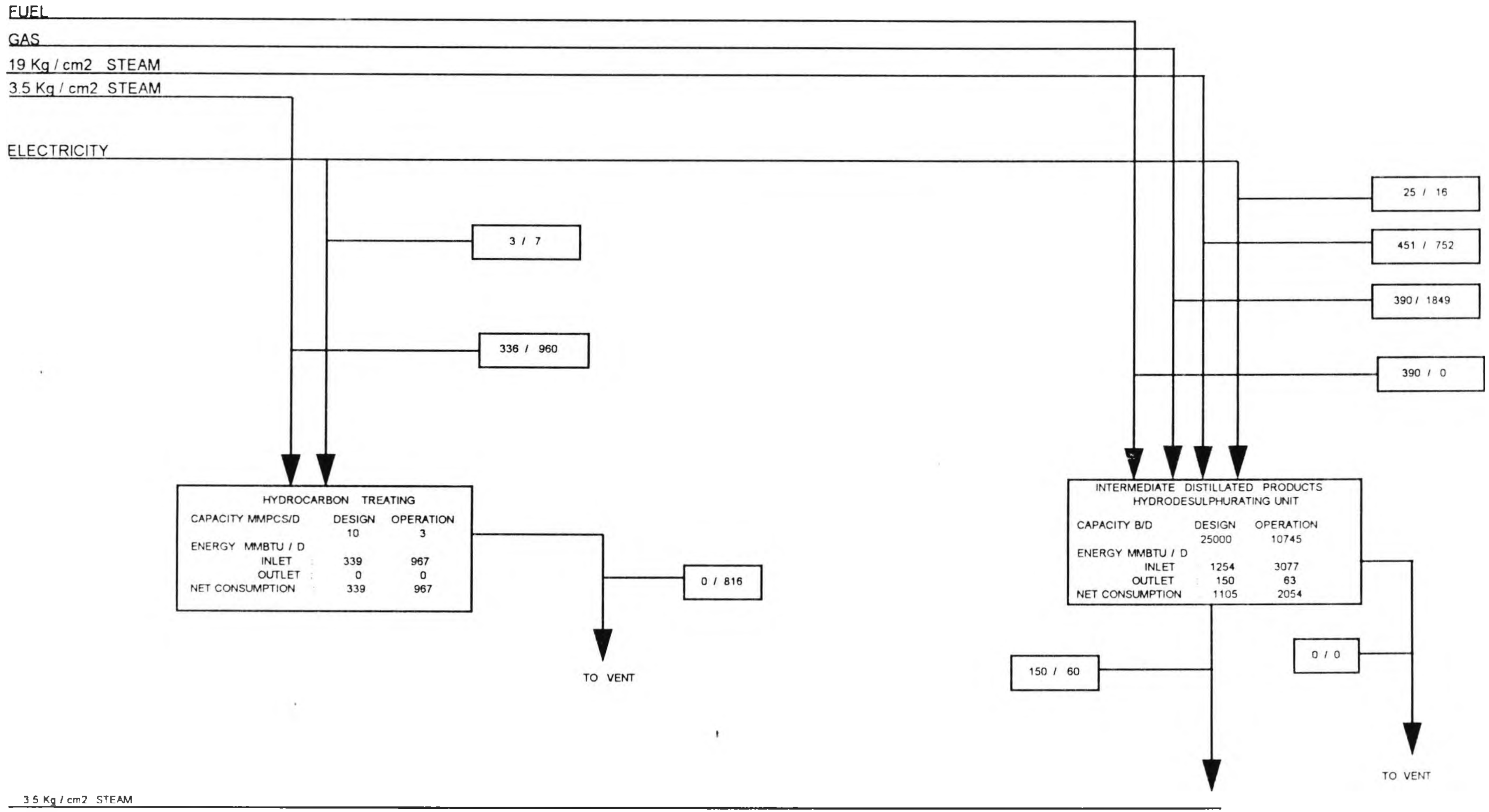
DIAGRAM 3.2.4



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ REFINERY
HIDRODESULPHURATION SECTOR
DATA FOR MARCH 1988

NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY.

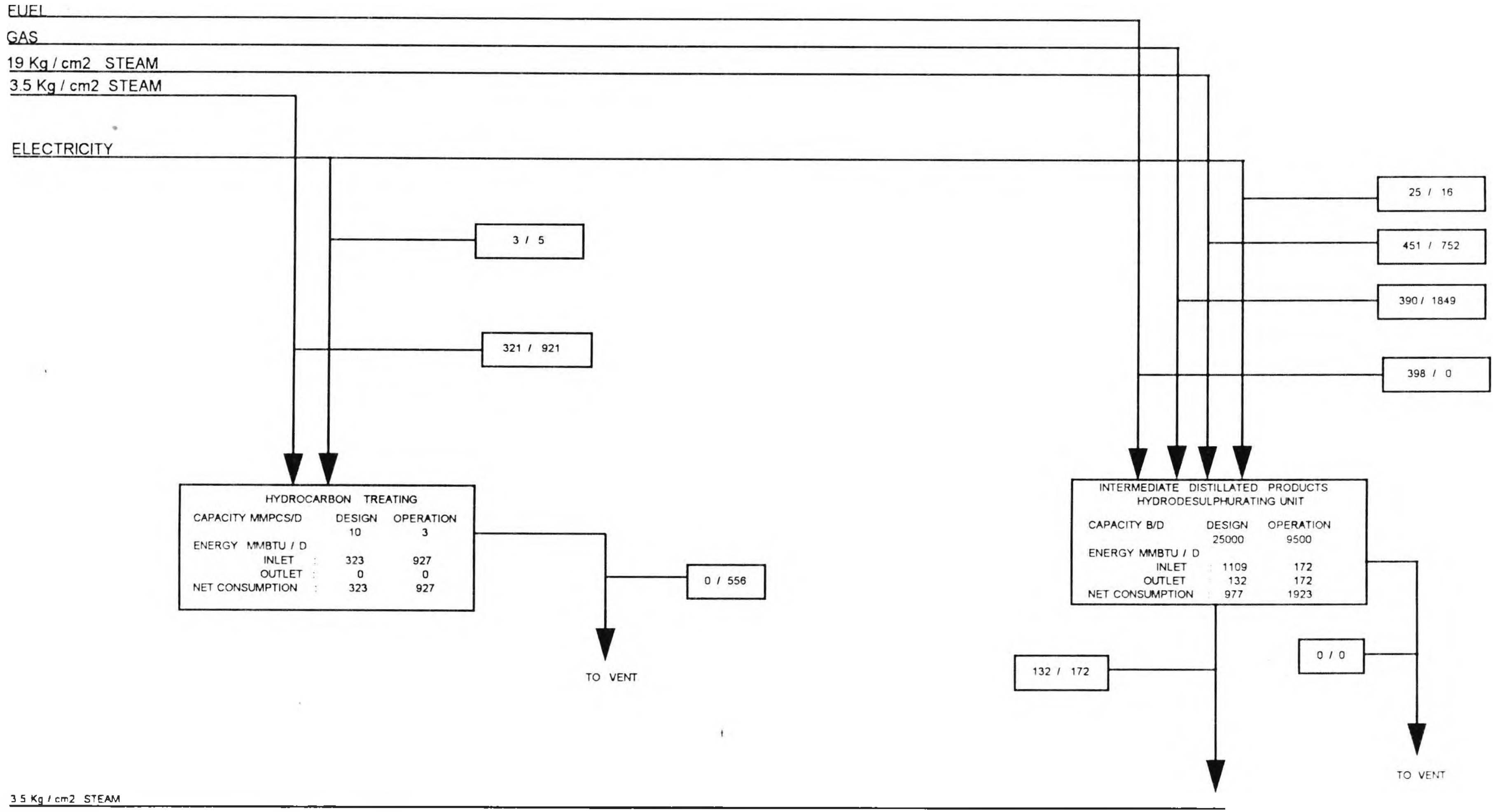
DIAGRAM 3.3.1



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ REFINERY
HYDRODESULPHURATION SECTOR
DATA FOR DECEMBER 1987

NOTE --THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

DIAGRAM 3.3.2



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ REFINERY
HYDRODESULPHURATION SECTOR
DATA FOR JANUARY 1988

NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY.

DIAGRAM 3.3.3

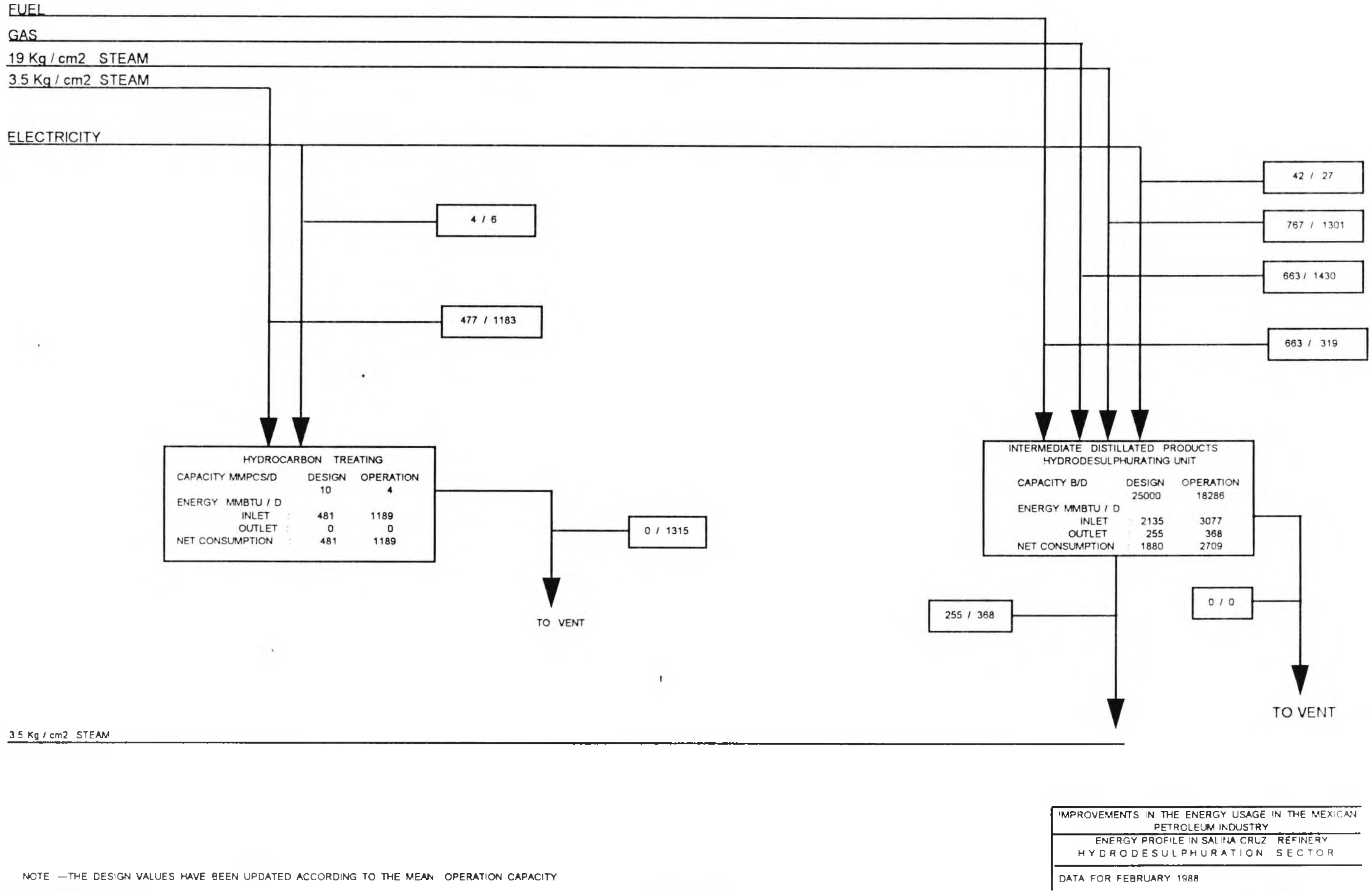
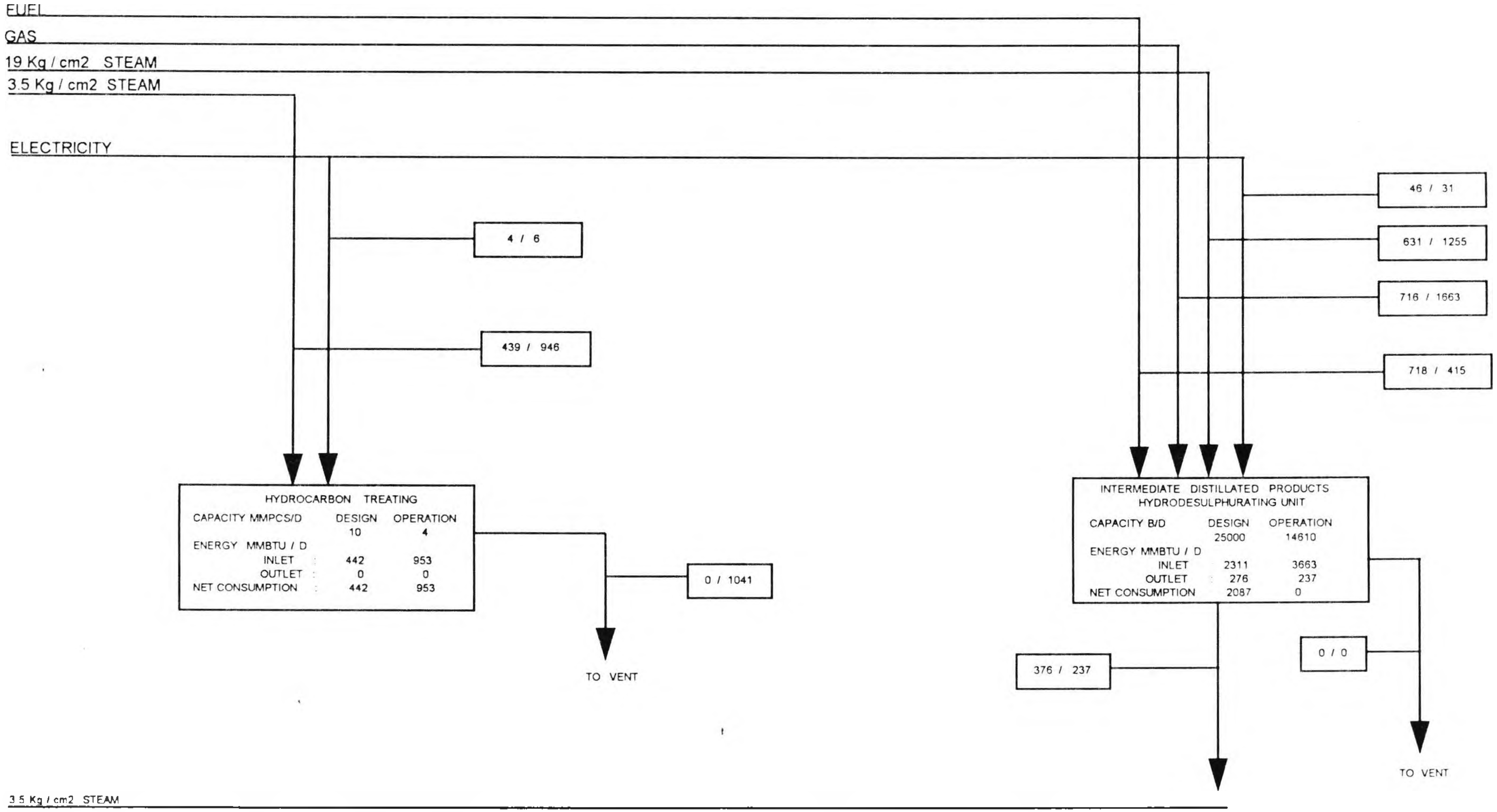

FUEL
GAS
19 Kg / cm2 STEAM
3.5 Kg / cm2 STEAM
ELECTRICITY
4 / 6
477 / 1183
HYDROCARBON TREATING
CAPACITY MMPCS/D DESIGN OPERATION
10 4
ENERGY MMBTU / D
INLET : 481 1189
OUTLET : 0 0
NET CONSUMPTION : 481 1189
0 / 1315
TO VENT
42 / 27
767 / 1301
663 / 1430
663 / 319
INTERMEDIATE DISTILLATED PRODUCTS
HYDRODESULPHURATING UNIT
CAPACITY B/D DESIGN OPERATION
25000 18286
ENERGY MMBTU / D
INLET : 2135 3077
OUTLET : 255 368
NET CONSUMPTION : 1880 2709
255 / 368
0 / 0
TO VENT
3.5 Kg / cm2 STEAM
NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY
IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ REFINERY
HYDRODESULPHURATION SECTOR
DATA FOR FEBRUARY 1988

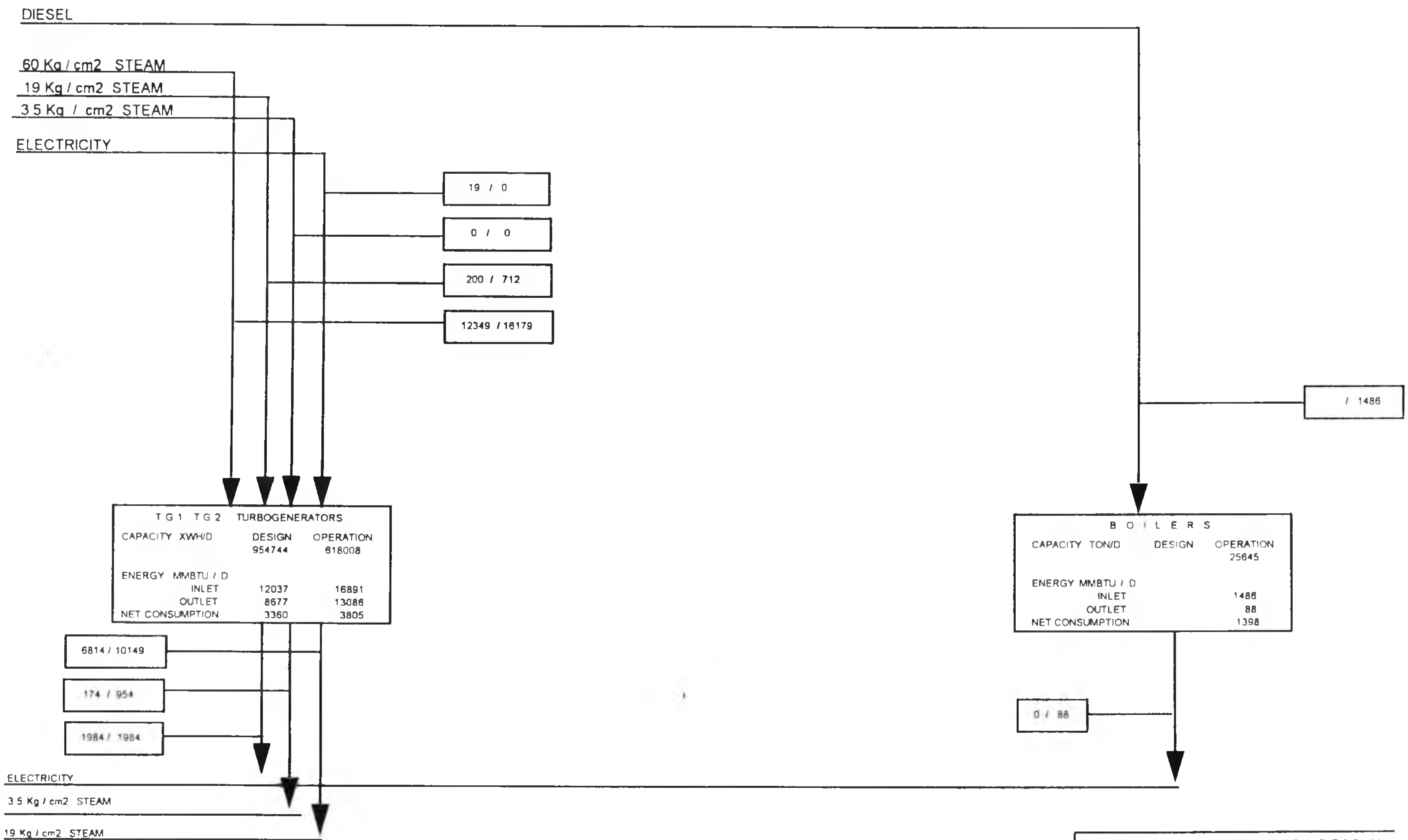
DIAGRAM 3.3.4



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ REFINERY
HYDRODESULPHURATION SECTOR
DATA FOR MARCH 1988

NOTE .- THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

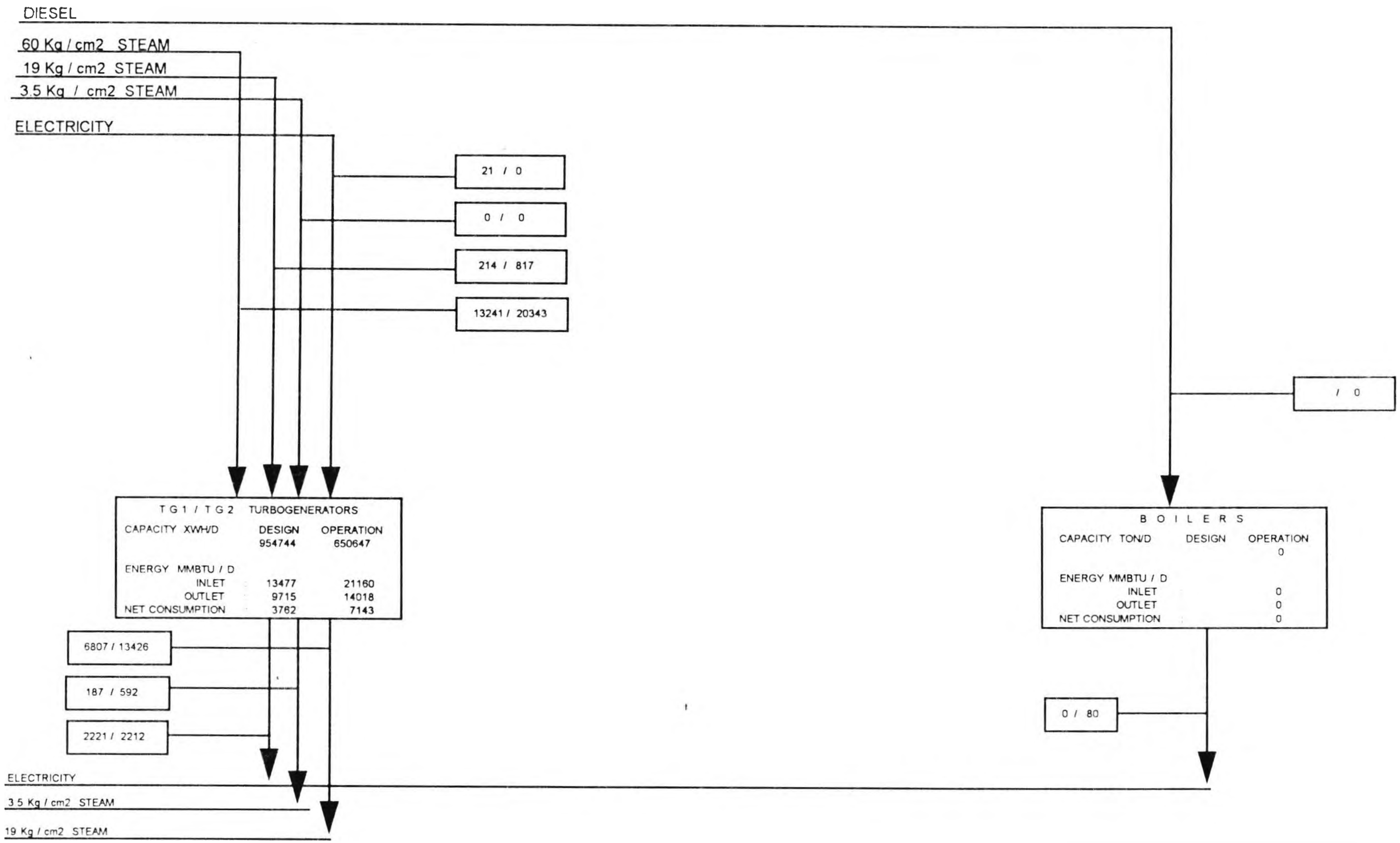
DIAGRAM 3.4.1



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ REFINERY B O I L E R S
DATA FOR DECEMBER 1987

NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

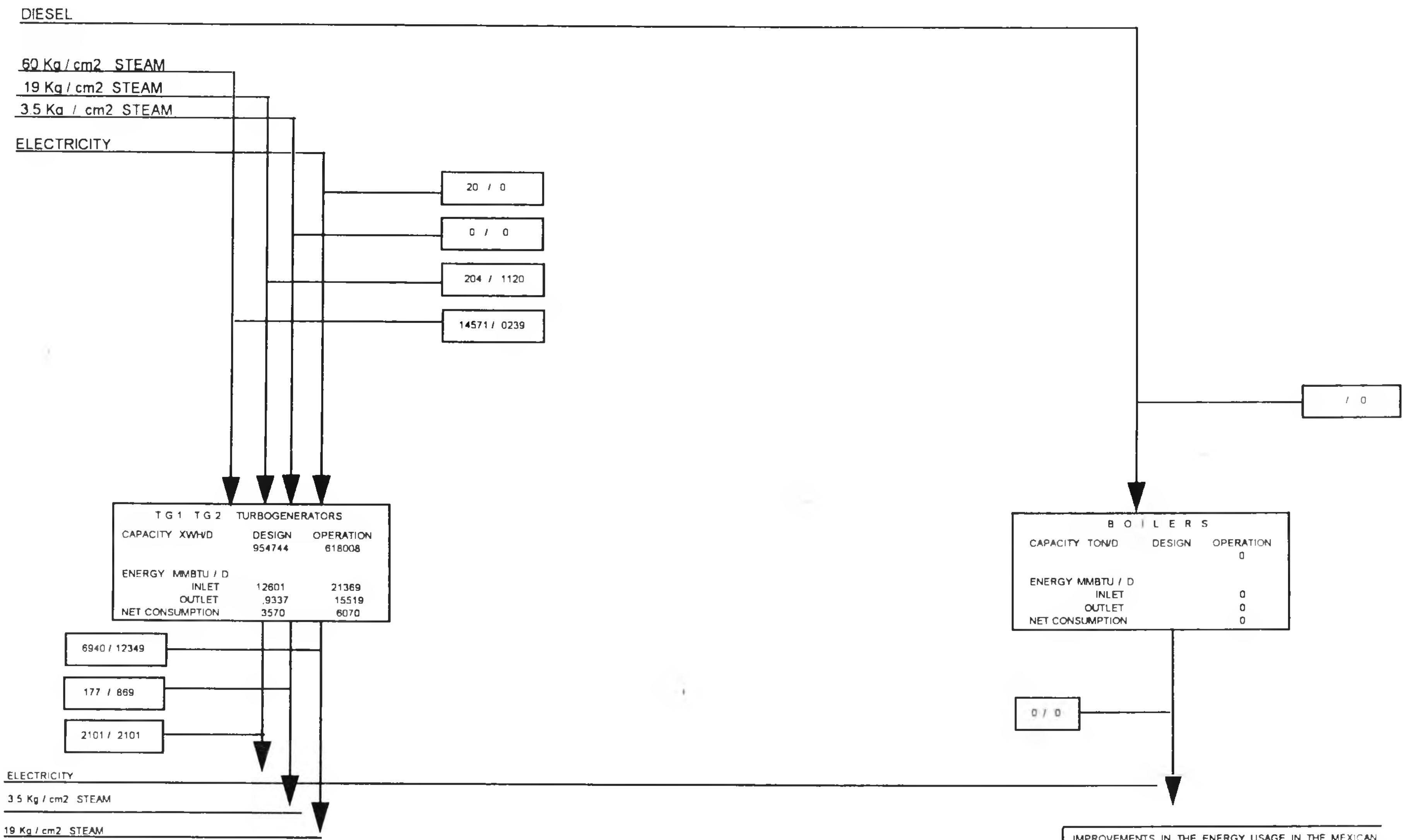
DIAGRAM 3.4.2



NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ. REFINERY
T U R B O G E N E R A T O R S
DATA FOR JANUARY 1988

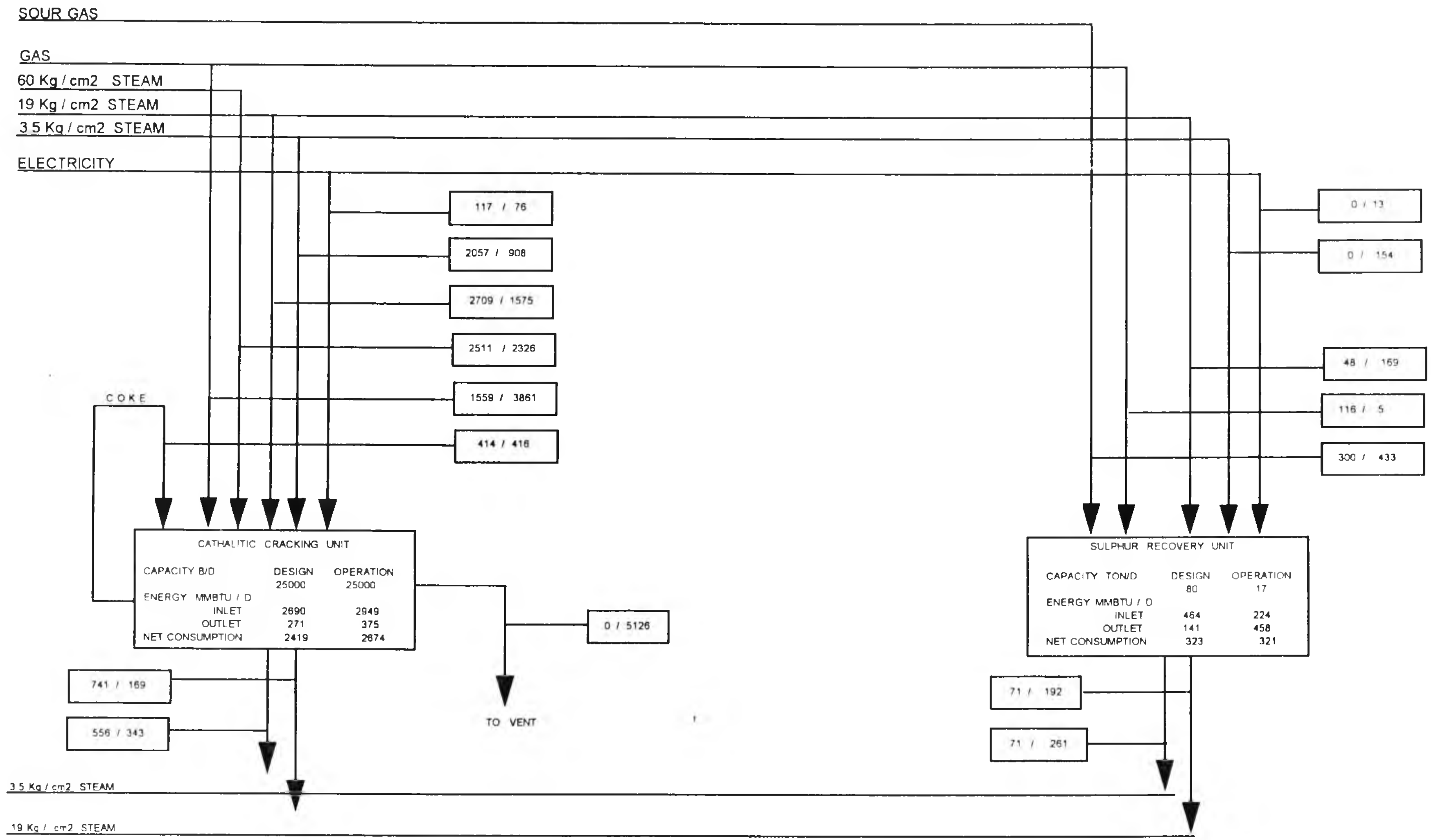
DIAGRAM 3.4.3



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ, REFINERY
B O I L E R S
DATA FOR FEBRUARY 1988

NOTE.—THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

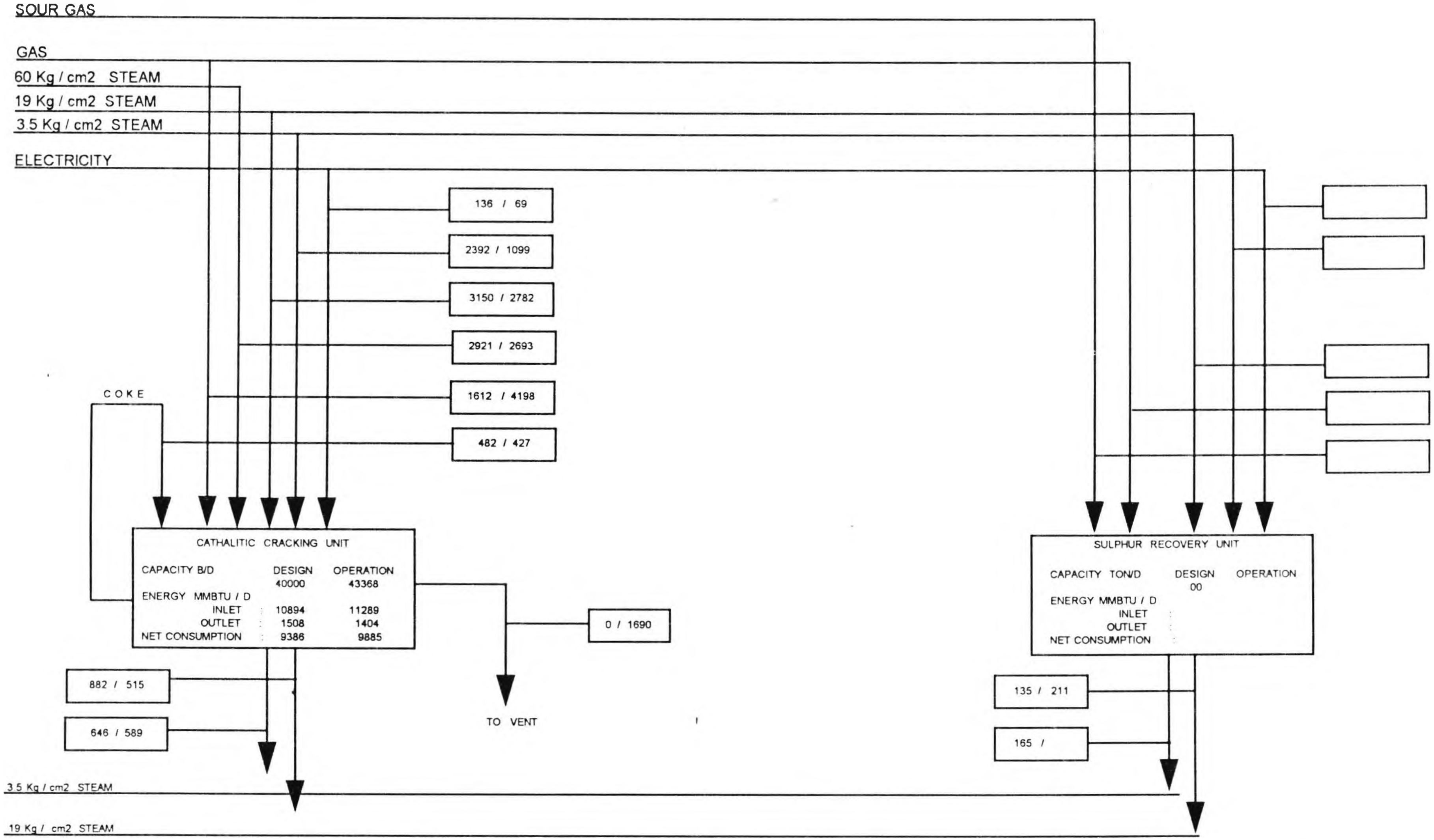
DIAGRAM 3.5.1



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ. REFINERY
CATHALITIC SECTOR
DATA FOR DECEMBER 1987

NOTE.—THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

DIAGRAM 3.5.2



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ REFINERY CATHALITIC SECTOR
DATA FOR JANUARY 1988

NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

DIAGRAM 3.5.3

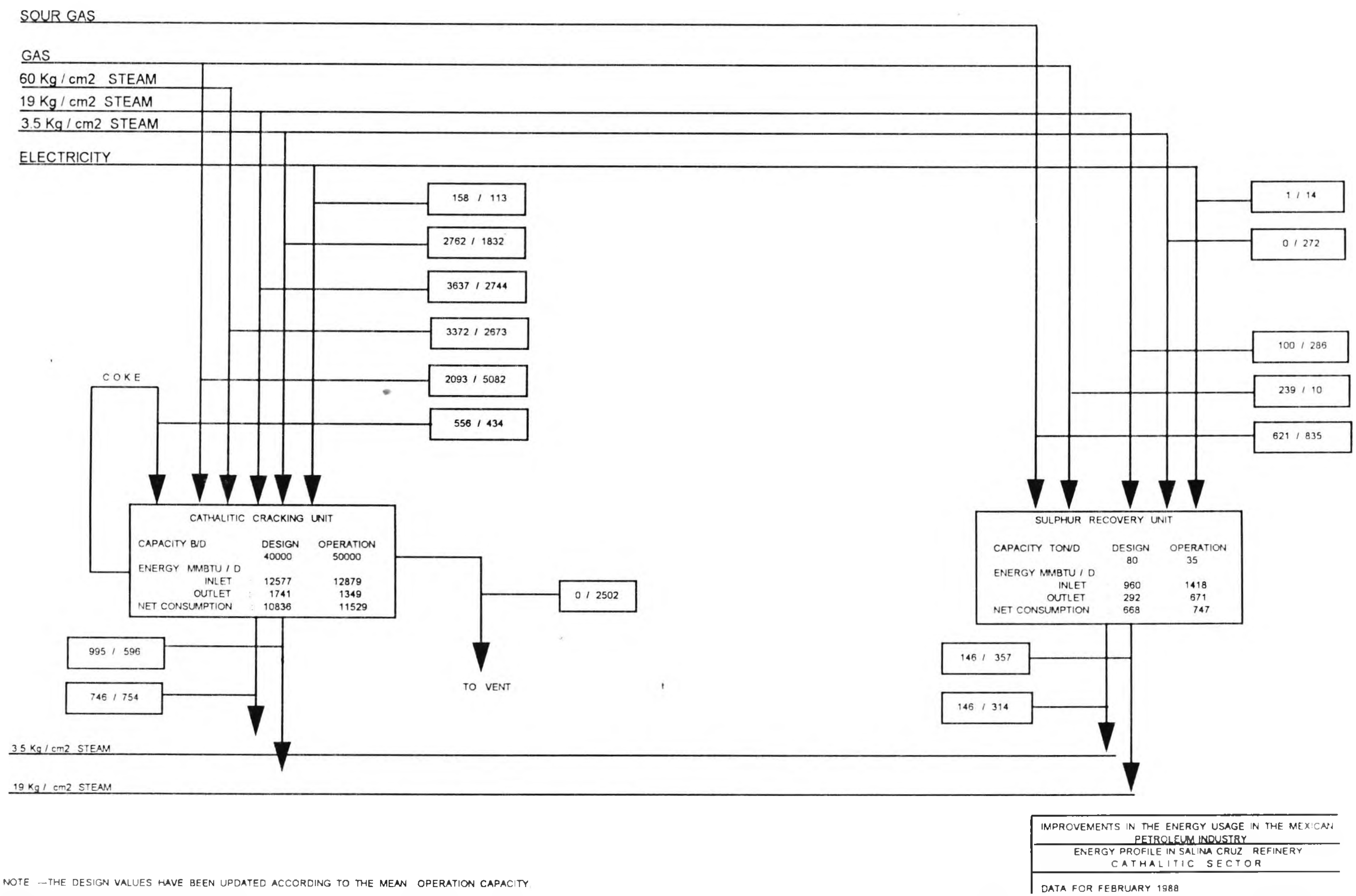
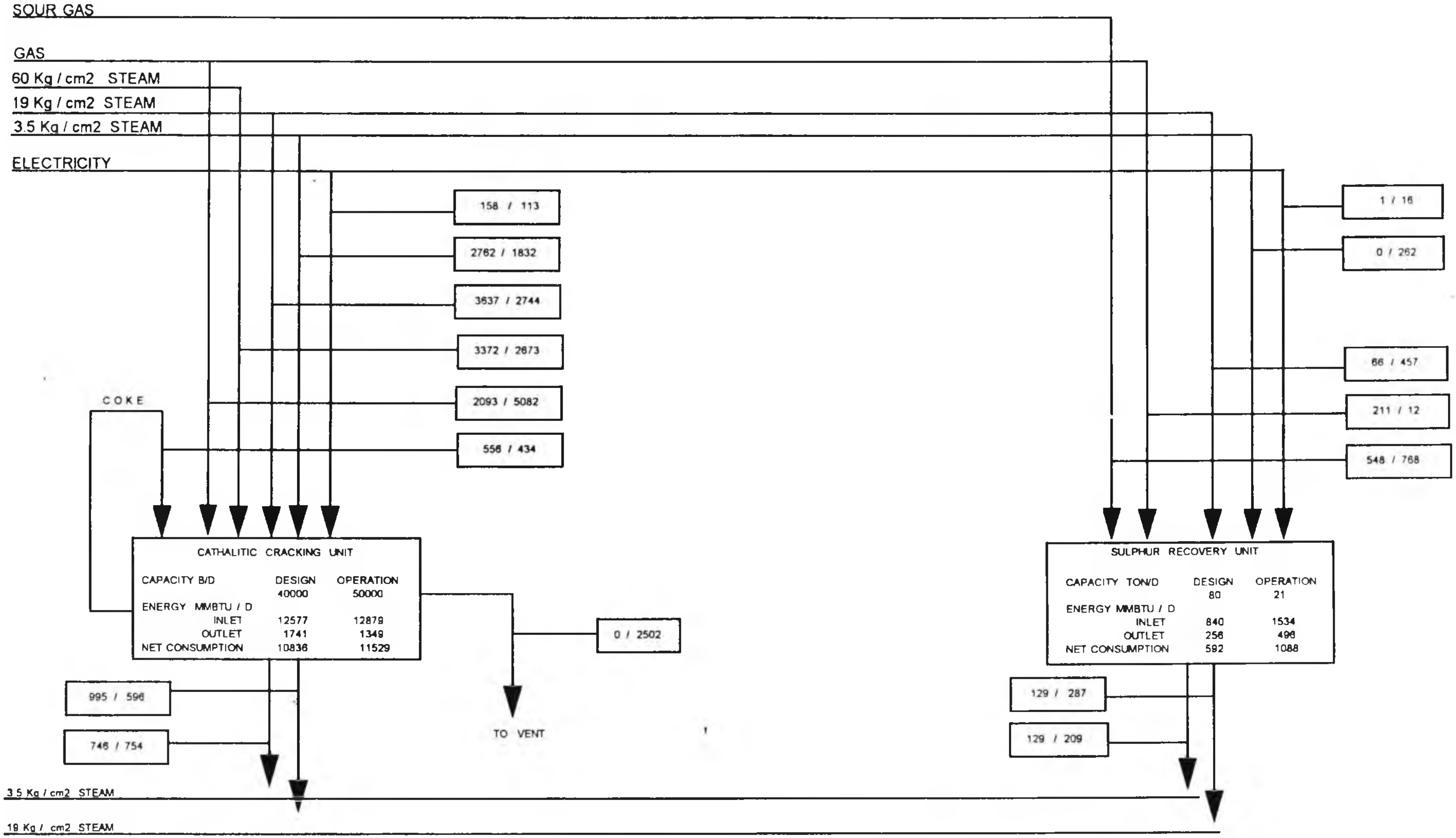

SOUR GAS
GAS
60 Kg / cm2 STEAM
19 Kg / cm2 STEAM
3.5 Kg / cm2 STEAM
ELECTRICITY
158 / 113
2762 / 1832
3637 / 2744
3372 / 2673
2093 / 5082
556 / 434
COKE
CATHALITIC CRACKING UNIT
CAPACITY B/D DESIGN OPERATION
40000 50000
ENERGY MMBTU / D
INLET 12577 12879
OUTLET 1741 1349
NET CONSUMPTION 10836 11529
0 / 2502
TO VENT
995 / 596
746 / 754
1 / 14
0 / 272
100 / 286
239 / 10
621 / 835
SULPHUR RECOVERY UNIT
CAPACITY TON/D DESIGN OPERATION
80 35
ENERGY MMBTU / D
INLET 960 1418
OUTLET 292 671
NET CONSUMPTION 668 747
146 / 357
146 / 314
3.5 Kg / cm2 STEAM
19 Kg / cm2 STEAM
IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ REFINERY
CATHALITIC SECTOR
DATA FOR FEBRUARY 1988
NOTE --THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

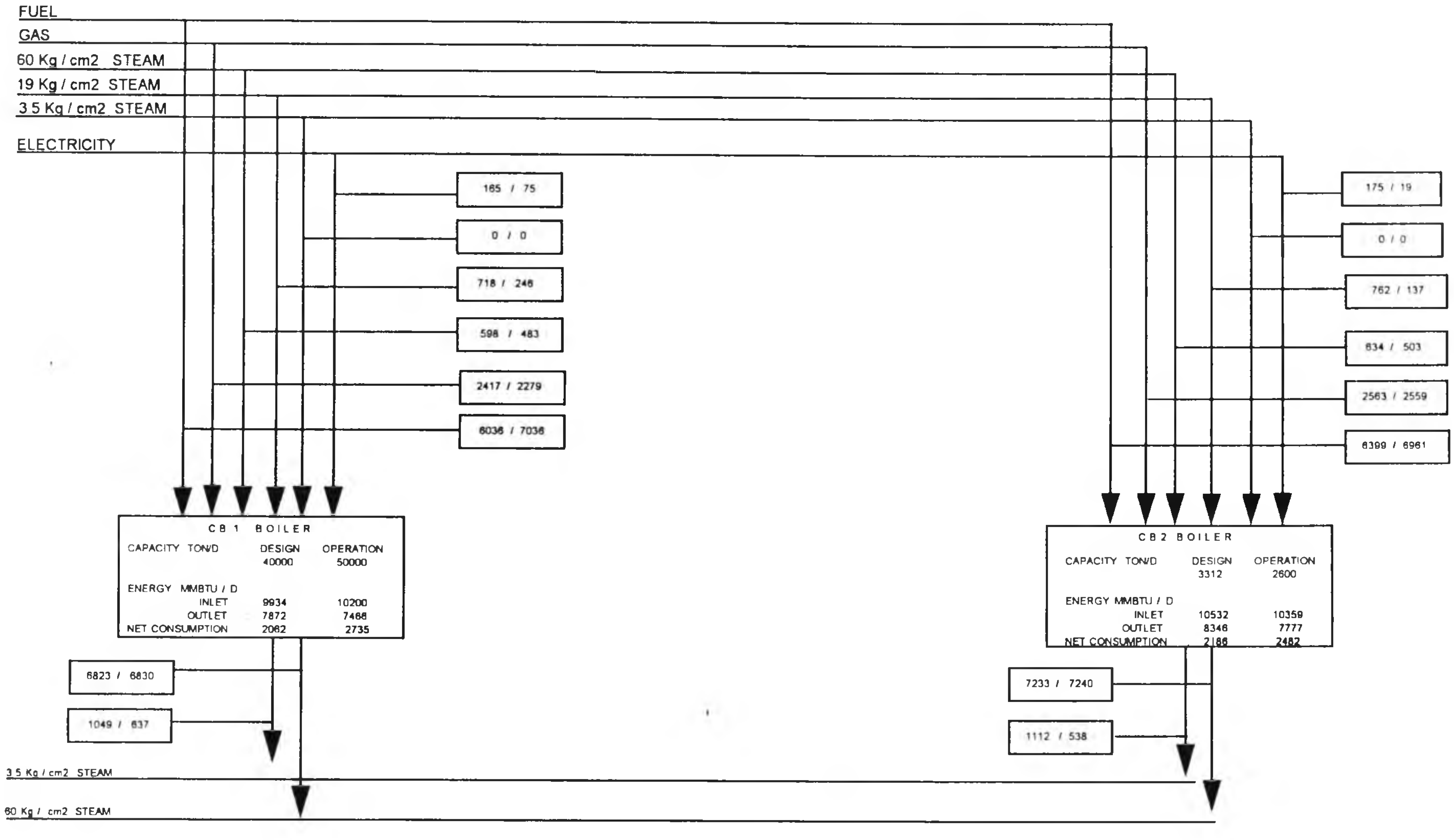
DIAGRAM 3.5.4



NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY.

IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ. REFINERY
CATHALITIC SECTOR
DATA FOR MARCH 1988

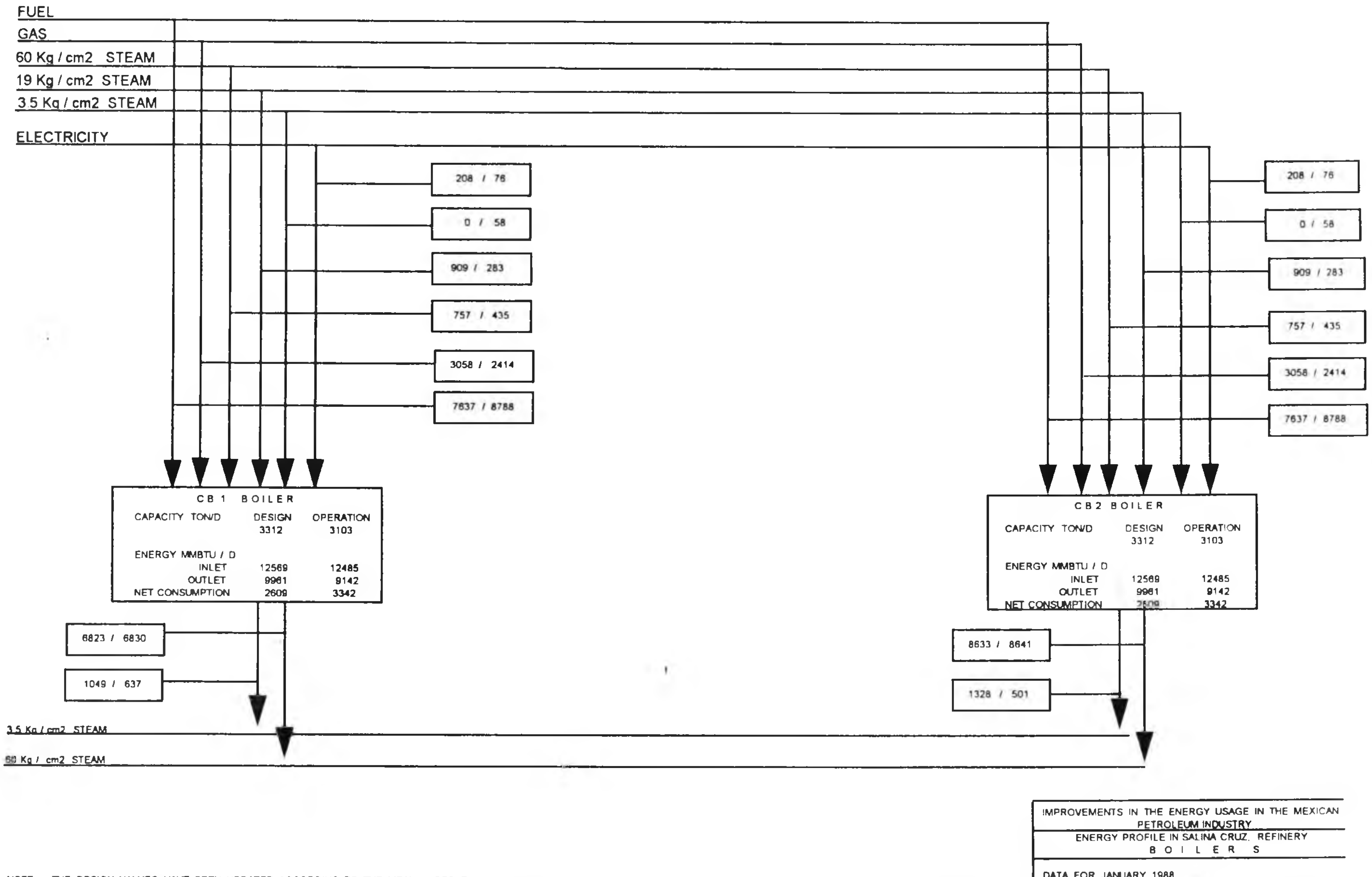
DIAGRAM 3.6.1



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ. REFINERY
B O I L E R S
DATA FOR DECEMBER 1987

