

การตัดสินใจเชิงเศรษฐศาสตร์ในการคัดเลือกเทคโนโลยี
ที่เหมาะสมในการเพิ่มมูลค่าของผลิตภัณฑ์พลอยได้



นางสาวศุภมาส อิศรภักดี

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาดبلومหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต

สาขาวิชาการจัดการทางวิศวกรรม

ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

ปีการศึกษา 2542


ISBN 974-333-459-9

ลิขสิทธิ์ของ จุฬาลงกรณ์มหาวิทยาลัย

13 ต.ย. 2544

I19265530

**ECONOMIC DECISION MAKING FOR SELECTING AN
APPROPRIATE BY-PRODUCT UPGRADING TECHNOLOGY**



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**A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering in Engineering Management
The Regional Centre for Manufacturing Systems Engineering**

Faculty of Engineering


Chulalongkorn University

Academic Year 1999

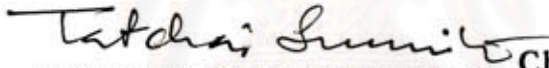
ISBN 974-333-459-9

Thesis Title Economic Decision Making for Selecting an
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ศุภมาส อิศรภักดี: การตัดสินใจเชิงเศรษฐศาสตร์ในการคัดเลือกเทคโนโลยีที่เหมาะสมในการเพิ่มมูลค่าของผลิตภัณฑ์พลอยได้ (ECONOMIC DECISION MAKING FOR SELECTING AN APPROPRIATE BY-PRODUCT UPGRADING TECHNOLOGY) อาจารย์ที่ปรึกษา: ผศ. สุทัศน์ รัตนเกื้อกั้วาน, 143 หน้า. ISBN 974-333-459-9

วิทยานิพนธ์ฉบับนี้เป็นการศึกษาการตัดสินใจเชิงเศรษฐศาสตร์ในการคัดเลือกเทคโนโลยีที่เหมาะสมในการเพิ่มมูลค่าของผลิตภัณฑ์พลอยได้ของบริษัท อะโรเมติกส์ (ประเทศไทย) จำกัด มหาชน ซึ่งจะแบ่งการวิเคราะห์ออกเป็น 2 หัวข้อหลักคือ การวิเคราะห์ทางเทคนิค และการวิเคราะห์ทางเศรษฐศาสตร์ โดยมีวัตถุประสงค์เพื่อศึกษาการตัดสินใจเลือกเทคโนโลยีที่เหมาะสมที่สุดจากเทคโนโลยีทั้งหมด 5 เทคโนโลยีอันได้แก่ 1) AROMAX 2) ALPHA 3) RZ-100 4) Z-FORMER และ 5) CYCLAR

ผลการศึกษาถึงศักยภาพของผลิตภัณฑ์พลอยได้ทั้ง 3 ตัวของบริษัท อะโรเมติกส์ฯ อันประกอบด้วย 1) LPG 2) Light Naphtha และ 3) Raffinate พบว่าผลิตภัณฑ์พลอยได้ทุกตัวที่บริษัท อะโรเมติกส์ฯ ผลิตได้นั้นมีปริมาณเพียงพอและมีคุณภาพได้ตรงตามมาตรฐานที่จะสามารถนำไปใช้เป็นวัตถุดิบในกระบวนการเปลี่ยนผลิตภัณฑ์พลอยได้ทั้งหมดให้กลับไปเป็นผลิตภัณฑ์หลักอีกครั้งหนึ่ง

ในด้านของการวิเคราะห์ทางเทคนิค เราจะเน้นศึกษาในแง่ของความเป็นไปได้ในการนำเทคโนโลยีทั้ง 5 เทคโนโลยีไปใช้ว่าผ่านการคัดเลือกแล้วจะสามารถนำมาใช้งานได้จริงหรือไม่ ซึ่งจากการศึกษาพบว่าเทคโนโลยี CYCLAR และ AROMAX ไม่ผ่านการคัดเลือกในเบื้องต้นนี้ ดังนั้นจึงเหลือ 3 เทคโนโลยีที่มีความเป็นไปได้ในเชิงเทคนิคที่จะสามารถนำไปใช้งานได้จริง ซึ่งได้แก่ เทคโนโลยี ALPHA, RZ-100 และ Z-FORMER ซึ่งเราจะนำเทคโนโลยีทั้งหมดนี้ที่ผ่านการวิเคราะห์ทางเทคนิคแล้ว ไปพิจารณาค่าทางด้านเศรษฐศาสตร์