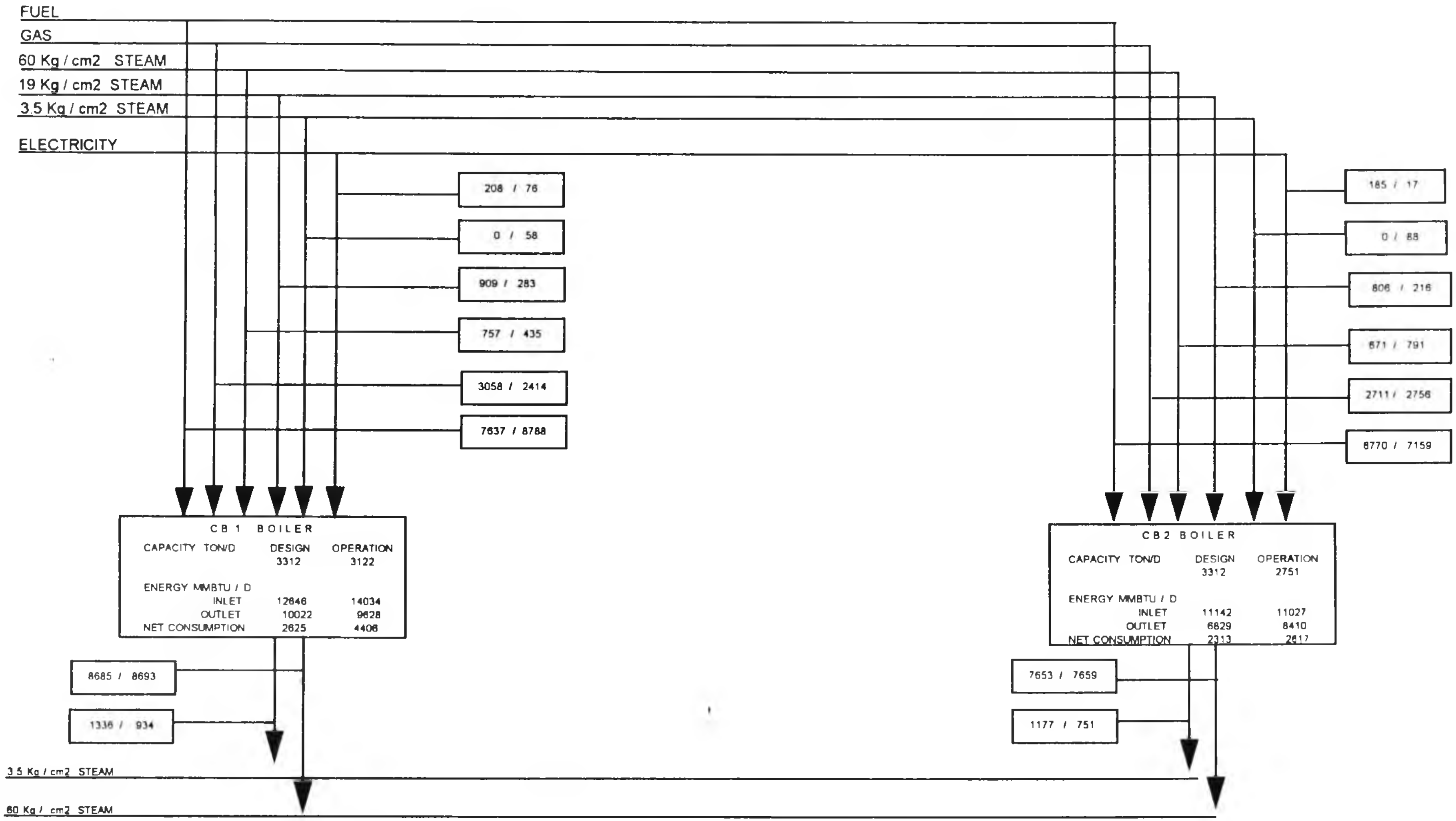
NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

DIAGRAM 3.6.2



NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

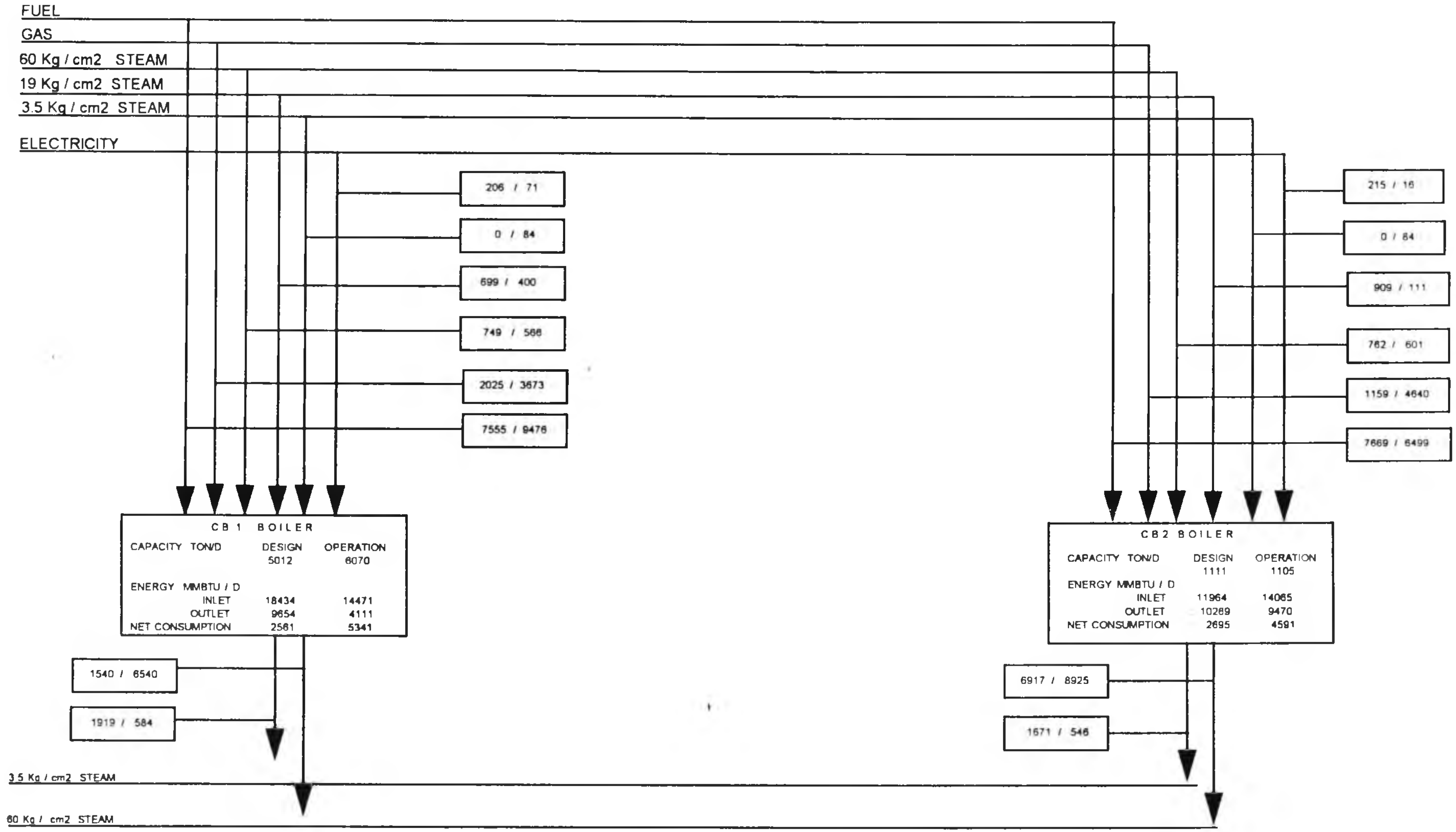
DIAGRAM 3.6.3



NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ REFINERY
B O I L E R S
DATA FOR FEBRUARY 1988

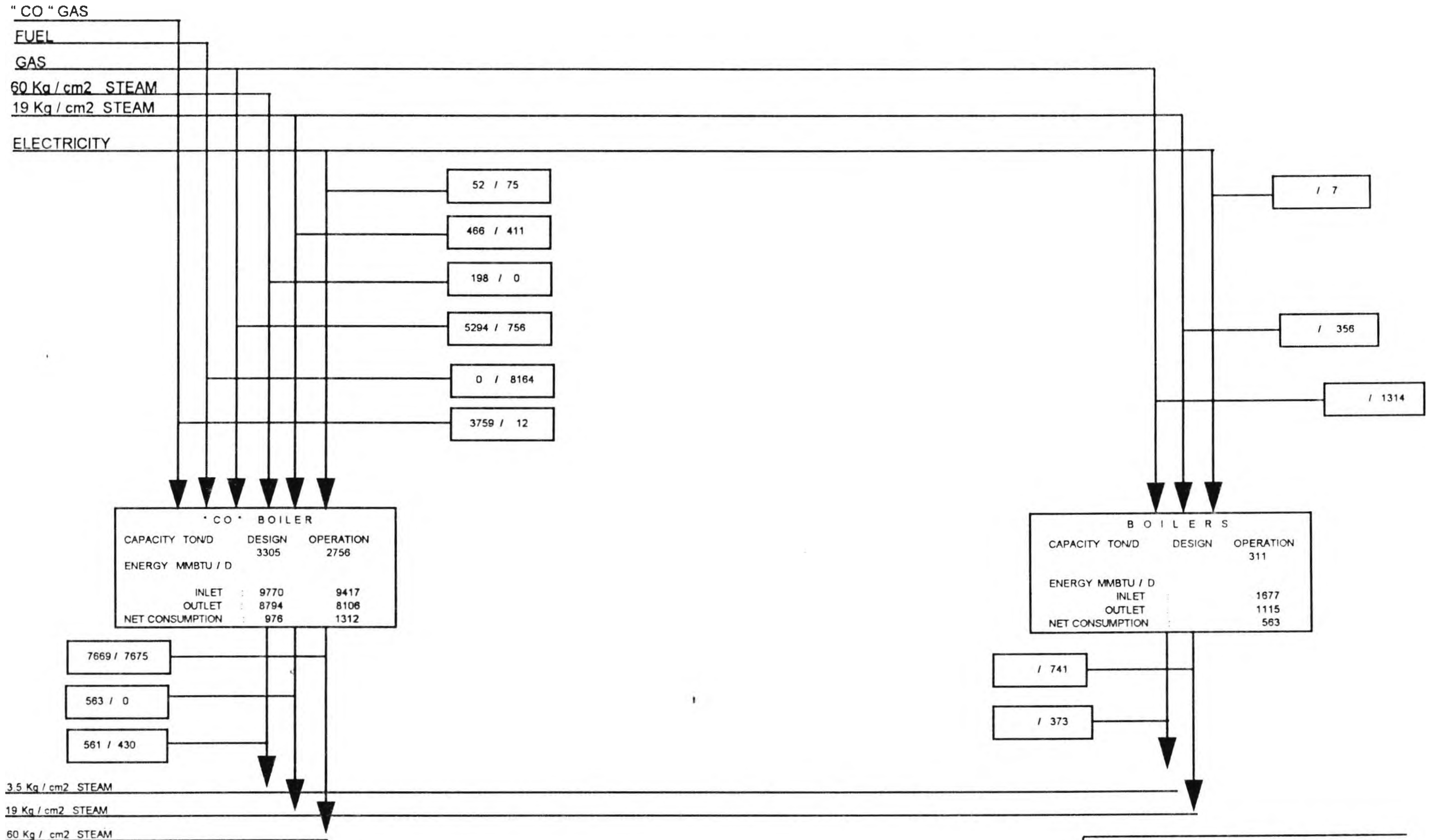
DIAGRAM 3.6.4



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ, REFINERY
B O I L E R S
DATA FOR MARCH 1988

NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

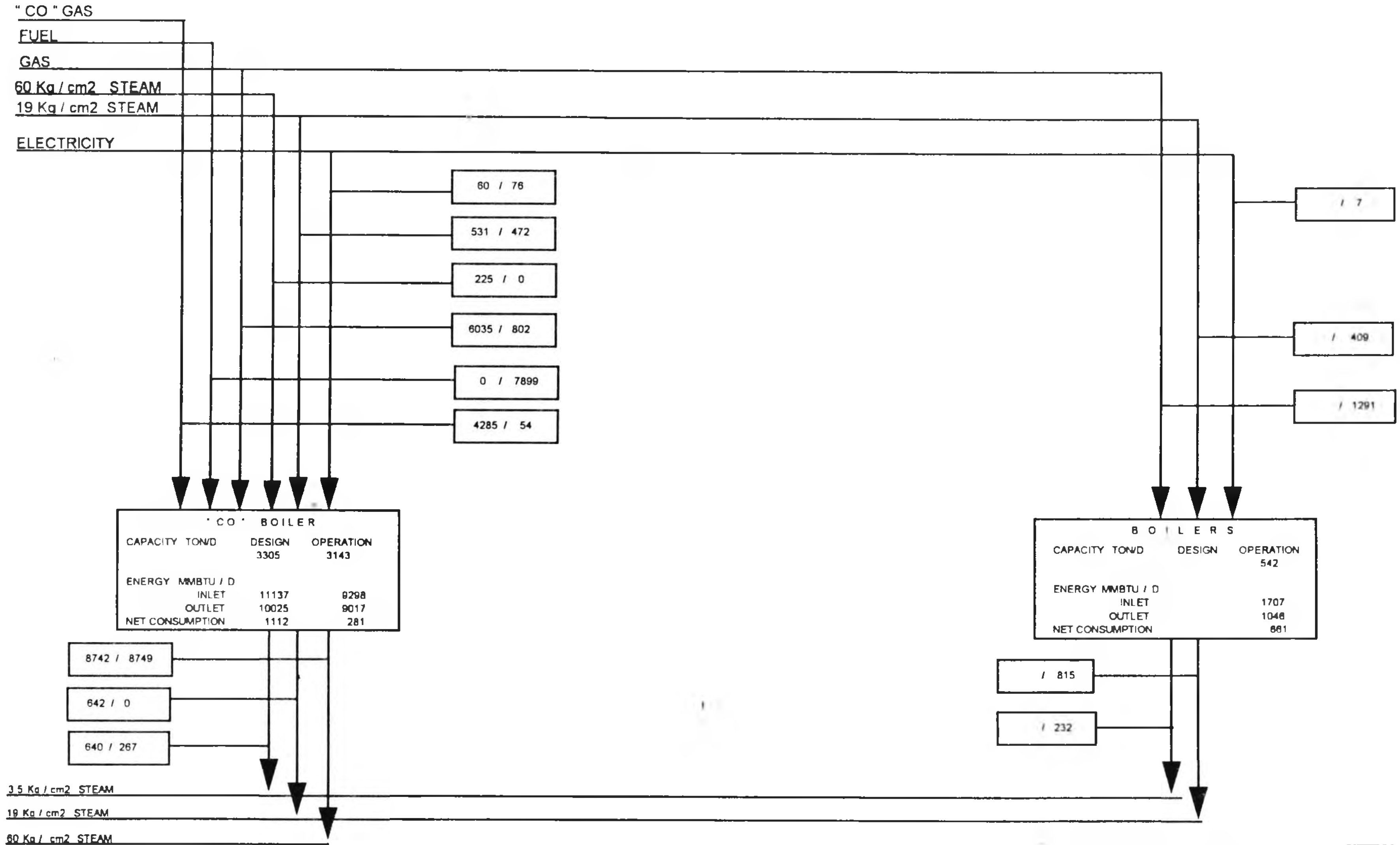
DIAGRAM 3.7.1



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ, REFINERY
B O I L E R S
DATA FOR DECEMBER 1987

NOTE: —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY.

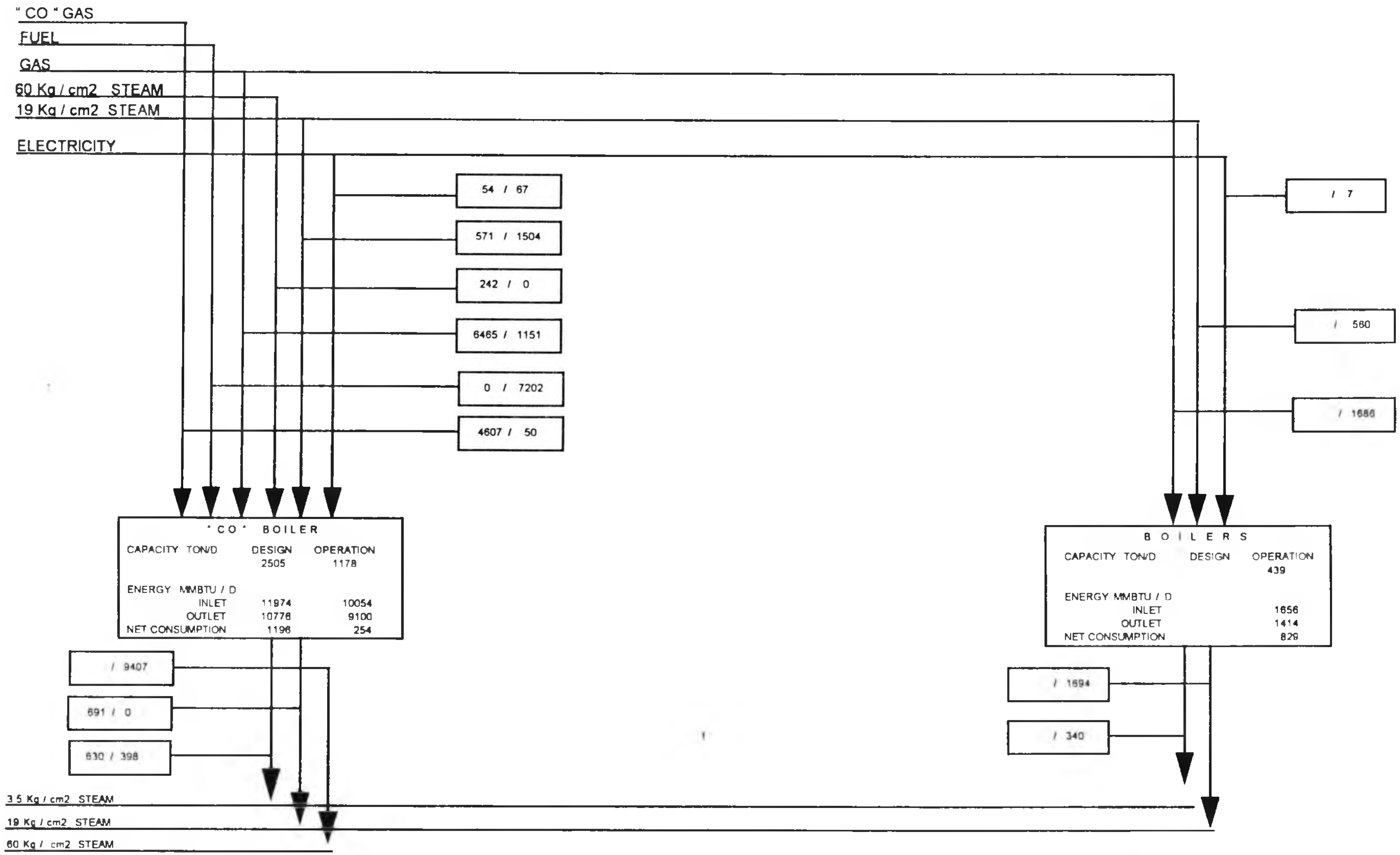
DIAGRAM 3.7.2



NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY.

IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ. REFINERY
B O I L E R S
DATA FOR JANUARY 1988

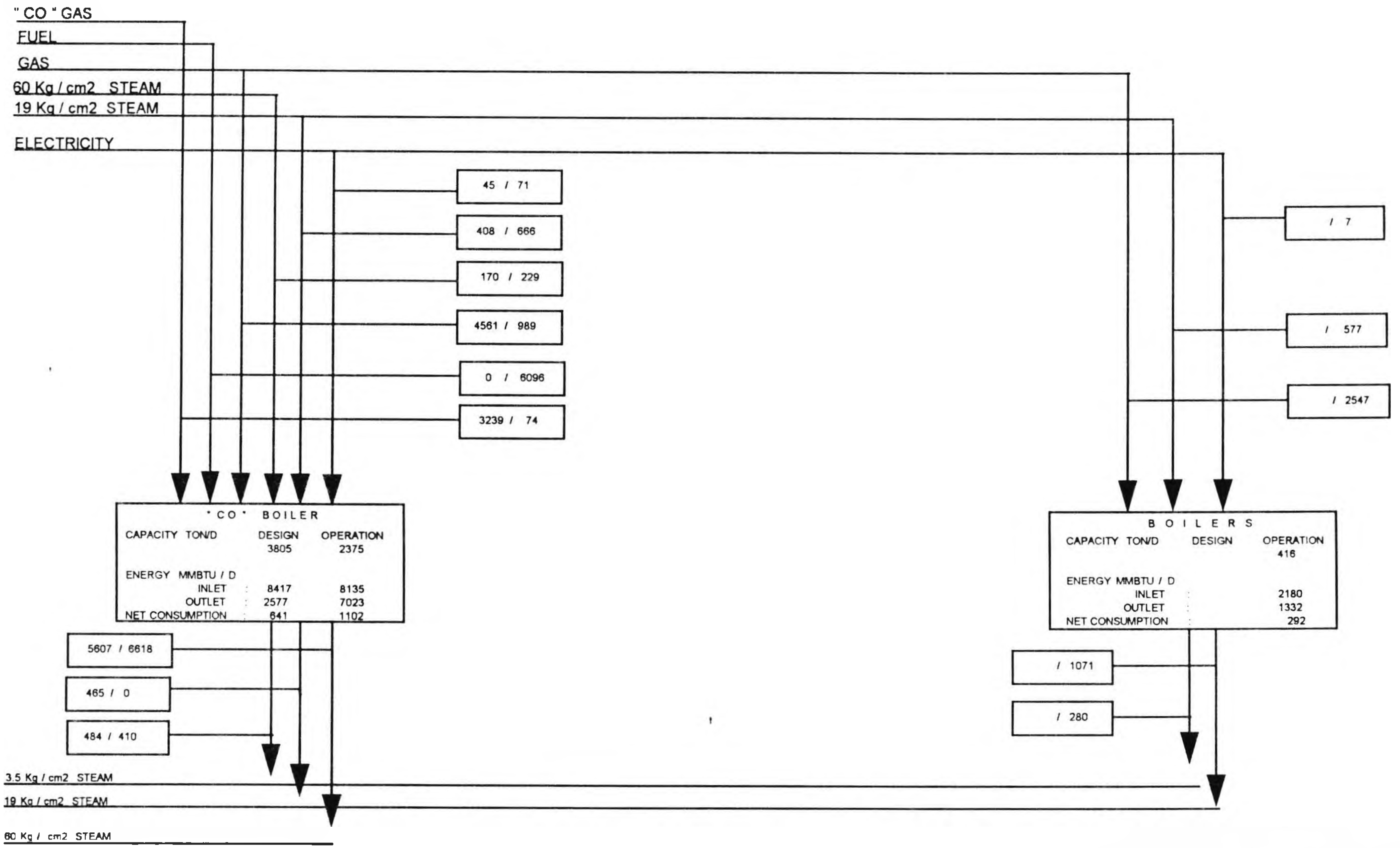
DIAGRAM 3.7.3



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ, REFINERY
B O I L E R S
DATA FOR FEBRUARY 1988

NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY

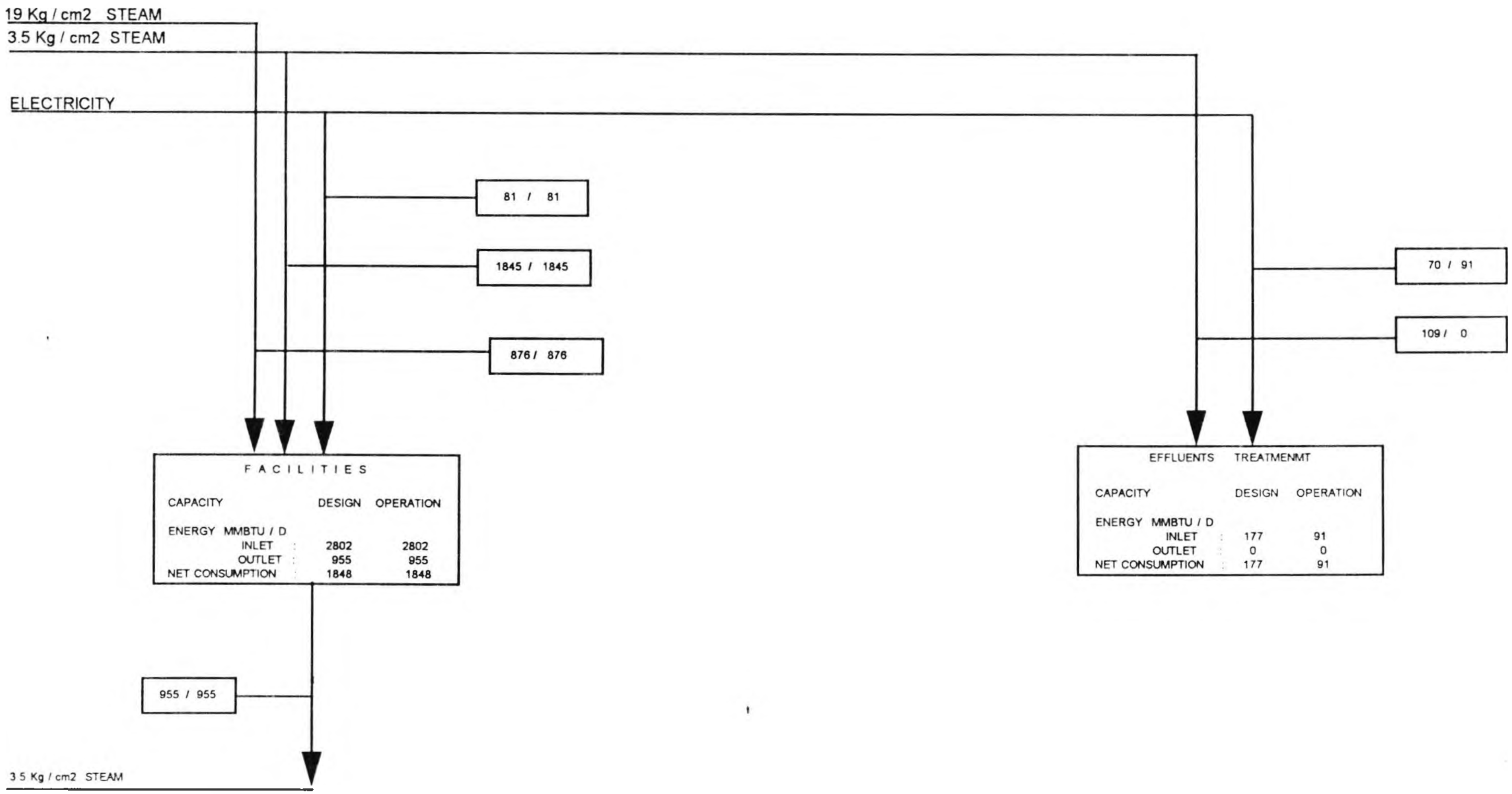
DIAGRAM 3.7.4



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ REFINERY
B O I L E R S
DATA FOR MARCH 1988

NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY.

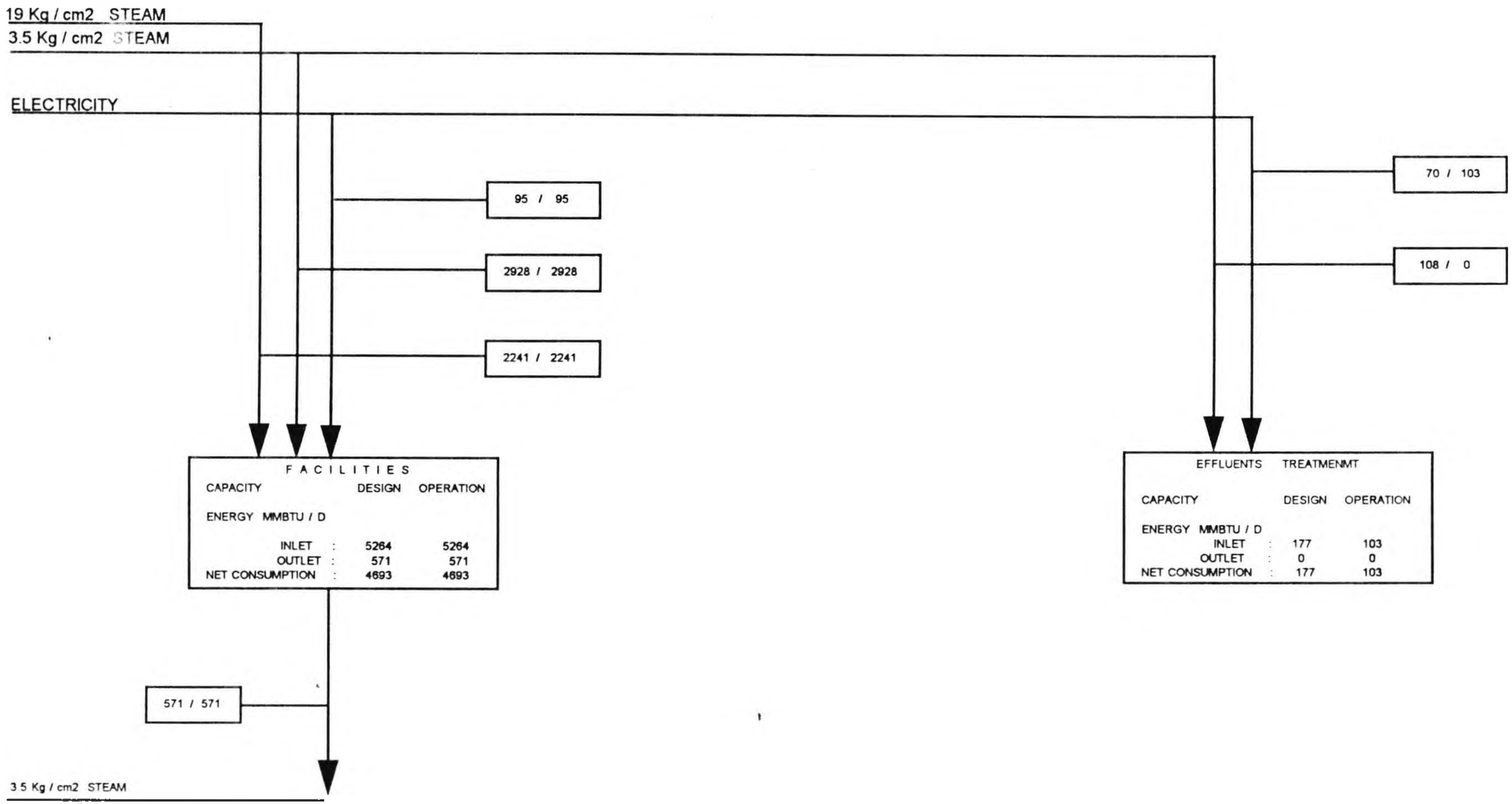
DIAGRAM 3.8.1



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ REFINERY
F A C I L I T I E S AND E F F L U E N T S
DATA FOR DECEMBER 1987

NOTE —THE DESIGN VALUES HAVE NOT BEEN UPDATED DUE TO THE MEAN OPERATION CAPACITY

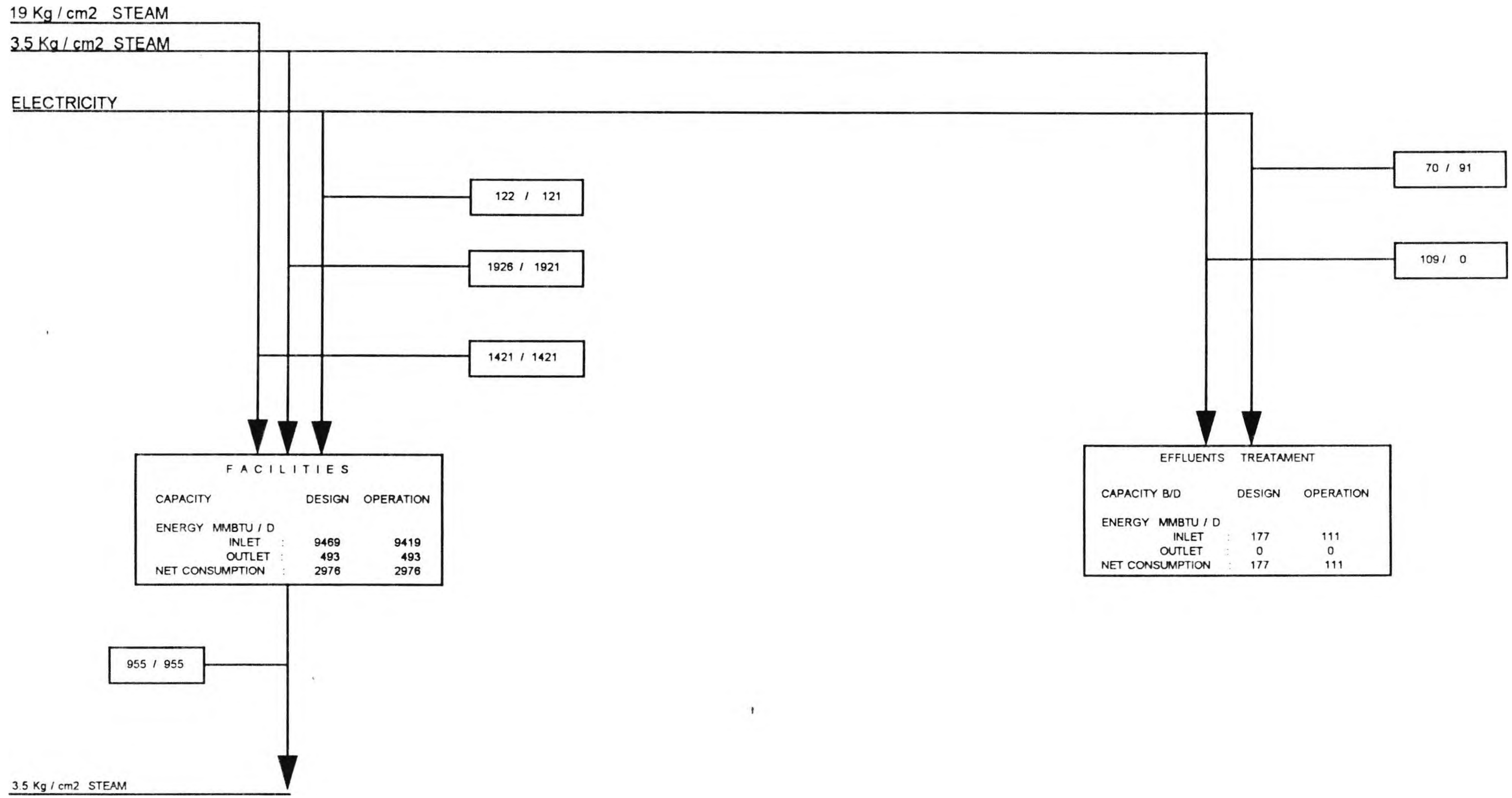
DIAGRAM 3.8.2



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY
ENERGY PROFILE IN SALINA CRUZ, REFINERY FACILITIES AND EFFLUENTS
DATA FOR JANUARY 1988

NOTE: —THE DESIGN VALUES HAVE NOT BEEN UPDATED DUE TO THE MEAN OPERATION CAPACITY

DIAGRAM 3.8.4



IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY

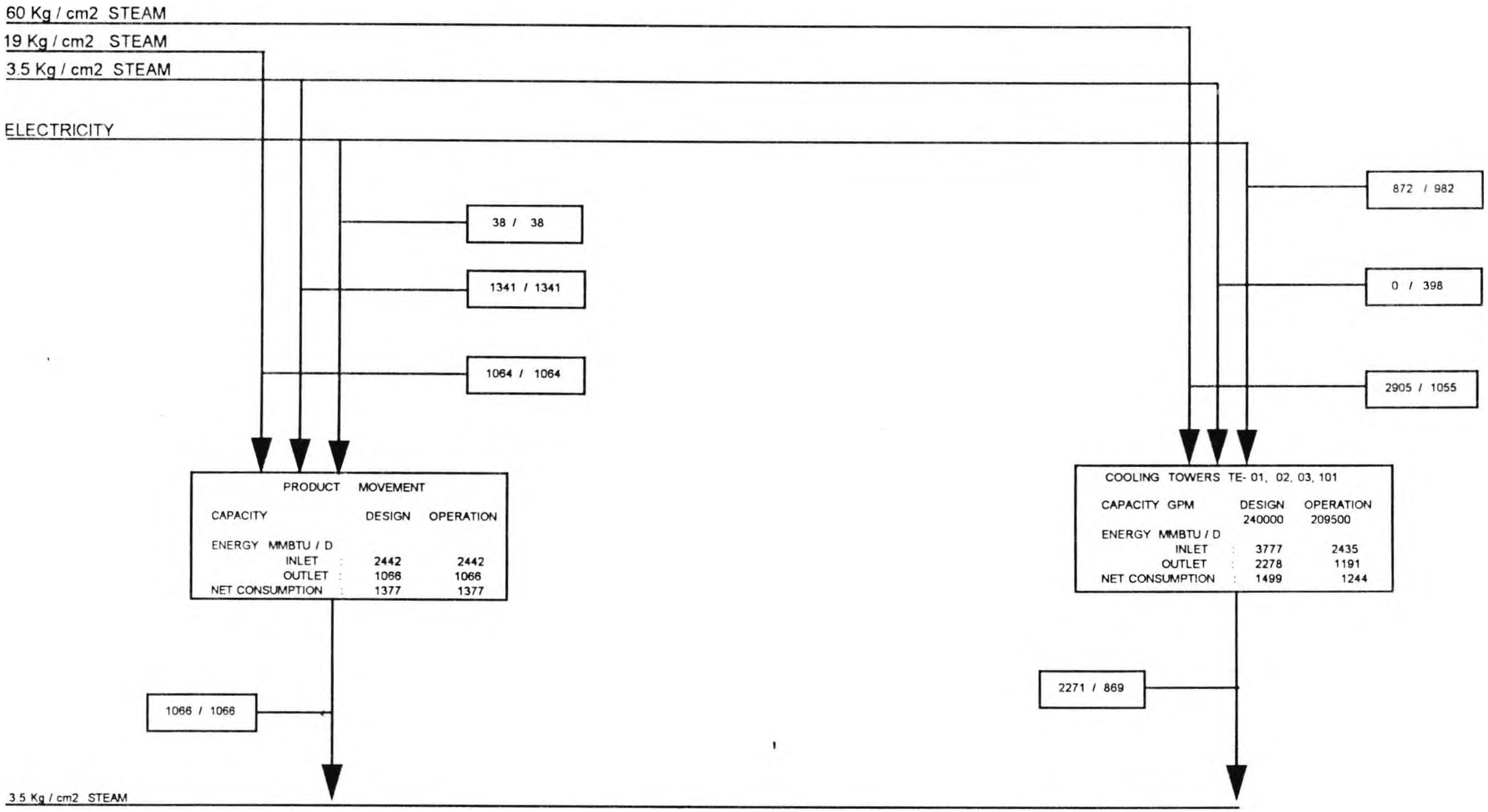
ENERGY PROFILE IN SALINA CRUZ. REFINERY

FACILITIES AND EFFLUENTS

DATA FOR MARCH 1988

NOTE —THE DESIGN VALUES HAVE NOT BEEN UPDATED DUE TO THE MEAN OPERATION CAPACITY

DIAGRAM 3.9.1



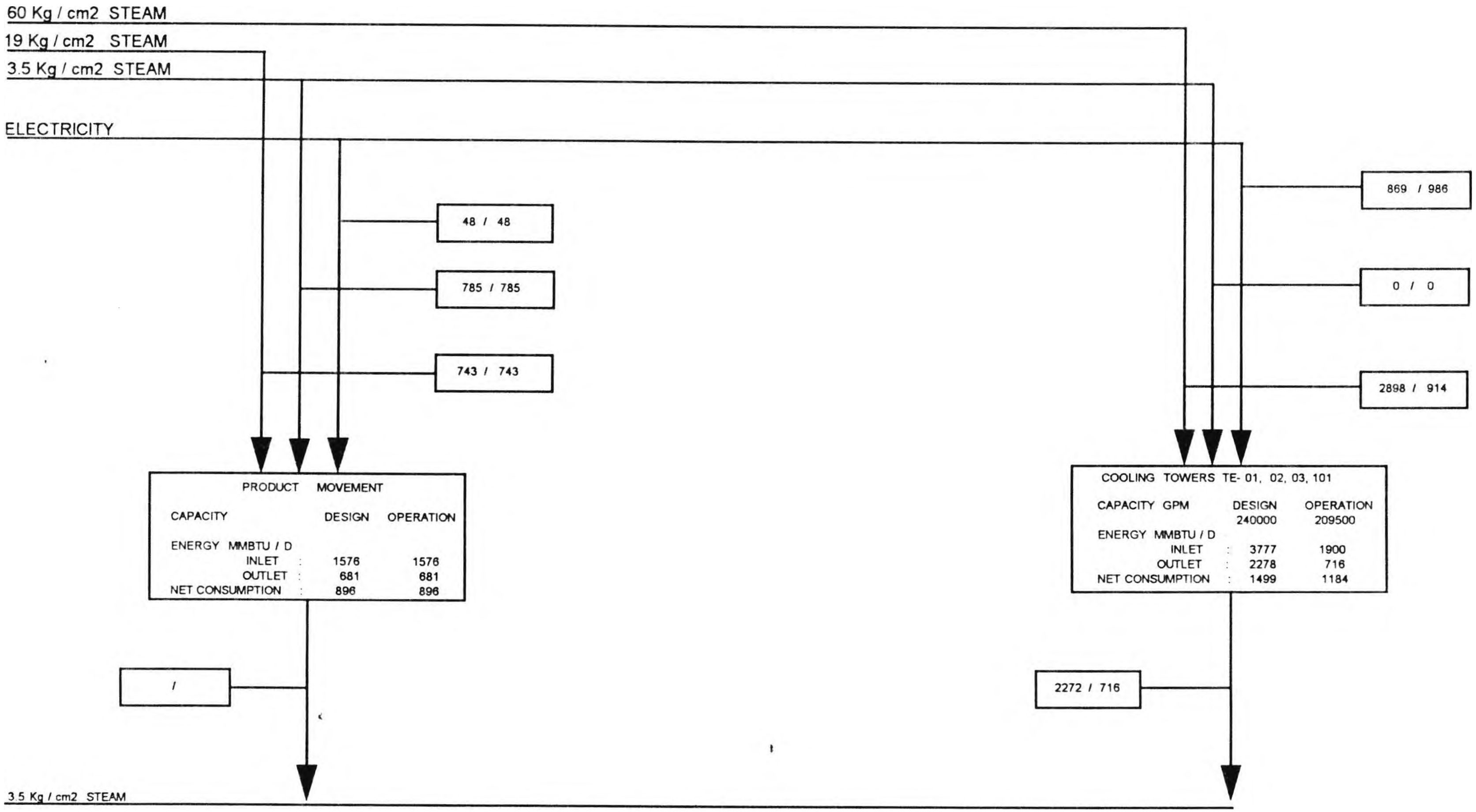
IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY

ENERGY PROFILE IN SALINA CRUZ, REFINERY PRODUCT MOVEMENT AND COOLING TOWERS

DATA FOR DECEMBER 1987

NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY, EXCEPT IN PRODUCT MOVEMENT

DIAGRAM 3.9.2



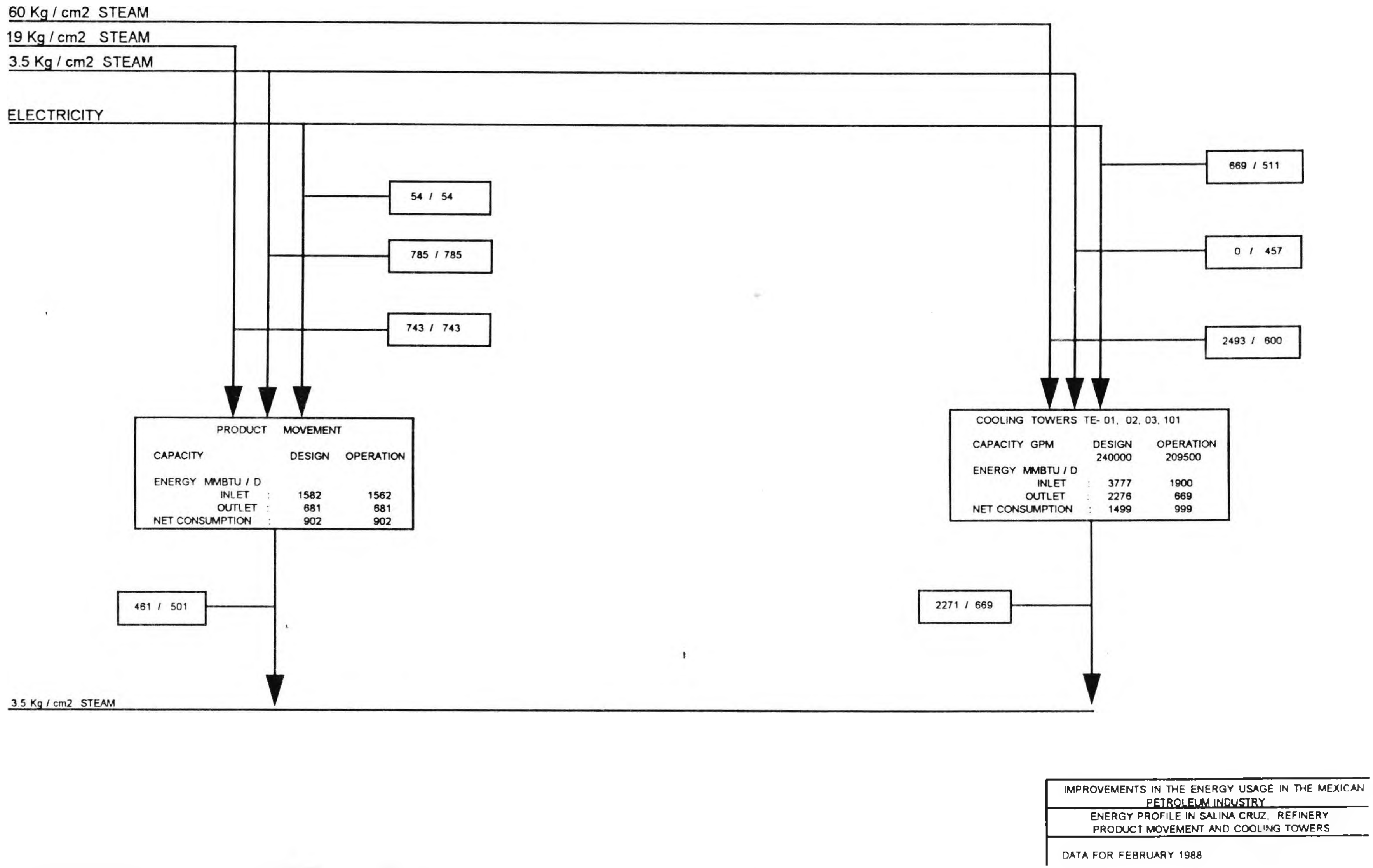
IMPROVEMENTS IN THE ENERGY USAGE IN THE MEXICAN PETROLEUM INDUSTRY

ENERGY PROFILE IN SALINA CRUZ, REFINERY
PRODUCT MOVEMENT AND COOLING TOWERS

DATA FOR JANUARY 1988

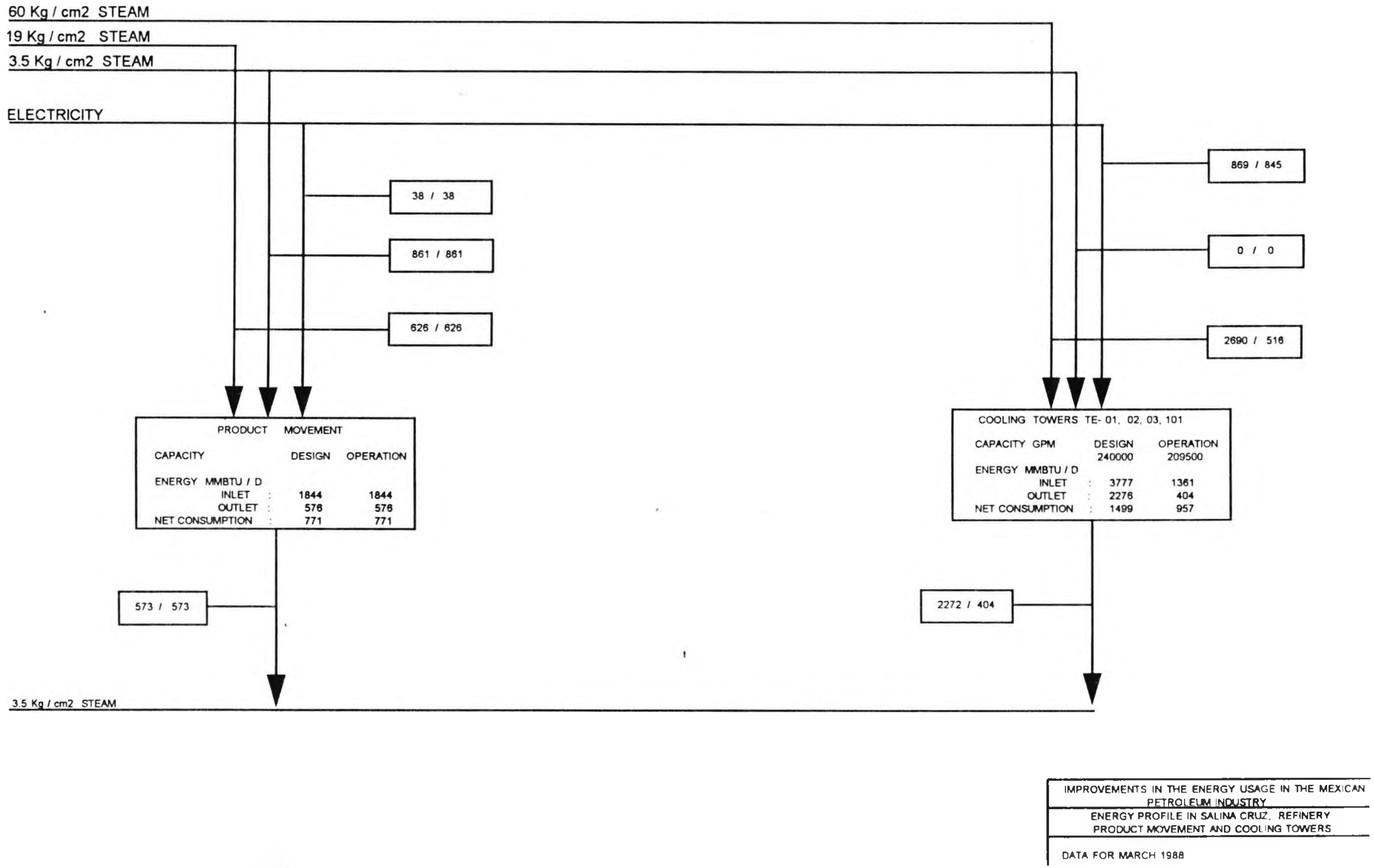
NOTE —THE DESIGN VALUES HAVE BEEN UPDATED ACCORDING TO THE MEAN OPERATION CAPACITY, EXCEPT IN PRODUCT MOVEMENT