ในการวิเคราะห์ทางเศรษฐศาสตร์นั้น เราแบ่งการศึกษาออกเป็น 3 กรณีด้วยกันคือ 1) คัดในสภาพการณ์ที่เศรษฐกิจดีมาก 2) คัดในสภาพการณ์ปกติ และ 3) คัดในสภาพการณ์ที่เศรษฐกิจไม่ดี ซึ่งจากการจำลองทั้ง 3 สภาพการณ์มาศึกษา สามารถสรุปได้ว่าทุกสภาพเศรษฐกิจที่กล่าวมาแล้ว ในเรื่องของการเปลี่ยนผลิตภัณฑ์พลอยได้ของบริษัท อะโรเมติกส์ฯ ให้กลับไปเป็นผลิตภัณฑ์หลักอีกครั้งหนึ่งนั้น เทคโนโลยีที่เหมาะสมที่สุดได้แก่ Z-FORMER ซึ่งมีความเป็นไปได้ทางด้านเทคนิค และมีความเหมาะสมทางด้านเศรษฐศาสตร์ โดยให้ผลตอบแทนการลงทุนที่เพิ่มขึ้นมากกว่าเทคโนโลยี ALPHA และ RZ-100 โดยเทคโนโลยี Z-FORMER นี้ ให้ค่า Incremental IRR เท่ากับ 26.88% และให้ค่า Incremental NPV เท่ากับ \$47,736,474.96 ในสภาพเศรษฐกิจที่ดีมาก 20.18% และ \$26,601,624.55 ในสภาพเศรษฐกิจปกติ 12.06% และ \$183,061.55 ในสภาพเศรษฐกิจที่ไม่ดี

ภาควิชา ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต

ลายมือชื่อนิสิต

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สาขาวิชา การจัดการทางวิศวกรรม

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ลายมือชื่ออาจารย์ที่ปรึกษาร่วม

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SUPAMAS ISARABHAKDI : ECONOMIC DECISION MAKING FOR
 SELECTING AN APPROPRIATE BY-PRODUCT UPGRADING TECHNOLOGY.
 THESIS ADVISER : ASST. PROF. SUTHAS RATANAKUAKANGWAN, 143 pp.
 ISBN 974-333-459-9

This thesis is a study of economic decision making for selecting an appropriate technology to upgrade the by-products of the Aromatics (Thailand) Public Co., Ltd. (ATC). The analysis will be made in two main methods: a technical analysis and an economic analysis. The objective is to study the decision making to select the appropriate technology from five available technologies which are 1) AROMAX 2) ALPHA 3) RZ-100 4) Z-FORMER and 5) CYCLAR.

The result of the study on the potential of the three by-products of ATC, consisting of 1) LPG 2) Light Naphtha and 3) Raffinate, shows that all the ATC by-products have enough quantity and have the quality up to the standard required, to be used as raw materials for reprocessing into main products.

On the technical analysis side, emphasis will be given on the possibility of using the five technologies. Once a technology is selected, will it be able to work? From the study, it is found that CYCLAR and AROMAX fail the preliminary selection. Therefore, there remain three technologies which are technically possible to be used. These technologies are ALPHA, RZ-100 and Z-FORMER. Once they have passed the technical analysis, they will be further considered on the economic aspect.

For the economic analysis, we divide the study into three economic cases 1) Best Case 2) Normal Case 3) Worst Case. From the three economic supposed cases, it can be concluded that in all the stated economic situations, to convert the ATC by-products into main products, the most appropriate technology is the Z-FORMER which has both the technical and economic suitability, yielding higher return on investment than ALPHA and RZ-100. The Z-FORMER gives an incremental IRR at 26.88% and an incremental NPV at \$47,736,474.96 in the best economic situation, 20.18% and \$26,601,624.55 in the normal economic situation, 12.06% and \$183,061.55 in the worst economic situation.

ภาควิชา ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต ลายมือชื่อนิติศ *Supamas*
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ACKNOWLEDGMENTS

The writer wishes to express her deepest gratitude to Assistant Professor Suthas Ratanakuakangwan for his dedication, guidance and encouragement that bring this Thesis to achievement.