DIAGRAM 3.9.3



NOTE —THE DESIGN VALUES HAVE BEEN UPDATED A[illegible] THE MEAN OPERATION CAPACITY, EXCEPT IN PRODUCT MOVEMENT

DIAGRAM 3.9.4



NOTE —THE DESIGN VALUES HAVE BEEN UPDAT' 'O THE MEAN OPERATION CAPACITY, EXCEPT IN PRODUCT MOVEMENT

ANNEX 4

Statistical Data About Mexican Petroleum Industry

TABLE 4.1

Mexico: proved oil and gas reserves and output million barrels

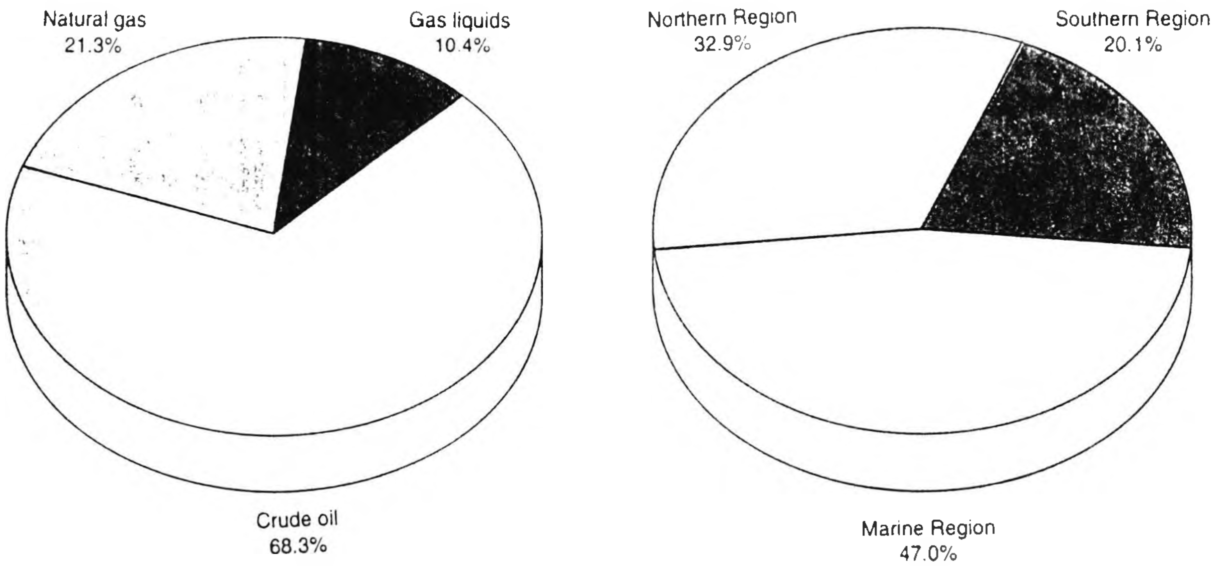
	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Total reserves [a]	72 500	71 750	70 900	70 000	69 000	67 600	66 450	65 500	65 000	65 050	64 516
Crude oil	49 911	49 260	48 612	48 041	47 176	46 191	45 250	44 560	44 292	44 439	44 043
Gas liquids	7 185	7 150	6 981	6 839	6 934	6 821	6 733	6 738	6 633	6 786	6 733
Natural gas [b]	15 404	15 340	15 307	15 120	14 890	14 588	14 467	14 202	14 075	13 825	13 740
Marine Region	34 467	34 288	33 506	32 857	32 249	31 509	30 677	30 427	30 138	30 805	30 328
Crude oil	28 734	28 506	27 914	27 330	26 772	26 156	25 494	25 195	25 016	25 571	25 093
Gas liquids	3 285	3 309	3 159	3 122	3 086	3 018	2 929	2 968	2 908	2 964	2 952
Natural gas [b]	2 448	2 473	2 433	2 405	2 391	2 335	2 254	2 264	2 214	2 270	2 283
Northern Region	22 148	22 054	22 076	22 000	21 921	21 754	21 744	21 462	21 338	21 278	21 242
Crude oil	12 614	12 566	12 572	12 545	12 436	12 415	12 392	12 300	12 273	12 248	12 243
Gas liquids	1 766	1 765	1 765	1 773	1 836	1 826	1 827	1 797	1 780	1 770	1 761
Natural gas [b]	7 768	7 723	7 739	7 682	7 649	7 513	7 525	7 365	7 285	7 260	7 238
Southern Region	15 885	15 408	15 318	15 143	14 830	14 337	14 029	13 611	13 524	12 967	12 946
Crude oil	8 563	8 188	8 126	8 166	7 968	7 620	7 364	7 065	7 003	6 620	6 707
Gas liquids	2 134	2 076	2 057	1 944	2 012	1 977	1 977	1 973	1 945	2 052	2 020
Natural gas [b]	5 188	5 144	5 135	5 033	4 850	4 740	4 688	4 573	4 576	4 295	4 219
Memorandum											
						(billion cubic feet)					
Natural gas reserves	76 998	76 702	76 536	75 796	74 831	73 356	72 744	71 508	70 954	70 046	69 675
Marine Region	12 241	12 365	12 166	12 023	12 003	11 724	11 296	11 343	11 113	11 503	11 645
Northern Region	38 845	38 618	38 692	38 604	38 479	37 798	37 870	37 076	36 681	36 578	36 472
Southern Region	25 912	25 719	25 678	25 169	24 349	23 834	23 578	23 089	23 160	21 965	21 558
						(million barrels)					
Hydrocarbons output	1 325	1 317	1 283	1 329	1 248	1 258	1 268	1 310	1 304	1 316	-
Reserves output ratio (years) [c]	54	54	54	55	52	54	53	52	50	50	49

a Beginning of year figures
b Crude oil equivalent
c Based on reserves at the beginning of the year and output of previous year

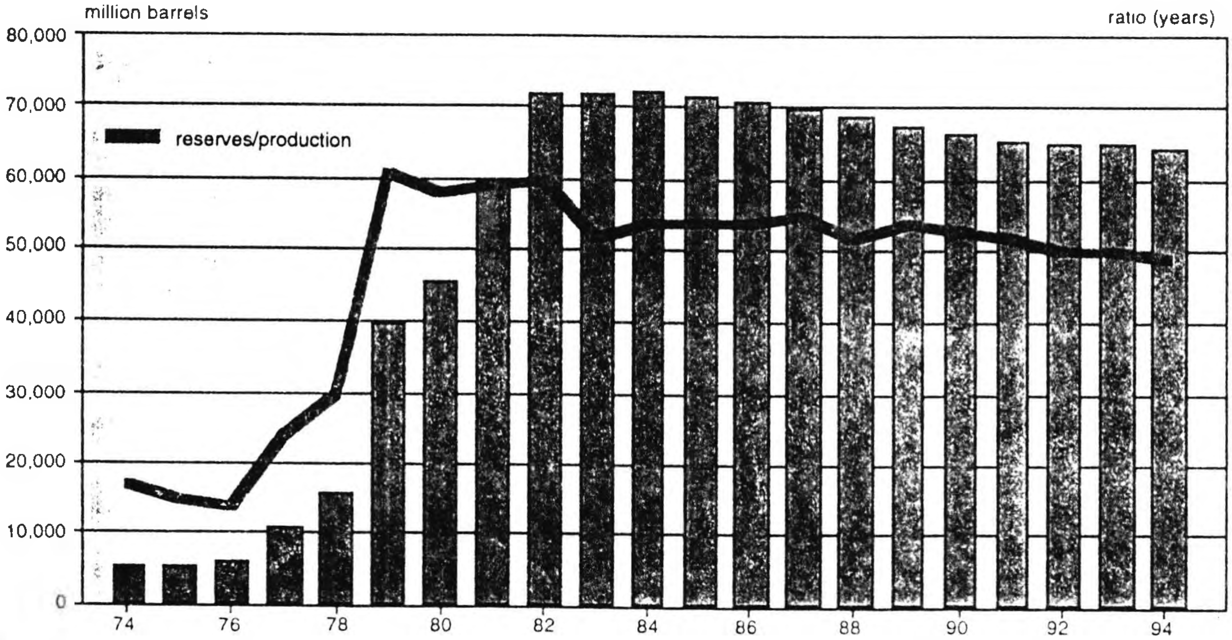
1_/ "Statistical Year Book 1994" Pemex. Published By Direccion Corporativa De Operaciones Reference 57 pp 1

TABLE 4.2

Mexico: proved oil and gas reserves, 1994



Reserves



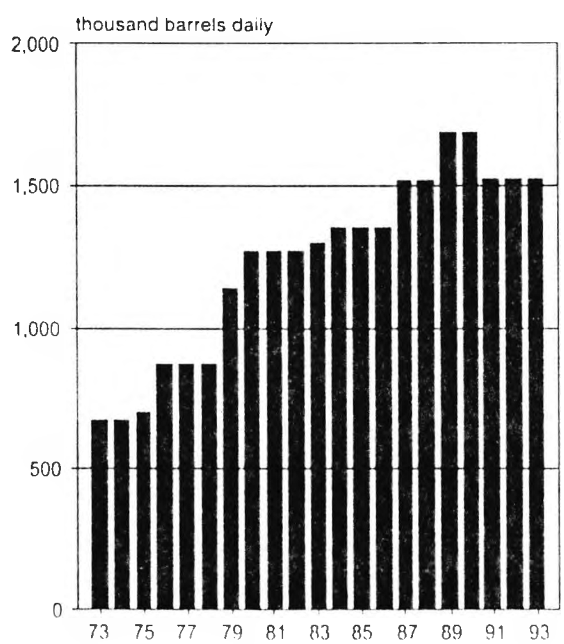
' "Statistical Year Book 1994". Pemex. Published By Direccion Corporativa De Operaciones Reference 57 pp 2

TABLE 4.3

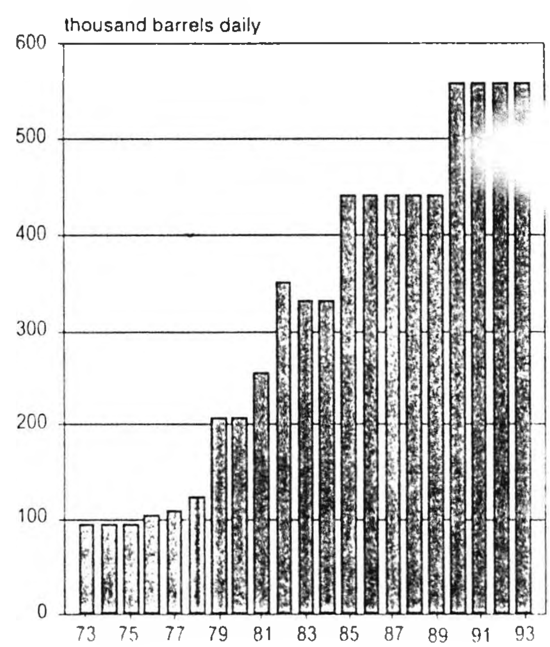
Pemex: refining capacity thousand barrels daily

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Atmospheric distillation	1 300 0	1 349 0	1 349 0	1 349 0	1 514 0	1 514.0	1 679.0	1 679.0	1 524 0	1 524.0	1 520 0
Vacuum distillation	594 2	600 7	600 7	600 7	680 7	680 7	760.7	760 7	712 7	712 7	760.7
Catalytic and thermal cracking	328 0	294 0	294 0	294 0	294.0	294.0	294 0	295.5	271 5	271 5	331 5
Visbreaking	69 0	73 0	73 0	73 0	73 0	73 0	73 0	77 0	53 0	49 0	91.0
Reforming	106.8	106 8	106.8	106 8	106 8	106 8	106 8	106.8	136.8	136.8	166.8
Hydrodesulfurization	475.6	457 0	457 0	457 0	457 0	457 0	458 0	476.0	562 0	562 0	648.0
Natural gas liquids fractionation	330.5	330 5	440.5	440 5	440.5	440.5	440 5	556.5	556.5	556.5	556.5

Atmospheric distillation



Natural gas liquids fractionation



1_/ "Statistical Year Book 1994". Pemex. Published By Direccion Corporativa De Operaciones Reference 57 pp 11

TABLE 4.4

Pemex: production by refinery [a] thousand barrels daily

Refinery	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total											
Refinery runs	1 056.0	1 142.2	1 163.0	1 141.1	1 184.4	1 197.9	1 240.7	1 309.0	1 321.2	1 289.5	1 319.6
Production	1 079.0	1 113.9	1 147.8	1 133.3	1 185.8	1 193.7	1 232.9	1 317.7	1 314.1	1 305.6	1 355.6
Azcapotzalco											
Refinery runs	91.5	101.6	98.6	95.6	103.2	89.9	92.0	87.1	18.7	-	-
Production	91.2	100.7	97.3	96.0	103.3	92.6	92.4	87.0	18.0	-	-
Cadereyta											
Refinery runs	149.1	158.6	181.9	192.6	183.3	166.4	173.6	191.5	190.7	180.4	182.9
Production	147.0	153.5	173.7	185.9	178.0	161.4	176.5	190.7	193.3	182.4	184.7
Madero											
Refinery runs	166.9	177.7	186.9	179.7	176.3	160.8	161.7	152.8	169.5	170.0	173.6
Production	170.5	167.3	180.2	184.6	185.4	167.7	161.7	159.0	178.2	187.2	180.9
Minatitlán											
Refinery runs	184.2	215.6	208.3	188.4	216.3	224.3	202.5	218.0	214.1	213.3	213.9
Production	214.1	205.7	204.0	187.6	213.6	209.9	199.0	215.7	202.2	209.1	226.4
Salamanca											
Refinery runs	172.0	199.2	197.4	199.1	195.4	181.2	197.9	194.1	183.4	172.6	190.3
Production	171.0	198.1	196.4	187.1	192.7	186.1	210.7	203.9	188.2	181.7	206.9
Salina Cruz											
Refinery runs	148.7	145.4	154.0	138.4	160.5	156.7	190.1	251.4	292.7	303.8	309.4
Production	143.5	144.3	152.8	135.5	160.1	162.1	182.3	246.8	282.6	293.1	314.2
Tula											
Refinery runs	143.6	144.1	135.9	147.3	149.4	218.6	222.9	214.1	252.1	249.4	249.5
Production	141.7	144.3	143.4	156.6	152.7	213.9	210.3	214.6	251.6	252.1	242.5

a Excludes gas processing plants

1_/ "Statistical Year Book 1994". Pemex. Published By Direccion Corporativa De Operaciones Reference 57 pp 13

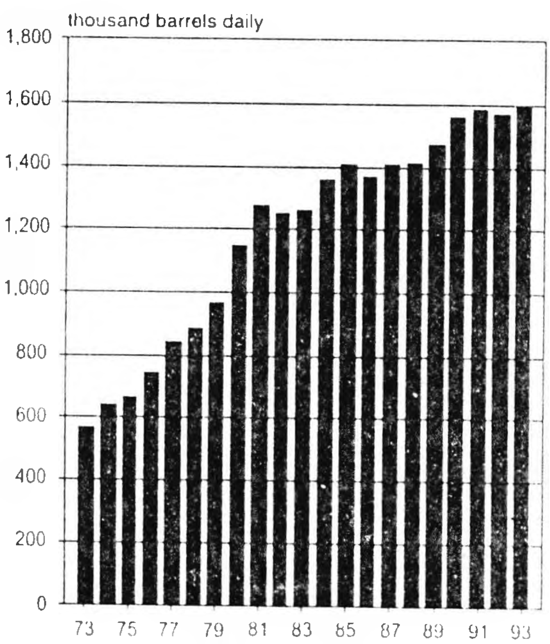
TABLE 4.5

Pemex: refinery production thousand barrels daily

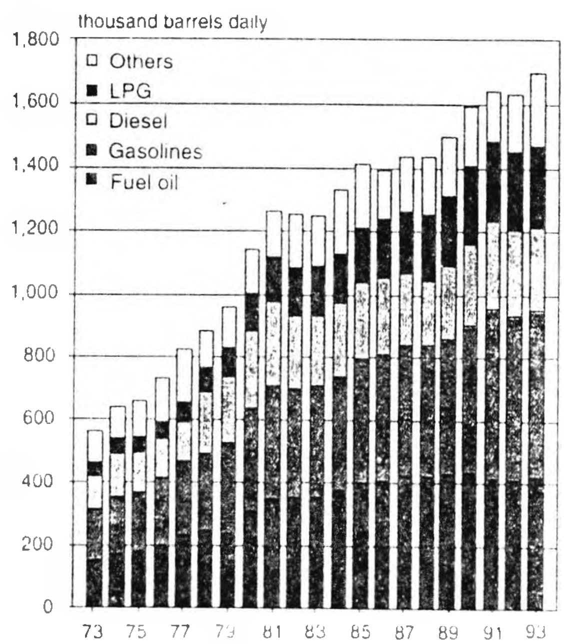
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Refinery runs	1 260.6	1 353.6	1 405.6	1 364.1	1 406.0	1 411.5	1 468.5	1 554.9	1 579.3	1 567.1	1 590.4
Refinery production	1 248.4	1 325.6	1 408.9	1 386.4	1 433.9	1 433.8	1 494.0	1 592.4	1 636.0	1 630.5	1 695.6
LPG	154.9	155.1	167.1	183.3	192.6	206.8	217.9	242.8	250.3	244.3	254.5
Gasolines [a]	355.2	362.6	393.8	404.5	410.2	415.2	427.4	464.1	538.5	517.7	526.8
Nova (leaded)	346.4	354.8	379.6	380.5	387.4	383.5	389.0	409.6	494.3	450.7	433.0
Extra/Magna Sin	5.7	4.5	4.5	7.7	11.3	21.5	30.9	43.1	41.8	65.2	92.2
Others	3.1	3.3	9.7	16.3	11.5	10.2	7.5	11.4	2.4	1.8	1.6
Jet fuel	27.4	33.8	33.9	34.6	41.5	45.1	43.5	51.0	61.6	64.6	71.9
Other kerosenes	39.1	31.8	30.9	26.8	30.2	27.2	24.9	15.8	9.8	11.7	11.7
Diesel	223.9	233.2	245.8	242.5	232.4	206.2	234.3	258.6	276.1	277.8	266.7
Diesel low sulfur	64.0	26.0	26.4	30.6	28.8	28.9	32.8	91.9	152.6	214.9	242.0
Diesel Sin	-	-	-	-	-	-	-	-	-	-	12.1
Others	159.9	207.2	219.4	211.9	203.6	177.3	201.5	166.7	120.3	62.9	12.6
Industrial gasoil	-	-	-	-	-	-	-	-	2.4	12.6	6.2
Fuel oil	350.2	374.9	397.9	405.4	424.5	420.8	426.9	435.1	414.2	407.7	419.4
Virgin stock 28 [b]	-	39.8	46.5	2.6	1.8	-	-	-	-	-	-
Asphalts	16.9	22.7	22.9	16.6	18.2	14.9	15.0	15.8	21.4	23.3	24.3
Lubricants	6.6	6.8	6.7	6.4	6.9	7.6	7.5	7.3	7.7	8.0	6.6
Greases	0.1	0.2	0.2	0.2	0.3	0.2	0.1	0.1	0.2	0.2	0.1
Paraffines	2.5	1.8	1.3	1.4	1.7	1.5	1.6	1.8	1.7	1.7	1.5
Still gas	34.9	22.7	30.5	34.2	34.9	43.1	48.4	48.3	50.7	49.3	50.5
Other refined products [c]	36.7	40.2	31.4	27.9	38.7	45.2	46.5	51.7	1.4	11.6	55.4

a Includes pentanes exports and naptha production which is petrochemical raw material. Since September 1990 Extra gasoline was replaced by unleaded gasoline Magna Sin
b Figures correspond to the volume exported
c Include aeroflex 1 2, coke oil refinery for carbon black manufacture and products delivered to petrochemical plants

Crude oil and NGL processed



Refinery production



_/ "Statistical Year Book 1994" Pemex. Published By Direccion Corporativa De Operaciones Reference 57 pp 12

TABLE 4.7

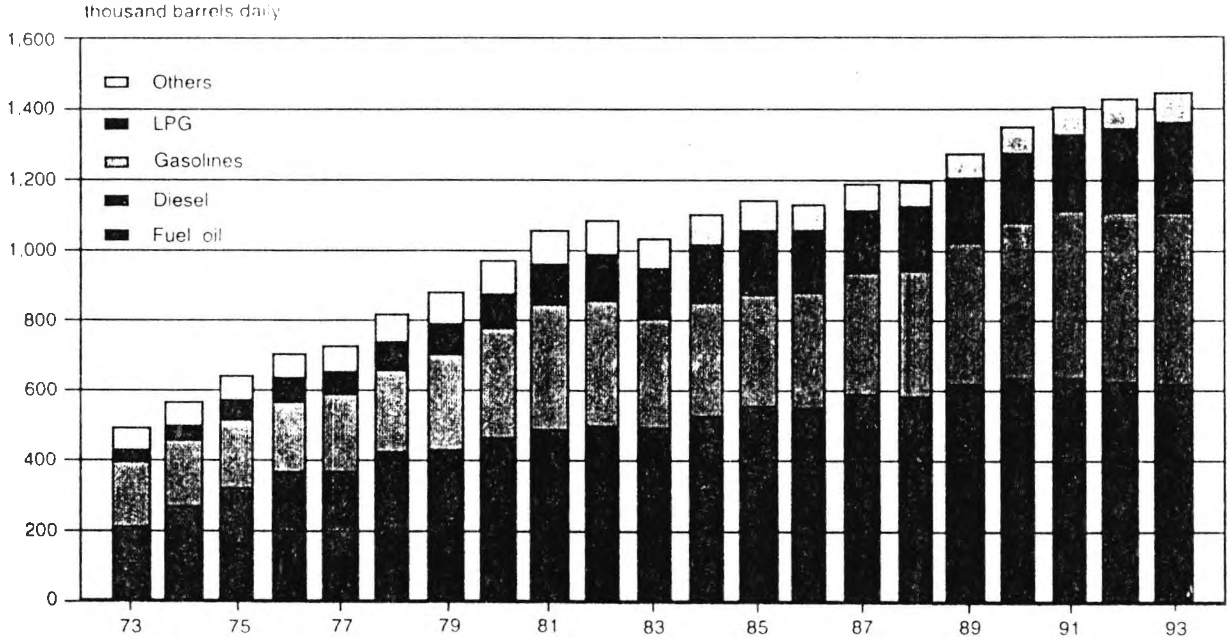
Pemex: domestic sales of oil products and natural gas

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
					(millon of new Mexican pesos) [a]						
Total	451 0	799.8	1 273.8	2 636.8	5 926.1	12 484.0	15 013.9	22 898.5	29 382 6	35 874.7	34 953.0
LPG	20 1	27 2	29 4	236 7	570 2	1 366 9	1 439 5	1 103 3	1 402.8	2 149 0	3 261.6
Gasolines	174 3	275 8	423 4	759 3	1 715 4	3 889 8	4 408 6	10 080 9	14 630 6	16 727 9	14 764 2
Nova (leaded) [b]	167 0	266 2	408 0	725 7	1 617.8	3 601.3	3 842 4	8 544.1	12 648 4	12 990 5	9 446.2
Extra / Magna Sin [c]	4.3	4 6	7 8	20 8	68 9	231.3	505.0	1 462 8	1 881 3	3 630 1	5 273 4
Aviation fuels	1.3	1 9	2 5	4 4	9 5	20 9	19 5	22 4	29 2	32 5	44 6
Others	1 7	3 1	5 1	8 4	19 2	36.3	41 7	51 7	71 7	74 8	-
Kerosenes	71 3	89 1	124.3	194 3	465 2	740 6	784 0	967 7	982.1	1 351 8	1 309 4
Jet fuel	59 1	67 7	93 9	138 7	319 3	440.6	533.1	793 0	819 0	1 118 0	1 098.0
Others	12 2	21 4	30 4	55 6	145 9	300 0	250 9	174 7	163.1	233 8	211.4
Diesel	63.7	113 6	175 1	384 3	866 6	1 817.2	1 923 8	4 185 8	5 165.7	6 889.4	6 823 4
Industrial gasoil	-	-	-	-	-	-	-	-	20 9	185 2	153 6
Fuel oil	36 3	106 7	192.6	446.2	1 044 7	2 242 9	3 179.6	2 993 9	3 358 7	4 375.3	4 294.4
Asphalts	2.2	7.1	19.5	16 2	46.3	83 3	118 6	156 2	294 5	317 7	449.6
Lubricants	30.2	48 6	76 0	104 4	194 1	425 8	408 9	454 4	749.4	745 8	383.1
Greases	0.9	1.4	2 1	2 7	6 8	15 8	12 8	10.5	20.6	22 1	21.3
Paraffines	2 4	3.5	5.1	7.2	15 9	31 6	37.9	51.0	60.5	66 4	58 3
Others [d]						2 1	3 4	5 0	5.6	7 0	7.9
Total refined products	401 4	673.0	1 047.5	2 151.3	4 925.2	10 616.0	12 317.1	20 008.7	26 691.3	32 837 6	31 526.8
Natural gas	49 6	126 8	226 3	485 5	1 000 9	1 868.0	2 696 8	2 889 8	2 691.3	3 037 1	3 426 2
					(thousand barrels daily)						
Total	1 236.4	1 292.3	1 329.0	1 299.4	1 357.8	1 355.5	1 449.9	1 541.8	1 618.2	1 641.5	1 646.2
LPG	141 4	167 5	179 0	176.1	175.1	178 2	186 6	197 3	212 9	234 4	248 0
Gasolines	316 8	324 2	324 0	332 7	347 9	361 2	405.6	445 5	479 8	483.6	491 5
Nova (leaded) [b]	308 7	317.2	316 3	322 2	332 5	339 2	360 9	390.2	428 9	379 6	327 2
Extra / Magna Sin [c]	5 4	4 1	4.8	7 8	12 6	19 4	42 0	52 7	48 6	101 7	163 7
Aviation fuels	1.2	1 3	1.1	1.1	1 1	1 1	1.0	1 0	0.9	0 8	0 6
Others	1.5	1 6	1 8	1 6	1.7	1.5	1.7	1.6	1.4	1.5	-
Kerosenes	55.9	53 5	50 3	48 4	51.1	46.5	46 9	44 8	44 4	48 2	48 0
Jet fuel	27.6	28.5	29.8	28 6	29 5	26 4	31.4	35 5	37 0	41 2	42 8
Others	28.3	25 0	20 5	19.8	21 6	20 1	15 5	9 3	7 4	7.0	5.2
Diesel	192 6	201 7	201 4	187 8	189 5	184 4	194 0	210 1	223 9	227 3	234 2
Industrial gasoil	-	-	-	-	-	-	-	-	1 4	10 3	6 7
Fuel oil	295 2	318 0	348 2	355 9	396 4	394 3	419 6	421 4	408.7	391 4	380 9
Asphalts	16 2	20 9	22 1	14 9	16 7	14 1	12.9	14 8	21 3	22 6	23 8
Lubricants	9 8	10 4	10 3	8 7	5.7	6 6	6.5	7 1	7 1	7 6	6 5
Greases	0 2	0 2	0 2	0 2	0 1	0.2	0 2	0.2	0.2	0 2	-
Paraffines	1 7	1 7	1 9	1 7	1 6	1 4	1 5	1 7	1 6	1 7	1 5
Others [d]	0 4	0 4	0 4	0 4	0.2	0 1	0.3	0.9	0 6	0 9	1 7
Total refined products	1 030.2	1 098 5	1 137.8	1 126 8	1-184.3	1 187.0	1 274.1	1 343.8	1 401.9	1 428.2	1 442.8
Natural gas [e]	206 2	193 8	191 2	172 6	173 5	168 5	175 8	198 0	216 3	213 3	203 4

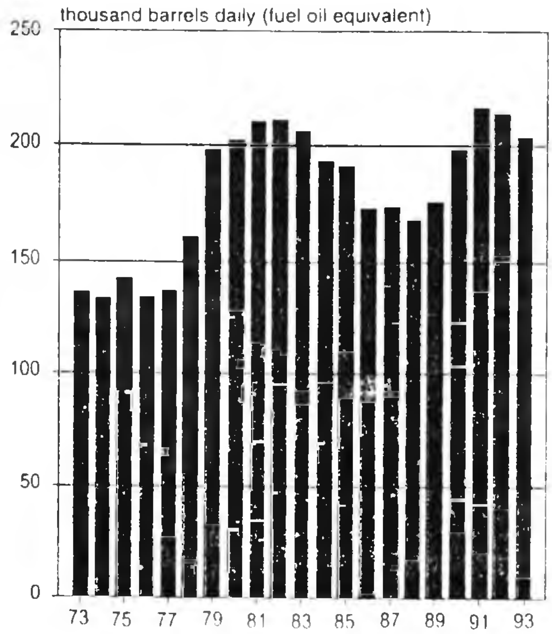
a Excludes SDPS and VAT
b 81 RON 0 5 ml of TEL per gallon
c Since September 1990 Extra gasoline (92 RON) was replaced by unleaded gasoline Magna Sin 87(R+M)/2
d Includes solvents coke bottom naphtha and pentanes
e Fuel oil equivalent

TABLE 4.8

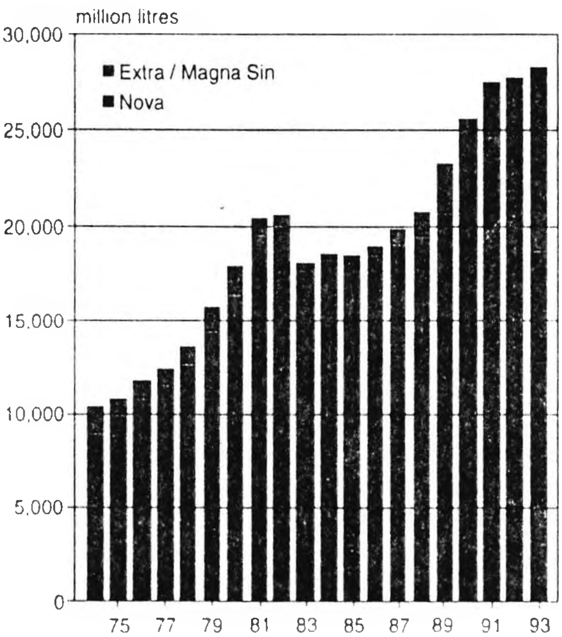
Pemex: domestic sales of oil products



Domestic sales of natural gas



Domestic sales of motor gasoline



1_/ "Statistical Year Book 1994". Pemex. Published By Direccion Corporativa De Operaciones Reference 57 pp 16

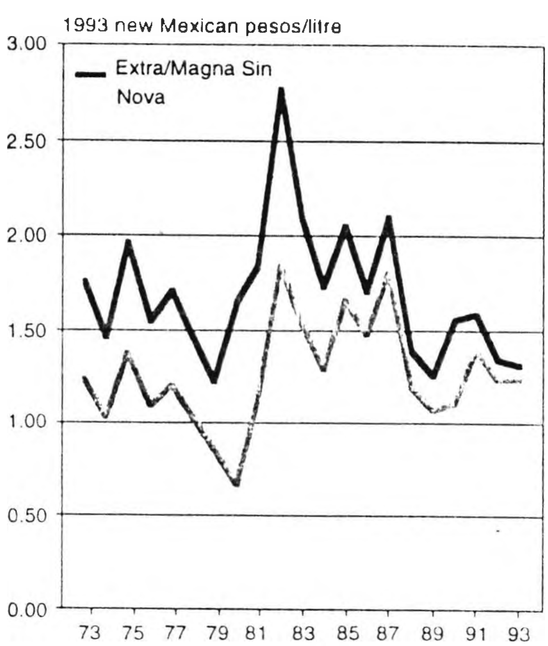
TABLE 4.9

Pemex: end user prices of oil products and natural gas [a] new Mexican pesos by litre

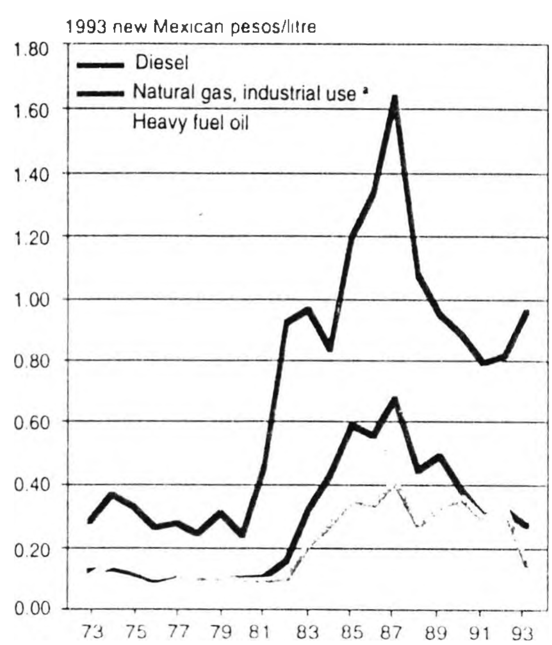
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
LPG (N$/kg)	0.011	0.012	0.030	0.105	0.334	0.334	0.357	0.425	0.446	0.600	0.807
Gasoline Nova (leaded)	0.030	0.040	0.085	0.155	0.493	0.493	0.525	0.710	1.100	1.120	1.230
Gasoline Extra / Magna Sin [b]	0.041	0.054	0.105	0.180	0.573	0.573	0.618	1.000	1.250	1.220	1.310
White gasoline	0.030	0.040	0.085	0.155	0.493	0.493	0.525	0.998	1.146	1.034	-
Diesel	0.019	0.026	0.061	0.140	0.445	0.445	0.470	0.565	0.620	0.740	-
Diesel low sulfur	-	-	-	-	-	-	-	0.605	0.665	0.785	0.905
Diesel Sin	-	-	-	-	-	-	-	-	-	-	0.960
Marine diesel	-	-	-	-	-	-	-	-	-	-	0.509
Jet fuel	0.043	0.052	0.061	0.091	0.261	0.273	0.400	0.708	0.483	0.501	0.414
Aviation fuel 80	0.030	0.040	0.085	0.155	0.493	0.493	0.525	0.710	1.100	1.120	-
Aviation fuel 100/130	0.041	0.054	0.105	0.180	0.573	0.573	0.618	1.000	1.250	1.250	1.310
Kerosene	0.012	0.022	0.045	0.094	0.301	0.301	0.446	0.565	0.620	0.740	0.860
Industrial gasoil	-	-	-	-	-	-	-	-	0.317	0.405	0.399
Heavy fuel oil	0.004	0.008	0.018	0.035	0.112	0.112	0.163	0.228	0.228	0.293	0.151
Light fuel oil	0.005	0.010	0.021	0.040	0.129	0.129	0.188	0.263	0.257	-	-
Natural gas											
Industrial use N$/m³	0.006	0.013	0.030	0.058	0.183	0.183	0.243	0.243	0.237	0.290	0.269
Residential use N$/m³	0.006	0.013	0.030	0.050	0.183	0.183	0.197	0.212	0.235	0.355	0.550

a At the end of year. Includes taxes
b Since september 1990, Extra gasoline was replaced by unleaded gasoline Magna Sin

Motor gasoline prices



Industrial fuels prices



1_/ "Statistical Year Book 1994". Pemex. Published By Direccion Corporativa De Operaciones Reference 57 pp 18

TABLE 4.10

Pemex: domestic sales of oil products by region thousand barrels daily

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total	1 030.2	1 098.5	1 137.8	1 126.8	1 184.3	1 187.0	1 274.1	1 343.8	1 401.9	1 428.2	1 442.8
Mexico City Area	196.7	211.9	170.1	167.2	169.8	165.1	169.3	173.0	163.0	170.7	175.9
Centre	142.9	145.5	169.8	191.7	207.2	229.5	225.3	226.1	258.8	268.4	272.6
West	146.1	157.8	172.1	164.2	166.0	157.4	187.9	208.9	213.8	213.8	227.1
North	137.9	144.1	155.3	162.4	161.9	156.4	166.9	172.2	179.6	175.7	163.2
North frontier	76.6	83.6	87.6	74.0	79.2	77.4	85.4	88.2	92.8	100.3	106.7
East	30.7	34.4	36.0	28.5	28.5	31.1	33.0	34.5	37.0	41.9	50.6
West	45.9	49.2	51.6	45.5	50.7	46.3	52.4	53.7	55.8	58.4	56.1
Pacific	156.0	173.6	186.1	190.3	199.5	205.0	221.9	239.0	247.5	243.8	246.0
North	95.1	106.5	103.3	110.1	117.4	118.4	119.6	123.5	130.0	128.9	131.1
South	60.9	67.1	82.8	80.2	82.1	86.6	102.3	115.5	117.5	114.9	114.9
Gulf	152.6	161.7	175.7	152.2	174.0	166.9	184.3	196.8	204.1	211.3	205.7
North	67.5	71.2	82.3	71.0	91.3	84.6	89.1	102.3	103.1	110.1	109.4
Centre	38.3	36.1	36.3	32.1	38.9	46.0	54.3	61.5	65.0	57.6	52.7
South	46.8	54.4	57.1	49.1	43.8	36.3	40.9	33.0	36.0	43.6	43.6
Peninsula of Yucatan	21.4	20.2	21.1	24.8	26.7	29.3	33.2	39.6	42.3	44.1	45.6

Domestic sales regionalization

1_/ "Statistical Year Book 1994". Pemex. Published By Direccion Corporativa De Operaciones Reference 57 pp 17

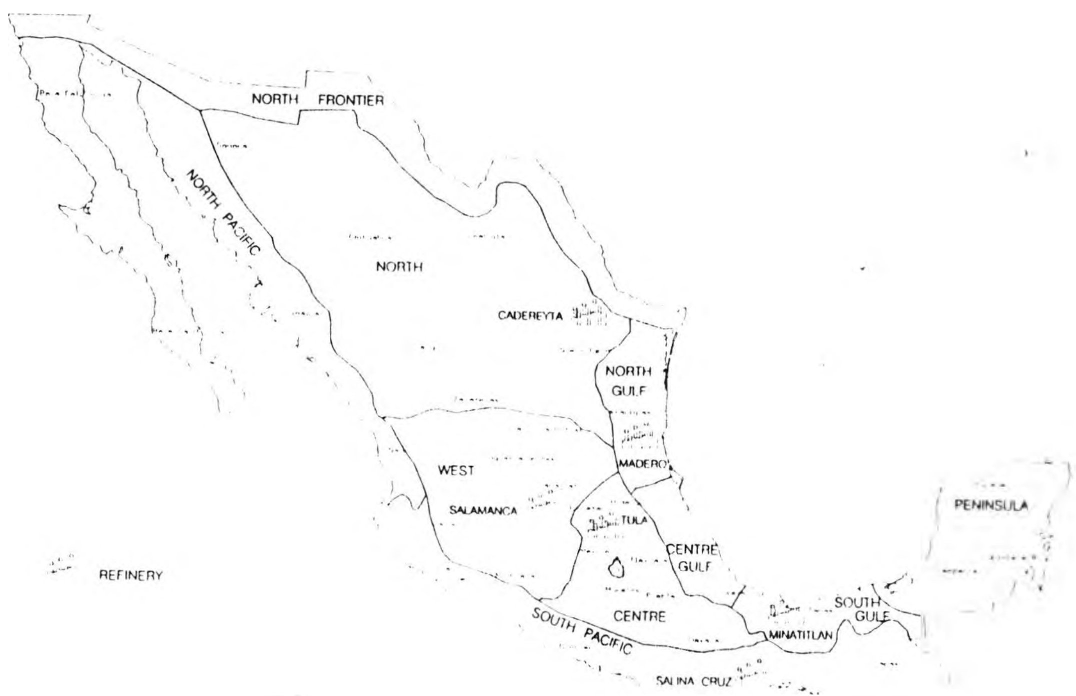


TABLE 4.11

Mexico: service stations by state

State	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total	2 987	2 947	2 978	3 002	3 045	2 953	2 992	3 159	3 189	3 221	3 268
Aguascalientes	24	20	20	20	21	23	25	24	25	25	25
Baja California	257	239	243	242	240	219	216	239	239	239	237
Baja California Sur	33	32	31	32	36	35	35	37	38	38	38
Campeche	19	18	20	20	20	21	21	20	20	21	21
Coahuila	88	90	89	90	90	93	92	94	96	98	99
Colima	20	22	24	25	25	26	27	27	27	27	25
Chiapas	72	68	70	69	71	85	85	73	73	74	75
Chihuahua	212	209	210	197	198	185	185	191	193	199	201
Distrito Federal	254	249	247	245	249	239	238	244	244	240	241
Durango	68	68	69	66	68	69	69	71	71	72	72
Guanajuato	102	109	108	113	116	110	113	123	124	125	132
Guerrero	62	62	63	65	66	63	66	70	70	70	64
Hidalgo	70	70	71	72	72	73	73	75	75	78	80
Jalisco	190	186	192	201	202	201	214	223	224	226	233
México	181	186	188	196	198	187	186	205	207	207	210
Michoacán	123	114	114	115	119	115	117	125	128	132	137
Morelos	33	30	30	31	31	31	31	31	31	31	33
Nayarit	37	34	34	35	35	36	36	36	36	36	37
Nuevo León	120	115	125	130	133	139	144	153	153	156	162
Oaxaca	68	65	66	66	65	63	63	68	69	70	67
Puebla	110	112	112	113	114	118	122	123	124	124	123
Querétaro	28	27	27	26	27	27	27	27	27	30	31
Quintana Roo	15	15	15	16	16	12	13	18	21	21	25
San Luis Potosí	66	67	68	67	67	64	64	71	71	71	72
Sinaloa	94	95	95	94	97	96	97	101	102	102	106
Sonora	178	176	175	180	181	181	185	194	195	197	195
Tabasco	34	36	36	37	39	18	18	40	41	41	40
Tamaulipas	127	130	131	129	135	132	136	138	141	141	148
Tlaxcala	26	24	24	28	28	21	21	29	30	30	34
Veracruz	156	157	160	161	163	153	153	167	169	171	172
Yucatán	58	59	59	58	59	59	60	61	62	65	66
Zacatecas	62	63	62	63	64	59	60	61	63	64	67

1_/ "Statistical Year Book 1994". Pemex. Published By Direccion Corporativa De Operaciones Reference 57 pp 19

TABLE 4.12

Pemex: oil product and natural gas exports and imports

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
					(million dollars)						
Net exports	956.7	1 014.5	786.3	172.3	148.6	200.6	-339.9	-157.1	-600.7	-844.7	-580.9
Exports	1 220.0	1 370.0	1 272.6	532.6	562.2	580.2	451.4	811.1	634.3	693.4	833.4
LPG	34.3	57.7	125.4	62.0	74.3	112.1	101.5	243.2	185.4	96.2	88.1
Pentanes		0.7	52.2	58.6	47.3	37.7	28.0	65.4	102.5	118.3	166.7
Gasolines	244.9	373.7	196.9	52.5	76.6	103.6	3.0	9.6	-	7.3	42.1
Jet fuel	31.3	56.2	63.2	47.4	102.0	132.7	88.3	161.0	142.5	126.2	129.2
Other kerosenes	8.0	-	-	-	-	-	-	-	-	-	0.3
Diesel	286.1	127.0	172.4	154.2	80.5	48.8	119.2	293.4	167.3	225.2	192.0
Vacuum gasoil		4.3	-	1.8	-	-	-	-	15.7	59.3	107.5
Vacuum residuum			-	-	-		-	-	-	-	4.0
Virgin stock 28	44.9	408.2	442.9	13.0	11.0	-	-	-	-	-	-
Fuel oil	212.4	110.7	219.6	142.9	170.1	145.3	111.1	38.5	21.0	60.7	100.1
Others	4.2		-	0.2	0.5	-	0.2	-	-	0.1	-
Natural gas	353.9	231.5	-	-	-	-	-	-	-	-	3.4
Imports	263.3	355.5	486.3	360.3	413.6	379.6	791.3	968.2	1 235.1	1 538.1	1 414.3
LPG	110.5	261.4	286.3	164.5	86.7	104.7	105.3	164.5	159.3	195.9	205.1
Gasolines	2.4	1.9	1.0	0.7	40.8	16.4	258.5	360.9	672.3	773.3	754.0
Kerosenes	15.1	16.4	14.1	12.0	12.8	0.8	-	-	-	-	-
Fuel oil	-	0.1	118.7	120.4	260.4	249.6	256.1	321.7	210.5	278.1	282.9
Lubricants	121.8	64.3	57.8	54.2	6.2	-	-	-	-	-	-
MTBE	-	-	-	-	-	-	12.6	90.1	86.6	111.3	94.7
Others	5.6	3.6	2.6	1.5	-	-	22.4	-	-	-	-
Natural gas	7.9	7.8	5.8	7.0	6.7	8.1	36.4	31.0	106.4	179.5	77.6
					(thousand barrels daily)						
Net exports	95.6	98.3	85.9	54.5	23.7	39.0	-45.4	-4.8	-67.3	-91.7	-34.0
Exports	113.7	132.0	139.9	115.7	95.1	120.7	83.4	110.1	99.5	117.1	156.6
LPG	4.3	7.9	18.2	17.5	15.2	30.0	28.6	47.2	36.9	19.1	17.8
Pentanes	-	0.1	6.2	13.0	8.6	7.0	4.8	8.6	15.5	21.2	29.2
Gasolines	21.7	36.1	19.6	10.3	11.5	16.3	0.4	0.7	-	1.2	6.7
Jet fuel	2.5	4.6	5.3	7.0	13.2	18.7	10.5	14.8	16.6	15.1	16.8
Other kerosenes	0.6	-	-	-	-	-	-	-	-	-	
Diesel	24.5	10.8	15.0	24.9	10.9	7.5	14.2	31.1	20.1	28.4	26.9
Vacuum gasoil	-	0.4	-	0.5	-	-	-	-	2.6	9.3	16.9
Vacuum residuum	-	-	-	-	-	-	-	-	-	-	1.8
Virgin stock 28	4.5	39.8	46.4	2.6	1.8	-	-	-	-	-	-
Fuel oil	25.9	12.1	29.1	39.9	33.5	41.2	24.9	7.7	7.7	22.9	39.8
Others	0.2	-	-		0.2	-		-	-	-	
Natural gas *	29.5	20.2	-	-	-	-	-	-	-	-	0.7
Imports	18.1	33.9	54.0	61.1	71.4	81.8	128.7	114.9	166.8	208.8	190.6
LPG	10.4	28.6	35.5	25.0	16.1	19.5	20.6	20.8	21.4	29.7	30.2
Gasolines	0.1	0.1	0.1		5.1	2.2	28.2	30.6	68.7	82.6	83.9
Kerosenes	1.1	1.2	1.1	1.4	1.5	0.1	-	-	-	-	
Fuel oil	-		13.6	30.4	47.3	59.1	69.5	51.8	46.6	53.3	55.7
Lubricants	5.6	3.1	3.0	3.5	0.5	-	-	-	-	-	-
MTBE	-	-	-	-	-	-	0.9	5.3	5.9	6.3	6.5
Others	0.2	0.1	0.1	0.1	-	-	2.7	-	-	-	
Natural gas *	0.7	0.8	0.6	0.7	0.9	1.0	6.7	6.4	24.2	36.9	14.2

a Fuel oil equivalent

1_/ "Statistical Year Book 1994". Pemex. Published By Direccion Corporativa De Operaciones Reference 57 pp 20

TABLE 4.13

Pemex: crude oil prices

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
					(U S dollars per barrel)						
Average realized price	**26.42**	**26.82**	**25.33**	**11.86**	**16.04**	**12.24**	**15.61**	**19.12**	**14.58**	**14.88**	**13.19**
Isthmus	29.54	29.00	27.12	13.49	17.51	13.85	17.10	22.68	18.11	18.01	15.80
Maya	23.96	25.33	24.02	10.56	15.10	11.08	14.37	17.01	12.25	13.11	11.44
Olmeca	-	-	-	-	-	14.22	18.76	23.57	20.07	19.54	16.95
					(1993 U S dollars per barrel)						
Average realized price	**38.34**	**37.31**	**34.03**	**15.63**	**20.40**	**14.94**	**18.19**	**21.14**	**15.47**	**15.32**	**13.19**
Isthmus	42.87	40.35	36.44	17.78	22.26	16.91	19.93	25.08	19.21	18.54	15.80
Maya	34.77	35.24	32.27	13.92	19.20	13.53	16.75	18.81	13.00	13.50	11.44
Olmeca	-	-	-	-	-	17.36	21.87	26.06	21.29	20.12	16.95

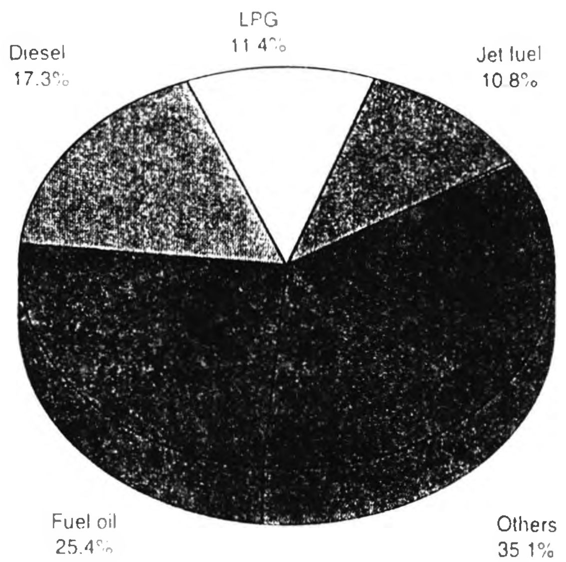
Crude oil prices by area of destination dollars per barrel

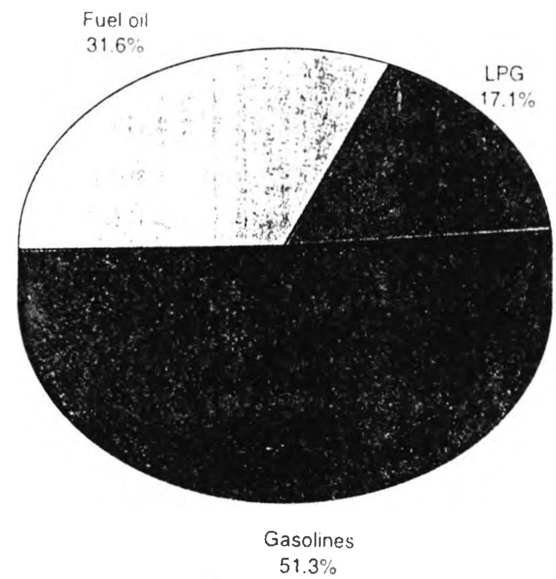
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total	**26.42**	**26.82**	**25.33**	**11.86**	**16.04**	**12.24**	**15.61**	**19.12**	**14.58**	**14.88**	**13.19**
America	26.30	26.69	25.34	11.85	16.32	12.29	16.07	19.30	15.33	15.30	13.71
United States	26.11	26.56	25.21	11.69	16.20	12.20	15.97	19.26	15.23	15.24	13.59
Others	27.32	27.36	26.28	13.23	17.35	13.28	17.23	19.82	16.47	15.74	14.84
Europe	25.94	26.50	24.88	11.43	15.25	11.76	14.47	17.45	12.19	13.23	11.01
Far East	28.72	28.36	26.40	12.74	16.83	13.03	15.73	20.92	16.70	17.17	14.77
Olmeca	-	-	-	-	-	**14.22**	**18.76**	**23.57**	**20.07**	**19.54**	**16.95**
America	-	-	-	-	-	14.22	18.76	23.27	20.08	19.54	16.95
United States	-	-	-	-	-	14.21	18.81	23.56	20.08	19.54	16.93
Others	-	-	-	-	-	14.77	18.04	19.57	19.77	19.41	17.70
Europe	-	-	-	-	-	-	-	29.08	19.81	-	-
Isthmus	**29.54**	**29.00**	**27.12**	**13.49**	**17.51**	**13.85**	**17.10**	**22.68**	**18.11**	**18.01**	**15.80**
America	29.57	29.00	27.29	13.85	17.86	14.13	17.72	22.84	18.41	17.95	15.91
United States	29.59	29.00	27.28	13.81	17.83	14.21	17.67	23.27	18.39	17.89	15.88
Others	29.52	29.00	27.32	14.04	17.93	13.89	17.83	21.48	18.45	18.07	15.96
Europe	29.51	29.00	26.92	13.28	17.11	13.66	17.23	23.69	17.74	17.55	15.43
Far East	29.46	29.00	26.95	13.11	17.31	13.65	16.34	21.98	17.86	18.52	15.80
Maya	**23.96**	**25.33**	**24.02**	**10.56**	**15.10**	**11.08**	**14.37**	**17.01**	**12.25**	**13.11**	**11.44**
America	23.95	25.33	24.19	10.78	15.55	11.25	14.75	17.27	12.90	13.42	11.94
United States	23.95	25.33	24.17	10.74	15.56	11.26	14.75	17.30	12.89	13.45	11.91
Others	23.95	25.32	24.39	11.52	15.39	10.87	14.61	16.37	13.06	13.20	12.50
Europe	23.94	25.33	23.71	10.07	14.46	10.78	13.77	16.41	11.15	12.49	10.24
Far East	24.32	25.33	23.95	10.53	14.51	10.83	13.59	17.96	12.89	13.41	11.04

/ "Statistical Year Book 1994" Pemex Published By Direccion Corporativa De Operaciones Reference 57 pp 33

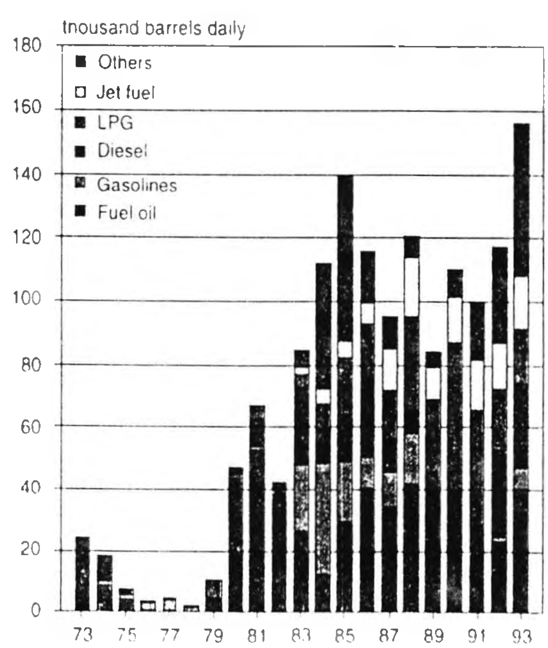
TABLE 4.14

Pemex: oil product exports and imports, 1993

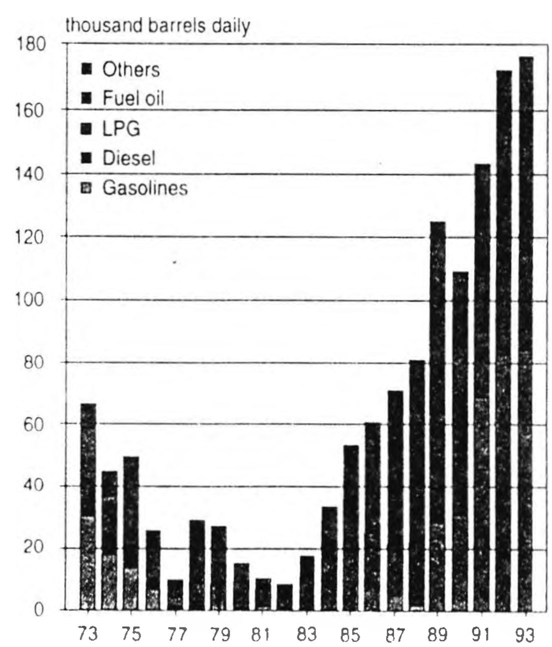




Oil product exports



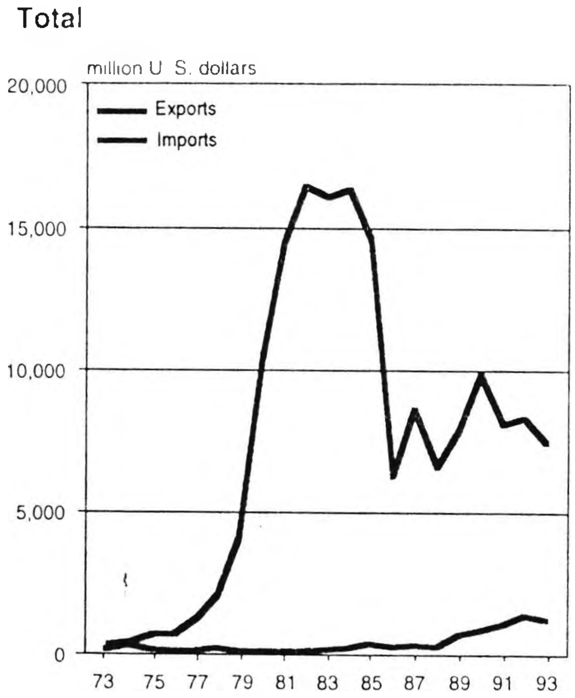
Oil product imports

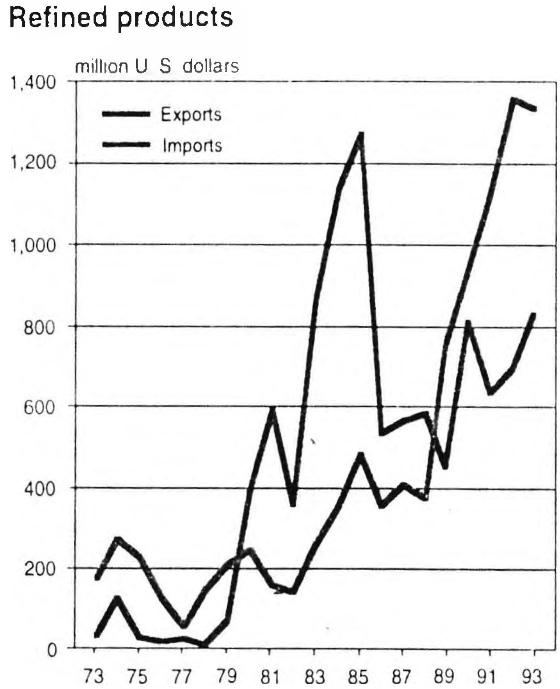


1_/ "Statistical Year Book 1994", Pemex Published By Direccion Corporativa De Operaciones Reference 57 pp 37

TABLE 4.15

Pemex: trade balance





1_/ "Statistical Year Book 1994". Pemex. Published By Direccion Corporativa De Operaciones Reference 57 pp 34

Crude oil prices

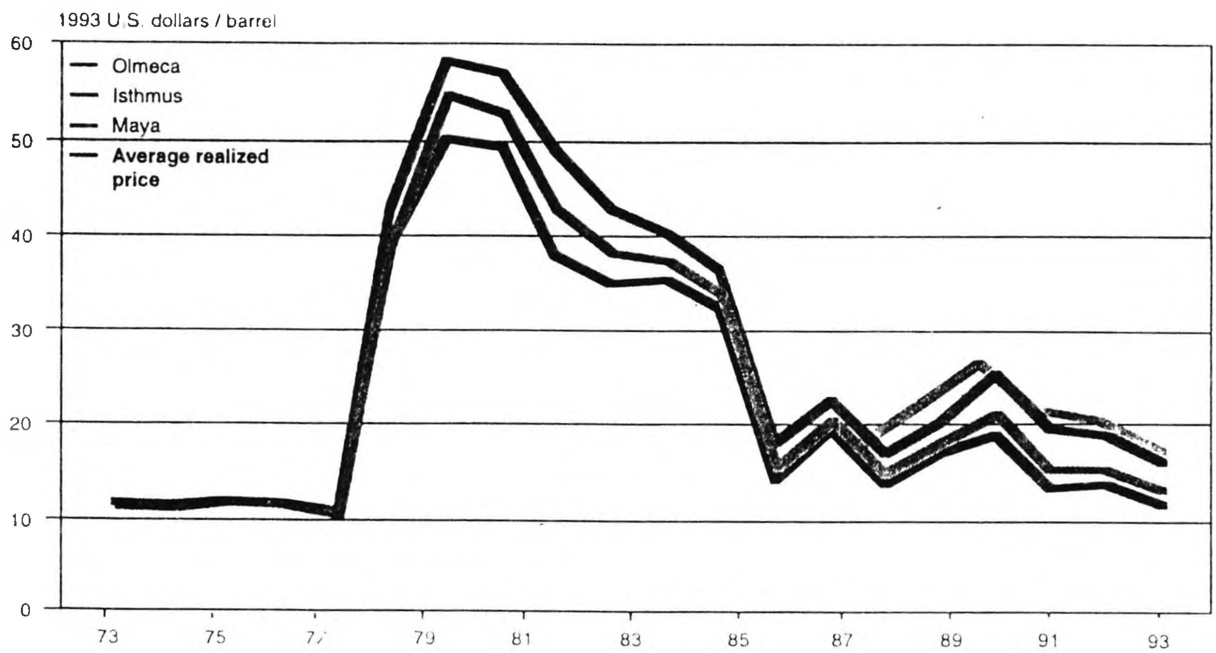


TABLE 4.16

Pemex: income statements millions of U.S. dollars

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Revenues	20 829	22 334	22 700	12 230	14 795	13 564	15 579	19 604	19 379	25 125	26 686
Domestic sales	4 727	5 645	5 822	4 935	5 018	6 535	7 260	9 255	10 977	16 505	17 907
Export sales	16 053	16 588	14 551	6 111	8 223	6 591	7 854	10 111	8 204	8 382	8 331
Other income	50	101	2 327	1 185	1 554	438	465	238	198	238	447
Costs and Expenses	12 607	6 420	7 690	5 080	4 433	7 220	7 586	8 222	8 557	14 314	17 177
Cost of sales [a]	10 319	4 208	6 090	3 804	3 625	5 830	5 545	6 053	6 753	8 007	8 673
Cost of distribution [a]	865	1 037	883	845	785	1 226	1 382	1 101	1 169	1 364	1 091
Administrative expense	-	-	-	-	-	-	-	666	786	1 125	1 896
Financial cost	1 356	1 103	611	354	-57	10	529	243	-157	-41	-40
Special tax on production and services (SDPS)	-	-	-	-	-	-	-	-	-	3 781	5 530
Other expenses	67	72	109	77	80	153	131	159	6	78	27
Net income before federal duties	8 222	15 915	15 010	7 151	10 361	6 344	7 992	11 382	10 822	10 811	9 508
Federal duties	8 197	10 258	11 274	5 884	7 314	5 887	7 655	9 893	9 772	9 740	8 549
Net operating income	25	5 651	3 736	1 267	3 047	458	338	1 489	1 050	1 071	959

a Includes administrative expense for the years not considered

Balance sheet as of December 31 millions of U.S. dollars

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Assets	38 901	44 075	36 654	30 777	34 729	46 155	42 379	45 079	48 049	49 808	47 970
Current	7 163	7 650	6 016	3 562	4 102	5 203	5 164	5 932	6 240	8 225	8 588
Fixed	31 488	36 222	30 509	27 157	30 575	40 753	36 829	38 459	40 628	40 469	38 387
Others	250	203	127	57	52	199	386	688	1 181	1 113	995
Liabilities	22 504	18 825	17 763	17 138	17 664	17 638	18 142	10 455	10 593	13 341	14 192
Short term	3 050	2 243	2 420	2 417	1 643	2 312	3 155	3 196	2 919	4 275	5 687
Long term	19 454	16 582	15 341	14 721	16 021	15 326	14 987	7 259	7 674	9 066	8 505
Equity	16 397	25 249	18 891	13 639	17 065	28 517	24 237	34 624	37 456	36 467	33 779
Certificates of contribution	42	31	16	7	3	3	2	7 600	7 265	7 164	7 000
Reserves	6 712	9 919	7 857	3 993	3 462	3 869	3 697	4 440	5 101	5 146	5 101
Surplus due to revaluation	9 609	15 258	10 993	9 627	13 593	24 632	20 520	21 611	23 132	23 095	20 792
Others	35	36	24	12	7	12	17	974	1 959	1 062	887
Total equity and liabilities	38 901	44 075	36 654	30 777	34 729	46 155	42 379	45 079	48 049	49 808	47 971

1_/ "Statistical Year Book 1994". Pemex. Published By Direccion Corporativa De Operaciones Reference 57 pp 35

TABLE 4.17

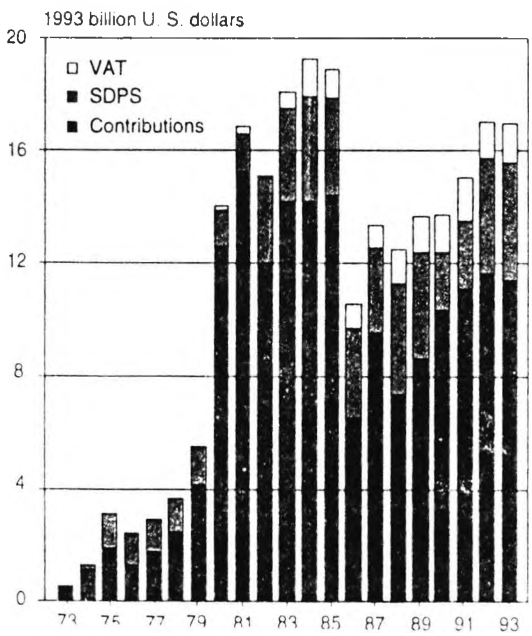
Mexico: fiscal revenues million of U.S. dollars

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total revenues	26 473	29 652	31 096	20 725	24 126	29 110	36 771	41 313	58 882	68 527	61 112
Oil revenues	12 458	13 772	13 992	7 937	10 450	10 178	11 680	12 377	14 113	16 474	16 924
Contributions	9 741	10 179	10 667	4 874	7 436	5 977	7 331	9 297	10 362	11 270	11 310
SDPS	2 301	2 682	2 640	2 449	2 397	3 234	3 256	1 841	2 307	3 940	4 241
VAT (net)	416	911	685	614	617	967	1 093	1 239	1 443	1 265	1 373
Non - oil revenues	14 015	15 880	17 101	12 788	13 676	18 932	25 091	28 936	44 769	52 052	44 188
Oil revenues/ total (%)	47 1	46 4	45 0	38 3	43 3	35 0	31 8	30 0	24 0	24 0	27 7

Source Dirección General de Planeación Hacendaria - SHCP

I_/ "Statistical Year Book 1994". Pemex. Published By Direccion Corporativa De Operaciones Reference 57 pp 21

Oil revenues



Non-oil revenues

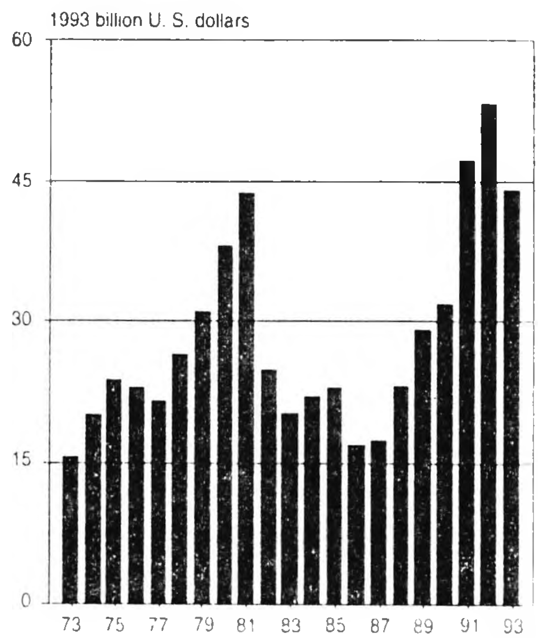
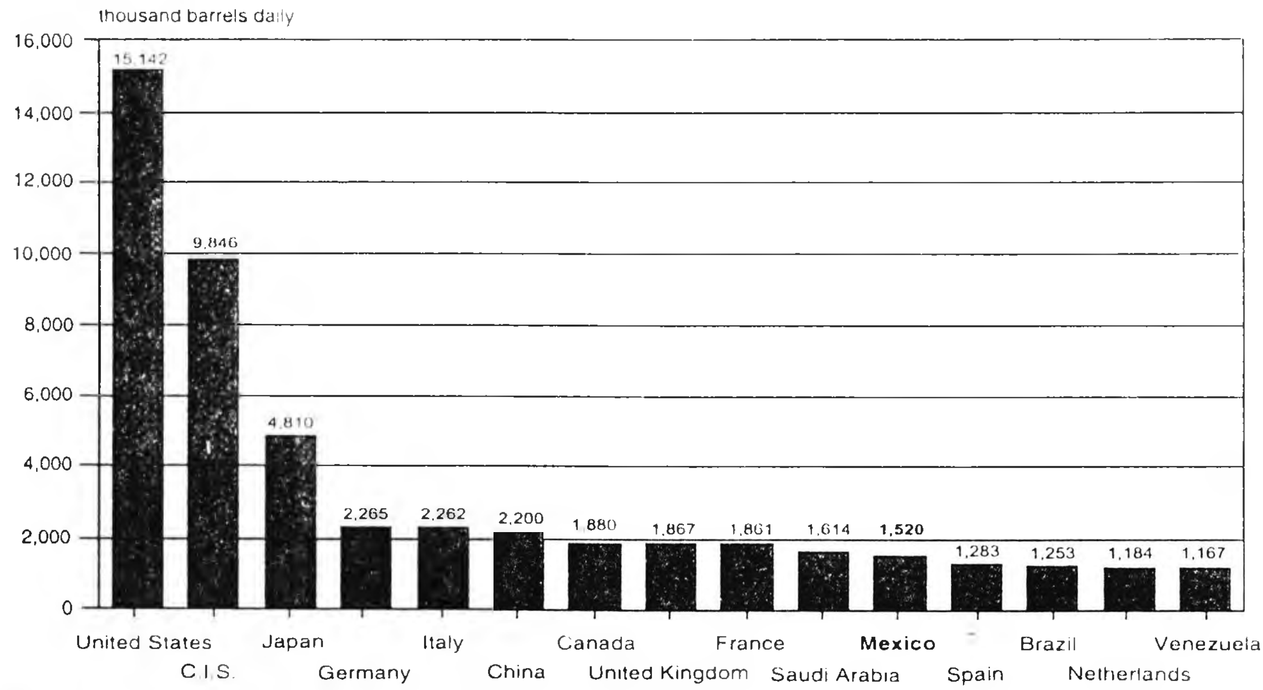


TABLE 4.18

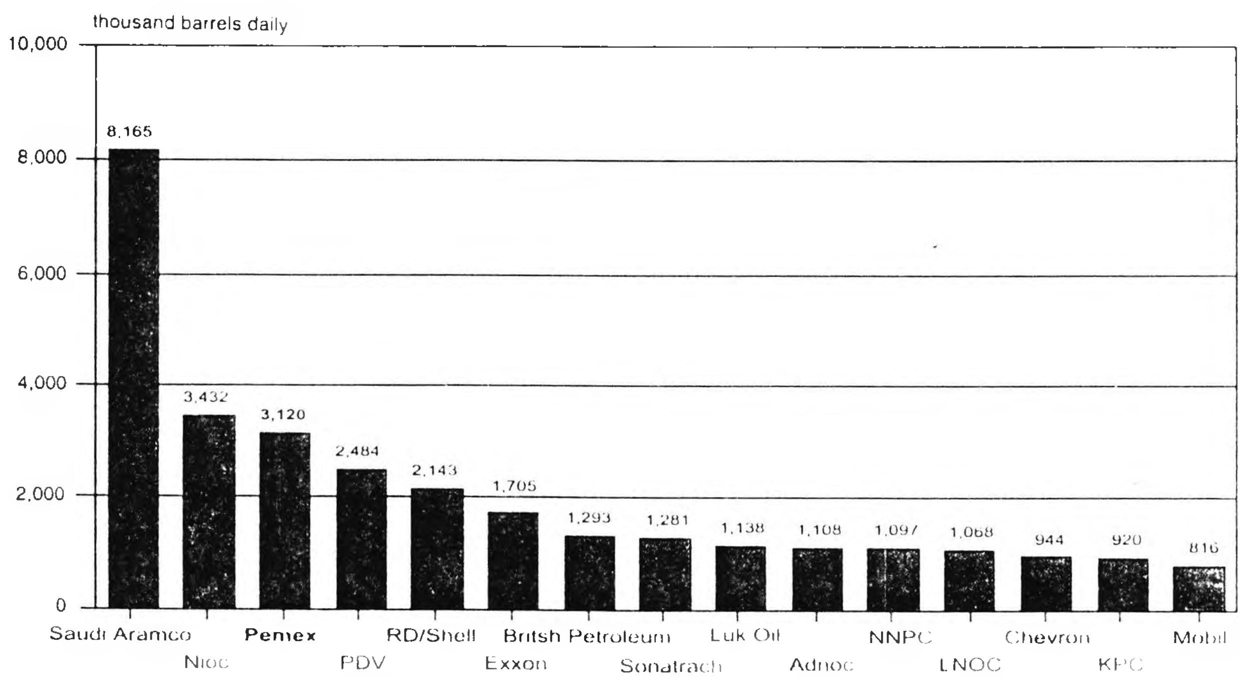
Atmospheric distillation capacity, selected countries, 1993



Source Oil and Gas Journal and Pemex

1_/ "Statistical Year Book 1994". Pemex. Published By Direccion Corporativa De Operaciones Reference 57 pp 41

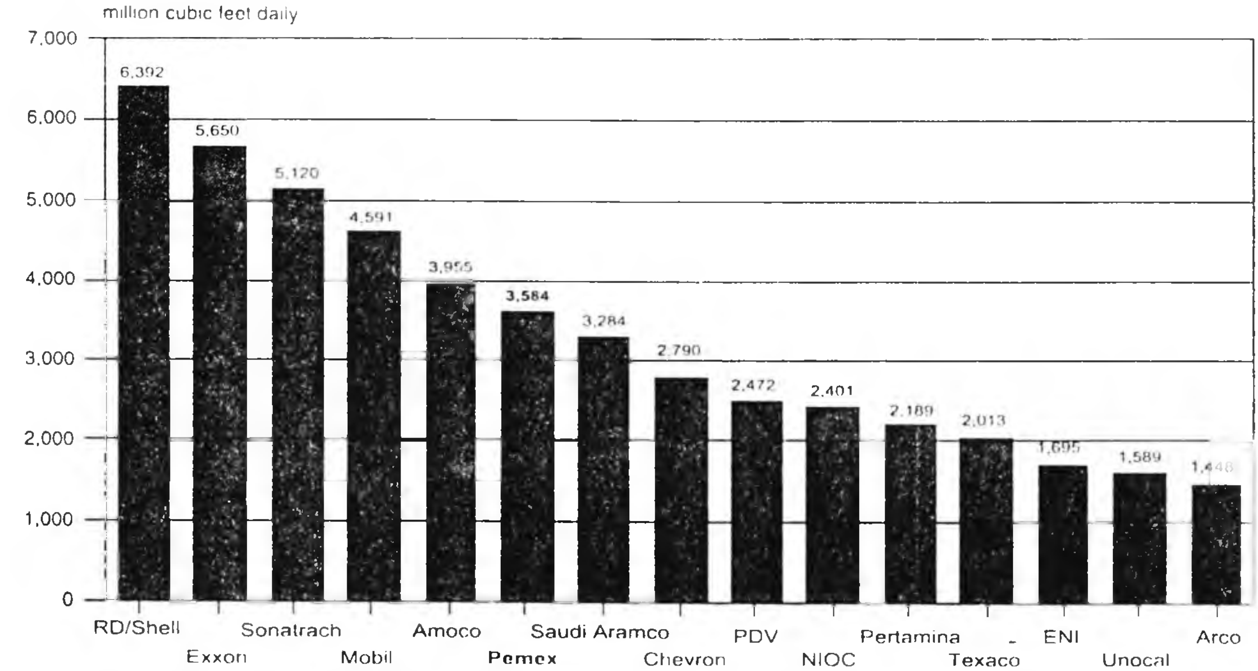
Top petroleum companies by crude oil output rank,[a] 1992



a Includes gas liquids
Source Petroleum and Energy Intelligence Weekly and Pemex

TABLE 4.19

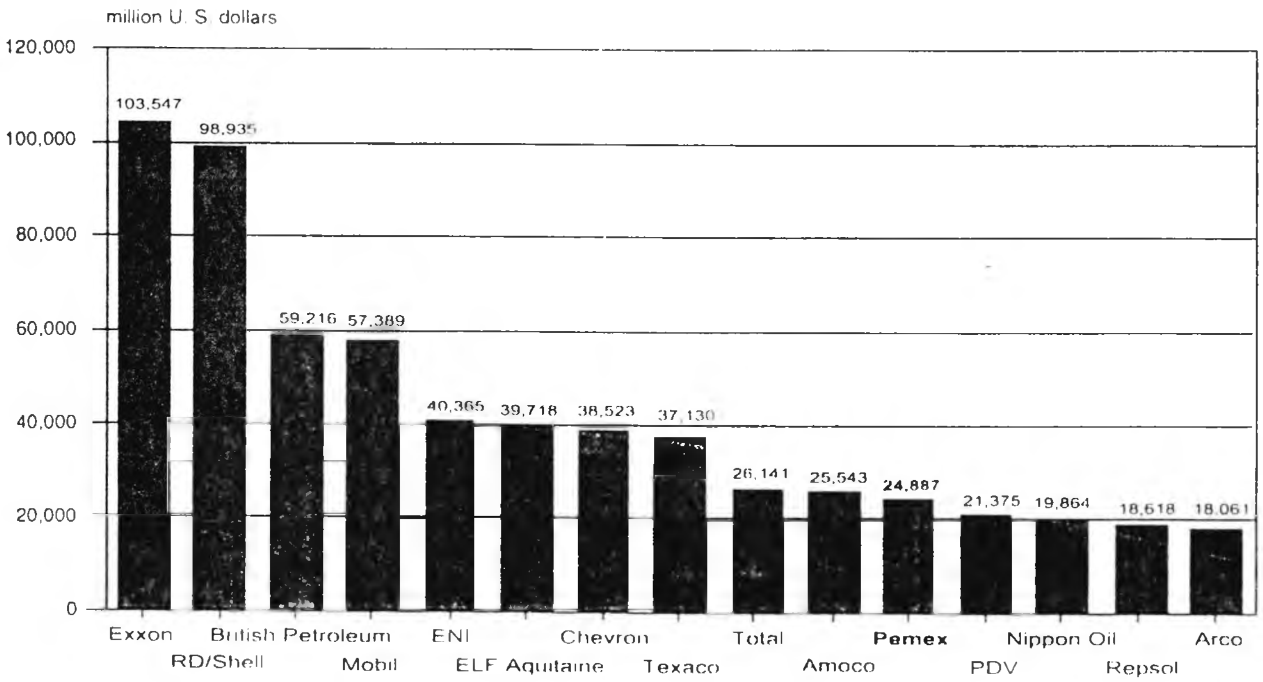
Top petroleum companies by natural gas output rank, 1992



Source Petroleum and Energy Intelligence Weekly, Inc and Pemex

1_/ "Statistical Year Book 1994". Pemex. Published By Direccion Corporativa De Operaciones Reference 57 pp 42

Top petroleum companies by sales rank, 1992



Source Fortune and Pemex

ANNEX 5

Complexity Indexes for Mexican Refineries

SALINA CRUZ REFINERY

COMPLEXITY INDEXES FOR MEXICAN REFINIERIES

1990

Process	Number of Units	Capacity (B/D)	Total KEDC	Capacity Utilized B/D	KEDC Utilized %	Capacity Utilized	Compl. Per Pro
Atmospheric Crude Distillation	2	325,000	360	251,110	278	77.3	1.11
Vacuum Distillation	2	130,000	150	100,165	116	77.1	0.46
Visbreaking	0	0	0	0	0	0.0	0.00
Thermal Cracking	0	0	0	0	0	0.0	0.00
Coking	0	0	0	0	0	0.0	0.00
Catalytic Cracking	1	50,000	360	48,150	547	96.5	1.11
Hidrocracking	0	0	0	0	0	0.0	0.00
Catalytic Reforming	1	20,000	72	18,600	67	93.0	0.22
Hydrogen Generation, KSCF/D	0	0	0	0	0	0.0	0.00
Polymerization(*)	0	0	0	0	0	0.0	0.00
Dimersol (*)	0	0	0	0	0	0.0	0.00
MTBE (*)	0	0	0	0	0	0.0	0.00
Alkylation (*)	0	0	0	0	0	0.0	0.00
C4 Isomerization	0	0	0	0	0	0.0	0.00
C5/C6 Isomerization	0	0	0	0	0	0.0	0.00
Hydrotreating							
Gasoline/NAphtha	1	25,000	50	23,850	48	95.4	0.15
Kerosene	0	0	0	0	0	0.0	0.00
Destillate	2	50,000	154	43,200	133	86.4	0.47
VGO Desulfurization	0	0	0	0	0	0.0	0.00
Residual Desulfurization	0	0	0	0	0	0.0	0.00
Solvent Deasphalting	0	0	0	0	0	0.0	0.00
Sulfur Recovery, LT/D	1	142	28	134	27	94.4	0.09
Tailgas Recovery , LT/D	0	0	0	0	0	0.0	0.00
Sulfuric Acid Regeneration, LT/D	0	0	0	0	0	0.0	0.00
Asphalt Manufacture	0	0	0	0	0	0.0	0.00
Special Fractionation							
Propane Splitter1	3,845	2	3,261	2	84.8	0.01	
Deisobutanizer	0	0	0	0	0	0.0	0.00
Deisopentanizer	0	0	0	0	0	0.0	0.00
Deisohexanizer0	0	0	0	0	0.0	0.00	
Deheptanizer	0	0	0	0	0	0.0	0.00
Alkylate/Reformate Splitter	0	0	0	0	0	0.0	0.00
Secondary Cat Cracked Gasoline Splitter	0	0	0	0	0	0.0	0.00
Other Process Units	0	0	0	0	0	0.0	0.00
Steam Generation, KLB/HR		350	0	266	0	76.0	0.00
Electrical Power Generation, KW							
Solid Fired Boiler & Generator		0	0	0	0	0.0	0.00
Liquid/Gas Boiler & Generator		0	0	0	0	0.0	0.00
Diesel Engine		0	0	0	0	0.0	0.00
Fired Turbine & Generator		29,830	60	3,878	8	13.0	0.18
Expander Turbine		0	0	0	0	0.0	0.00
Cogeneration							
Steam, KLB/HR		1,634	1	961	0	58.8	0.00
Power, KW		83,200	166	37,690	75	45.3	0.51
Cat Cracker Power Recovery, HP		0	0	0	0	0.0	0.00
Total Process Units	11	---	1,403	---	1,100	78.4	4.32

Rew Material Receipt							
Railcar		40	0	40	0	100.0	0.
Tank Truck		40	0	40	0	100.0	0.
Tanker Berth (**)		0	0	0	0	0.0	0.
Offshore Buoy(**)		0	0	0	0	0.0	0.
Barge Berth(**)		0	0	0	0	0.0	0
Product Shipment							
Railcar		0	0	0	0	0.0	0.
Tank Truck		0	0	0	0	0.0	0.
Tanker Berth		2,918	1	2,918	1	100.0	0
Offshore Buoy (**)		0	0	0	0	0.0	0.
Barge Berth(**)		0	0	0	0	0.0	0
ATRACADERO D'LANCHNES		0	0	0	0	0.0	0.
Process Related Offsites							
Other Offisites							
Initial Catalysts & Chemicals							
Spare Parts Inventory							
Total Fuels Refinery	11	---	1,405	---	1,102	78.4	4.

(*) EL MULTIPLICADOR ES EL RENDIMIENTO DIARIO DE PRODUCTO EN BARRILES
(**) EL MULTIPLICADOR ES LA CAPACIDAD DIARIA REALMENTE UTILIZADA.
(***) SEGUN EL CASO.

ANNEX 6

Environmental Control Processes

ANNEX 6

HYDROGEN SULFIDE

CONTROL PROCESS CP 1

Gases containing h2s are treated with a liquid (usually an amine solution) which preferentially absorbs h2s. The h2s is recovered by stripping it from the liquid. it is subsequently converted to sulfur and recovered.

CONTROL PROCESS CP 2

Sour water stripping. Aqueous effluents from refinery processes which contain h2s are steam stripped to remove the h2s.

SULFUR OXIDES

Emitted to the atmosphere with flue gases from burning fuels containing sulfur.

CONTROL PROCESS CP 3

Hydrodesulfurization. the oil containing sulfur is reacted with hydrogen at elevated temperatures and pressures in the presence of a solid catalyst. Sulfur is converted to h2s. hydrogen used in the hydrodesulfurization is generally recovered as a by-product of catalytic reforming.

CONTROL PROCESS CP 4

Stack gas scrubbing. the sulfur-oxide containing combustion gas is contacted with solid or liquid material that preferentially absorbs the sulfur oxides; these are recovered in concentrated form from the absorbing material and converted to sulfur or sulfuric acid.

CARBON MONOXIDE

Present in stack gas from catalytic cracking unit

CONTROL PROCESS CP 5

Combustion. the stack gas is enriched with fuel gas and burned. Useful heat is recovered and the carbon monoxide is burned to harmless carbon dioxide

SMOKE. Produced when insufficient air is used in fired boilers and furnaces or by incomplete incinerations of materials vented and flared.

CONTROL PROCESS CP 6

Proper control of boilers and furnaces

CONTROL PROCESS CP 7

Incinerate vented materials in a smokeless flare

soot and fly ash from furnaces and boilers

CONTROL PROCESS CP 8

Electrical precipitation

Hydrocarbon vapors

CONTROL PROCESS CP 9

Install floating roofs or vapor recovery system on tanks

CONTROL PROCESS CP 10

Good housekeeping practices

Oil entrained in refinery waste water

CONTROL PROCESS CP 11

Api separator when oil is allowed to rise to the surface of the contaminated water and is skimmed off

CONTROL PROCESS CP 12

Aeration. Air is blown through the contaminated water oil rises to the surface as froth and is skimmed off.

Water soluble organic compounds

Dissolved in refinery waste water

CONTROL PROCESS CP 13

Biological treatment. Contaminated water is trickled through a pile of rocks on which colonies of bacteria live the bacteria convert the contaminants into harmless compounds.

CONTROL PROCESS CP 14

Biological treatment. contaminated water is contacted with a suspension of bacterial colonies nutrients and air. The bacteria converts the contaminants into harmless compounds. Clean water is separated by settling of bacterial sludge.

PHENOLIC COMPOUNDS

Produced in cracking processes and extracted from cracked products.

CONTROL PROCESS CP-15

Sold to chemical industry

CONTROL PROCESS CP 16

Incinerated

CONTROL PROCESS CP 17

Barged to sea and dumped

CONTROL PROCESS CP 18

Pumped into underground formation which is sealed to prevent contaminating fresh water

CONTROL PROCESS CP 19

Hydrotreat the cracked product to eliminate the need to extract phenols

FLUID CATALYST

Entrained in stack gas from catalytic cracking units.

CONTROL PROCESS CP 20

Centrifugal separation. The stack gas is passed through a stationary centrifugal device at high speed

CONTROL PROCESS CP 21

Electrical precipitation. The stack gas is passed between metal plates which are electrically charged to a high voltage. The dust is attracted to and settles on the plates from which it is recovered Other new processes to meet proposed environmental standards

CONTROL PROCESS CP 22

Hydrogen sulfide removal from refining fuel gas and conversion to elemental sulfur in plants equipped with tail gas scrubbing

CONTROL PROCESS CP 23

Floating roofs on gasoline and volatile crude oil storage tanks with more than 40 000 gallons capacity

CONTROL PROCESS CP 24

Catalyst removal from catalytic cracker regeneration flue gas by electrical precipitation and incineration of the flue gas in carbon monoxide boilers.

CONTROL PROCESS CP 25

BOD (biological oxygen demand) substance effluent treatment plant including equipment for water flow equalization, oil separation, neutralization, flotation, sedimentation, coagulation and biological treatment.

CONTROL PROCESS CP 26

Oil and suspended solids removal and neutralization in a water effluent treating plant are simpler than those needed at BOD removal.

ANNEX 7

General Data for Process Coolers

TABLE 7.1.1 TECHNICAL DATA FOR PROCESS COOLERS COMBINATION UNIT 1

Service/Task	Cooling Fluid	N° of Cooler	Design Temp. °C	Design Duty MW	Data Duty MM BTU/h
Fractionator Reflux Condenser	Water	EX-10	168	30.4	103.7
Fractionator Product Condenser	Water	EX-11	149	51.8	177.0
Turbine Fuel Cooler	Water	EX-12	188	5.2	17.8
Kerosene Cooler	Water	EX-13	121	4.3	14.7
Diesel Fuel Cooler	Water	EX-15	156	12.9	43.9
Heavy Gas Oil Cooler	Water	EX-16	204	3.0	10.2
Sour Water Stripper Condenser	Water	EX-23	113	4.0	13.6
Residuum Cooler Box	Water	EX-18	193	21.4	73.1
Vacuum Light Gas Oil Cooler	Water	EX-204	227	4.5	15.3
First Stage Ejector Condenser	Water 1)	EX-206	102	1.3	4.3
Second Stage Ejector Condenser	Water 1)	EX-207	116	1.2	4.2
Third Stage Ejector Condenser	Water 1)	EX-208	135	1.0	3.3
Stabilizer Condenser	Water	E-11	60	- 2)	- 2)
Stabilizer LPG Cooler	Water	E-31	68	0.1	0.2
Stabilized Nafta Trim Cooler	Water	E-49	54	1.6	5.6
Preflash Condenser	Water	EA-501	150	9.5	32.3 3)
Preflash Condenser	Water	EA-502	150	9.5	32.3 3)
Vacuum Heavy Gas Oil Cooler	Air	EX-212	177	6.8	23.3
Vacuum HGO Reflux Cooler	Air	EX-203	238	23.5	80.3
Stabilized Nafta Cooler	Air	E-47	177	13.8	47.0

These data are taken from technical studies about the Salina Cruz refinery

TABLE 7.1.2 TECHNICAL DATA FOR PROCESS COOLERS COMBINATION UNIT 2

Service/Task	Cooling Fluid	N° of Cooler	Design Temp. °C	Design Duty MW	Data Duty MM BTU/h
Fractionator Reflux Condenser	Water	A-EA 17	147	67.5	230.4
Turbine Fuel Cooler	Water	A-EA 25	96	6.8	23.2
Kerosene Trim Cooler	Water	A-EA 26	60	0.8	2.7
Diesel Fuel Trim Cooler	Water	A-EA 27	60	1.1	3.7
Heavy Gas Oil Trim Cooler	Water	A-EA 28	60	0.5	1.6
Nafta Product Cooler	Water	A-EA 32	49	0.7	2.4
Desalter Water Cooler	Water	A-EA 20	133	4.5	15.2
Desalter Water Cooler	Water	A-EA 21	133	4.5	15.2
Preflash Condenser	Water	A-EA 15	153	9.8	33.4
Preflash Condenser	Water	A-EA 16	153	9.8	33.4
Compressor After Cooler	Water	A-EA 29	141	1.1	3.7
Light Gas Oil Product Cooler	Water	V-EA 6	82	2.4	8.2
Light Gas Oil Reflux Cooler	Water	V-EA 5	82	6.2	21.0
Vacuum Heavy Gas Oil Cooler	Water	V-EB 1[1)]	193	9.5	32.6
Vacuum Resid Cooler	Water	V-EB 1[1)]	224	17.1	58.3
Amine Stripper Condenser	Water	A-EA 63	114	0.4	1.5
Lean Amine Cooler	Water	A-EA 61	75	0.3	0.9
Caustic Solution Cooler	Water	A-EA 66 X	70	0.1	0.5
Debutanizer Condenser	Water	A-EA 51	78	7.5	25.5
Debutanized Nafta Cooler	Water	A-EA 55	88	3.9	13.2
Kerosene Cooler	Air	A-EC 1	138	3.1	10.5
Diesel Fuel Cooler	Air	A-EC 3	143	8.8	30.0
Heavy Gas Oil Cooler	Air	A-EC 2	107	1.2	4.2
Upper Reflux Cooler	Air	A-EC 6	121	5.6	19.0
Lower Reflux Cooler	Air	A-EC 4	213	12.6	43.0
Vacuum Light Gas Oil Cooler	Air	V-EC 1	142	22.3	76.2
Vacuum HGO Reflux Cooler	Air	V-EC 2	204	4.1	14.1
Sour Water Stripper Condenser	Air	A-EC 81	118	7.8	26.7

These data are taken from technical studies about the Salina Cruz refinery

TABLE 7.1.3 TECHNICAL DATA FOR PROCESS COOLERS
FLUID CATALITIC CRACKING UNIT No. 1

Service/Task	Cooling Fluid	N° of Cooler	Design Temp. °C	Design Duty MW	Data Duty MM BTU/h
Fractionator Condenser	Water	1-C	154	49.1	167.7
Compressor Intercooler	Water	27-C	65	2.5	8.4
Lean Oil Chiller	Water	28-C	38	0.6	1.9
Unit Gas Cooler	Water	9-C	57	5.0	16.9
Debutanized Gasoline Cooler	Water	17-C	149	13.8	47.1
Debutanized Condenser	Water	15-C	59	12.4	42.5
Depropanizer Condenser	Water	19-C	46	4.9	16.9
Propane-Propylene Cooler	Water	22-C	44	0.1	0.3
Butane-Butylene Cooler	Water	20-C	98	1.3	4.3
Lean Amine Cooler	Water	24-C	76	5.1	17.5
Amine Stripper Condenser	Water	26-C	110	5.7	19.6
Propylene Splitter Condenser	Water	57-C	52	15.8	53.9
Sponge Oil Trim Cooler	Water	12-C	143	5.5	18.8
Light Cycle Oil Cooler	Air	4-C	232	9.5	32.6
Residuum Cooler	Air	7-C	232	3.6	12.3

These data are taken from technical studies about the Salina Cruz refinery

TABLE 7.1.4 TECHNICAL DATA FOR PROCESS COOLERS FLUID CATALITIC CRACKING UNIT No. 2

Service/Task	Cooling Fluid	N° of Cooler	Design Temp. °C	Design Duty MW	Data Duty MM BTU/h
Fractionator Trim Condenser	Water	E-2	57	6.4	21.9
Compressor Intercooler	Water	E-10	69	4.5	15.3
High Pressure Condenser	Water	E-12	62	9.8	33.5
Absorber Upper Intercooler	Water	E-11	51	1.3	4.3
Lean Oil Cooler	Water	E-15	66	2.1	7.0
Absorber Lower Intercooler	Water	E-7	47	1.0	3.4
Debutanized Condenser	Water	E-17	55	10.9	37.1
Debutanized Gasoline Cooler	Water	E-20	131	9.7	33.2
Depropanizer Condenser	Water	E-21	43	5.4	18.3
Propane-Propylene Cooler	Water	E-22	42	0.3	0.9
Butane-Butylene Cooler	Water	E-24	96	1.1	3.9
Lean Amine Cooler	Water	E-25	82	5.9	20.1
Amine Stripper Condenser	Water	E-26	108	6.4	22.0
Fractionator Condenser	Air	E-29	137	23.1	79.0
Light Cycle Oil Cooler	Air	E-3	180	2.7	9.3
Residuum Cooler	Air	E-5	233	2.2	7.5

These data are taken from technical studies about the Salina Cruz refinery

TABLE 7.1.5 TECHNICAL DATA FOR PROCESS COOLERS

NAFTA DESULFURIZATION UNIT No.1
NAFTA REFORMING UNIT No. 1
FRACTIONATION AND TREATING UNIT No. 1

Service/Task	Cooling Fluid	N° of Cooler	Design Temp. °C	Design Duty MW	Data Duty MM BTU/h
Reactor Effluent Cooler	Water	EA-402	167	13.1	44.8
Deisohexanizer Condenser	Water	EA-403	118	3.6	12.4
Sour Gas Cooler	Water	EA-406	199	0.6	2.1
Nafta Product Cooler	Water	EA-407	112	5.8	19.9
Compressor Intercooler	Water	EA-502	54	1.9	6.6
Reactor Effluent Trim Cooler	Water	EA-507	54	2.0	6.8
Booster Compressor Intercooler	Water	EA-508	101	0.7	2.5
Debutanized Reformate Cooler	Water	EA-511	54	0.7	2.4
Debutanizer Trim Condenser	Water	EA-512	54	0.4	1.3
Reactor Effluent Cooler	Air	EC-501	162	15.2	51.8
Debutanized Reformate Cooler	Air	EC-502	82	1.5	5.0
Debutanizer Condenser	Air	EC-503	79	1.9	6.6
LPG Product Cooler	Water	EA-601	94	0.1	0.3
Debutanizer Condenser	Water	EA-602	55	-	0.1
Lean Amine Cooler	Water	EA-605	79	6.7	22.9
Amine Stripper Condenser	Water	EA-606	112	6.4	22.0

These data are taken from technical studies about the Salina Cruz refinery

TABLE 7.1.6 TECHNICAL DATA FOR PROCESS COOLERS

INTERMEDIATE DESTILLATE DESULFURIZATION UNITS No.1 (700/800)

Service/Task	Cooling Fluid	N° of Cooler	Design Temp. °C	Design Duty MW	Data Duty MM BTU/h
Reactor Effluent Coolers	Water	EA-702 EA-802	167	13.1	44.8
Stripper Condenser	Water	EA-703 EA-803	163	4.0	13.5
Sour Gas Cooler	Water	EA-708 EA-808	47	-	0.1
Fractionator Condenser	Water	EA-705 EA-805	96	2.3	7.9
Fractionator Bottoms Cooler	Water	EA-707 EA-807	117	6.9	23.5
Reactor Effluent Coolers	Water	EA-404	102	7.8	26.7
Flash Drum Gas Coolers	Water	EA-406	143	0.6	2.0 1)
Debutanizer Condenser	Water	EA-407	93	5.4	18.3
Deisohexanizer Condenser	Water	EA-408	78	17.3	59.2
LPG Cooler	Water	EA-410	67	0.1	0.5
Nafta Product Cooler	Water	EA-411	147	2.6	8.9

...a are taken from technical studies about the Salina Cruz refinery

TABLE 7.1.7 TECHNICAL DATA FOR PROCESS COOLERS

NAFTA REFORMER No. 2

Service/Task	Cooling Fluid	N° of Cooler	Design Temp. °C	Duty MW	Data Duty MM BTU/h
Reactor Effluent Trim Coolers	Water	EA-502	60	4.7	16.1
H.P. Separator Liquid Coolers	Water	EA-503	43	5.6	19.2
Booster Compressor Intercooler	Water	EA-504	142	4.0	13.2
Stabilizer Condenser	Water	EA-506	74	5.0	17.1
Reformate Cooler	Water	EA-507	92	3.1	10.6
Reactor Effluent Cooler	Air	EC-501	136	23.0	78.6

These data are taken from technical studies about the Salina Cruz refinery

TABLE 7.1.8 TECHNICAL DATA FOR PROCESS COOLERS

FRACTIONATION AND TREATING UNIT No. 2

Service/Task	Cooling Fluid	N° of Cooler	Design Temp. °C	Design Duty MW	Data Duty MM BTU/h
Lean Amine Cooler	Water	EA-602	79	8.4	28.8
Amine Stripper Condenser	Water	EA-604	106	6.4	22.0
Depropanizer Condenser	Water	EA-605	61	2.2	7.5
Deethanizer Condenser	Water	EA-607	52	0.1	0.2
Deisobutanizer Condenser	Water	EA-609	56	4.3	14.8
Depropanizer Bottoms Cooler	Water	EA-625	129	0.9	3.0
Propane Product Cooler	Water	EA-613	76	0.1	0.3
Normal Butane Product Cooler	Water	EA-612	71	0.2	0.7
Isobutane Product Cooler	Water	EA-611	55	-	0.1
Deisopentanizer Condenser	Water	EA-614	55	10.0	34.0
Isopentane Product Cooler	Water	EA-615	53	0.1	0.2
Normal Pentane Product Cooler	Water	EA-617	74	0.4	1.3
Primary Fractionator Condenser	Water	EA-618	101	0.3	1.1
Light Nafta Cooler	Water	EA-620	91	0.1	0.2
Secondary Fractionator Cond.	Water	EA-621	138	0.2	0.8
Heavy Nafta Cooler	Water	EA-623	166	0.2	0.7
Intermediate Nafta Cooler	Water	EA-624	130	0.1	0.3

These data are taken from technical studies about the Salina Cruz refinery

TABLE 7.1.9 TECHNICAL DATA FOR PROCESS COOLERS

INTERMEDIATE DISTILLATE DESULFURIZATION No. 2
VISBREACKER UNIT

Service/Task	Cooling Fluid	N° of Cooler	D e s i g n		D a t a
			Temp. °C	Duty MW	Duty MM BTU/h
Reactor Effluent Cooler	Water	EA-702 EA-802	166	13.1	44.8
Stripper Condenser	Water	EA-703 EA-803	163	4.0	13.5
Fractionator Condenser	Water	EA-705 EA-805	96	2.3	7.9
Fractionator Bottoms Cooler	Water	EA-707 EA-807	117	7.0	23.8
Sour Gas Cooler	Water	EA-708 EA-808	47	-	0.1
Fractionator Condenser	Water	EA-3	144	11.6	39.6
Fuel Oil Cooler	Water	EC-1	222	23.4	79.9
Compressed Gas Cooler	Water	EA-8	117	0.8	2.7
Gas Oil Cooler	Air	EC-2	254	4.7	16.0

These data are taken from technical studies about the Salina Cruz refinery

TABLE 7.1.10 TECHNICAL DATA FOR PROCESS COOLERS

TECHNICAL DATA OF HEATERS

Item N°	normal Throughput BPD	normal Process Duty 10^6BTU/HR	Duty[1)] %	Overall Efficiency %[1)]
H-01A/B	150,000	480.0[2)]	109	75.0
H-201A/B	67,500	166.0[2)]	114	74.0
A-BA-1/2	155,000	456.0[2)]	101	80.0
A-BA-51	60,000	36.0	100	84.0
V-BA-1/2	65,000	134.0[2)]	72	78.0
2-B	48,000	115.0	116[1)]	77.0
BA-401	25,000	34.6	100	78.0
BA-402	-	30.9	100	81.0
BA-501	20,000	170.0[3)]	93	79.0
BA-502	-	15.9	100	78.0
BA-701	25,000	36.7	100	78.0
BA-702	-	34.6	100	78.0
BA-801	25,000	36.7	100	78.0
BA-802	-	34.6	100	78.0

These data are taken from technical studies about the Salina Cruz refinery

ANNEX 8

Design Sequence of Activities from a Mathematical Point of View

ANNEX 8 1_/

Design Sequence of Activities

To search the best candidate action or design to fulfill stated objectives in the future. The sequence is summarized below in analytical form.

- Let the set of generated candidates be

$$A = \{A_1, A_2, \ldots, A_i, \ldots, A_I\}. \qquad (1)$$

- The designer will synthesize a configuration $S_i(x_i)$ with the vector of design alterables α_j for the candidate A_j.

- The predicated performance Y_i of the candidate will depend on

  (i) the configuration and setting of alterables;
  (ii) the environmental state N_j in which the system is presumed to be operating.

- Let the set of possible environmental states be

$$N = \{N_1, N_2, \ldots, N_j, \ldots, N_J\} \qquad (2)$$

  Where the state N_j is a distinct future incorporating variables to which the system is sensitive but is not in the designer's control , e.g. one of several possible operational states, climate, quality of resources, prices, threats .....

- The state N_j is assumed to occur with the probability p_j at the designated future time, i.e.

$$p_j(t_f) \Rightarrow (N(t_f) = N_j \mid N(t_o) = N_o); \sum_j p_j = 1 \qquad (3)$$

  Where (N_o, t_o) is the initial environmental state.
  Denote the set of probable future environments by $\{p_j, N_j\}$.

- Let the set of performance functions be

$$Y_i = \{Y^i_1, Y^i_2, \ldots, Y^i_n, \ldots, Y^i_N\} \qquad (4)$$

  For the candidate A_j.

- Let the level of the nth performance function, given that the jth environment exists, be Y^i_{nj} this is a design outcome.

1_/ M'pherson P.K. "A Framework For System Engineering Design". The Radio And Electronic Engineer , Vol. 51 Num. 2 Feb. 1981. pp. 59-87 Reference 17.

These data are taken from technical studies about the Salina Cruz refinery

- Then the expected value of the *n*th performance function for the *i*th candidate with configuration $\$_i$ and alterables at α_i evaluated over the range of possible environments is given by:

$$\tilde{Y}^i_n \Rightarrow (Y^i_n | A_i, \$_i, x_i, \{p_j, N_j\}) \qquad = \sum_j p_j, Y^i_{nj} \qquad (5)$$

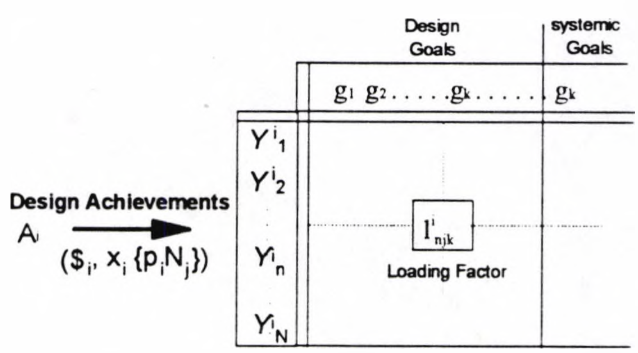
- Let the set of expected performance levels be

$$\tilde{\tilde{Y}}_i = \{\tilde{Y}^i_1, \tilde{Y}^i_2, \ldots, \tilde{Y}^i_n, \ldots, \tilde{Y}^i_n\} \qquad (6)$$

for example, in a servo design, the performance functions would be the expected response time, stability factor, accuracy, reliability, energy consumption, cost... for a specified range of possible operational environments.

- The expected values of the performance functions (called the design achievements) have to be screened against the design goals and systemic objectives *g*. The screening is affected via a loading matrix (fig. 8.1) in which each design goal and systemic goal.

The assessment is subjective and is expressed as a loading factor l^i_{njk} entered in the cell recording the loading of the achievement $\tilde{y}^i_n$ on the goal g_k. The loading factors range between 0 and 1 for very low/high impacts.
They may be scores or drawn in the form of a loading function that rests on the same axiomatic basis and construction as the utility function in Decision Analysis.
The completed loading matrix is signified as l^i_{njk}.

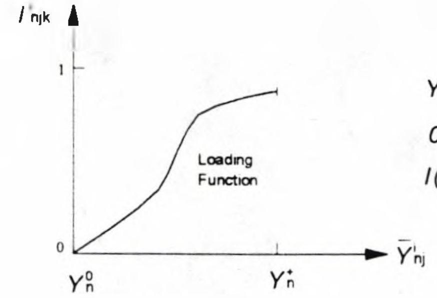


The loading factor may be in the form of:

(i) a score, e.g. 1 for very high impact, 0 for very low impact.

-

(ii) a loading function, e.g.:



$$Y_n^0 \leq \bar{Y}_{nj} \leq \bar{Y}_{nj}^+$$

$$0 \leq l'_{njk} \leq NK$$

$$l(Y_n^0) = 0; \quad l(Y_n^+) = 1$$

fig. 8.1 loading matrix and function.

Screening is effected as follows:

- Since all goals g_k are expressed in desirable form (high capability, high pollution avoidance), each g_k column should have at least one high loading factor l'_{njk}.
- A column with many high l'_{njk} is no more effective than one with a single high factor, but it signifies a better A_j with a respect to that goal g_k in that many of the achievements contribute towards g_k.
- Achievements with no high loading factors in their row are probably mismatched or redundant.
- Achievements with many high factors in their row are important, perhaps too much so as goal satisfaction should not depend on too few achievements.
- Candidates with one or more g_k columns empty or with only a few low factors should be discarded or designed to increase the loading of g_k.

The diagonal loading matrix has $l'_{njj} = 1$. $l'_{njk} = 0$, and J = K. This signifies a unique 1 : 1 relationship between the achievements and the goals. It is a special case that occurs quite often in engineering design where the design objective is expressed only in terms of desirable levels of design achievement.

- The load matrix has now to be evaluated with respect to the objectives hierarchy and customer's preferences to obtain an overall figure of merit, or worth for the candidate design A_j. This requires the design of a multi attribute value criterion that matches the multiple objectives and customer's preferences.
- The Design Problem facing the designer can now by expressed quite simply:

(i) Find that configuration S_i and alterables setting $\hat{x}_i$ that maximizes the worth of each candidate design A_i when evaluated over the appropriate range of future environments, using a value criterion V that is matched to the objectives G and the customer's preferences.

(ii) Each candidate design must be feasible and, when optimized, must not exceed any of the stated constraints.

(iii) The best candidate design with respect to V is that which has maximum worth W relative to the objectives set G.

The design

$$A^* \Rightarrow \max_{V_i} W^*(A_i) \qquad (7)$$

where

$$W^*(A_i) = \max_{S_i, X_i} V(L'_{njk} | G, \{ p_j, N_j \}) \qquad (8)$$

and

$$B'_m \leq B^+_m, \; V_m, \qquad K'_p \leq K^+_p, \; V_p \qquad (9)$$

The process of finding the maximum worths is an iterative constrained optimization search. B_m and k_p are resource and cost constraints.