She wishes to thank the teaching staff of The Regional Centre for Manufacturing Systems Engineering for their support and assistance throughout the course, as well as the librarians of Chulalongkorn University and Sasin for their kind cooperation.

She is grateful to Mr. Pathomrath Sutabutr, Procurement Division Manager of the Aromatics (Thailand) Public Company Limited, for his moral support and kind understanding as well as his valuable help to carry out this study.

Her thanks go to her classmates and friends around her, especially at The Aromatics for their help and encouragement.

She cannot find enough words to say how much she is grateful to her dearest mother and sister who help her along these few difficult years with great love, understanding, patience and moral support.



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CHAPTER 1

INTRODUCTION



1.1 COMPANY BACKGROUND

THE AROMATICS (THAILAND) PUBLIC COMPANY LIMITED

When natural gas was discovered in commercial quantity in the Gulf of Thailand in 1980, the Thai government envisaged a master plan to maximize its utilization to the fullest extent for the development of the national economy. As a result, plans for the development of the National Petrochemical Complex 1 (NPC1) and thereafter the National Petrochemical Complex 2 (NPC2) were respectively implemented. NPC2 was divided into the Upstream, Intermediate and Downstream phases. The Upstream phase consists of Thai Olefins Co., Ltd. (TOC) and The Aromatics (Thailand) Public Co.,Ltd. (ATC) which are bound under long-term sale contract to supply each other with certain products of their individual outputs, for feedstocks.

ATC was established, with government support, on December 25,1989 with the objectives of producing and selling aromatics, the Upstream raw material to be used as feedstocks for Intermediate and Downstream industries for the manufacture of a multitude of essential products for everyday uses.

Table 1.1
ATC Production

Unit : Ton per year

Products	Production	Offtakers
Benzene	234,000	Siam Styrene Monomer Co.,Ltd.
Toluene	55,000	The Shell Company of Thailand Thai MC Co.,Ltd.
Paraxylene	335,000	Tuntex Petrochemical Co.,Ltd.
Orthoxylene	29,000	Eternal Petrochemical Co.,Ltd.
Mixed Xylenes	16,000	The Shell Company of Thailand Thai MC Co.,Ltd.
Condensate Residue	586,000	Rayong Purifier Co.,Ltd.
Heavy Aromatics	17,000	Asia Solvent Co.,Ltd.
Light Naphtha	375,000	Thai Olefins Co.,Ltd.
Raffinate	230,000	Thai Olefins Co.,Ltd.
LPG	89,000	Petroleum Authority of Thailand

Source : ATC's Annual Report 1996

1.2 INTRODUCTION

The economy of Thailand has continuously expanded. The greatest change of the Thai economic structure is in the industrial sector that has increased in importance more than the agricultural sector. In the rapid and continued expansion of the Thai industries, plastic industry, which is in the petrochemical industry, is also an industrial group with rapid growth. This is because of the expansion of local market resulted from population increase, demand of new form of goods, decline in natural resources such as wood, rubber and metals, as well as the increase in demand of other industries using plastic. In particular, natural gas was discovered in the Gulf of Thailand in 1980, and has since been commercialized. This is the starting point of the Thai petrochemical industry and of The Aromatics (Thailand) Company as well.

In this thesis, by-products, which are used, represent an excessive material produced not as main products in relatively high quantity, which their chemical structure can be easily transformed into aromatics compound. The transformation of by-products will be made by some processes in order to maximize their commercial value.

To upgrade or add value to the by-products, they can be introduced to an additional process in a new unit where the final result becomes aromatics main products again.

The economic decision making is a quantitative decision making mostly used in the industries, because the conditions of business decision making wholly require economic data. Taking Income-Capital and Profit-Loss as guide line in decision making is a normal business procedure.

The economic analysis is an analysis of expenses and other advantages, to be used to compare and decide on the selection of the tactical method to solve problems. The decision to compare investment that bears expenses and benefits arising at present and in the future, must be adjusted to the present money value or what is defined as "present value". To enable the economic analysis to vary in the nearest real value, the following supposition must be adhered to:

1. Money is related to time
2. Slight change for the future
3. Comparatively accurate forecast for the future
4. Rather stable interest rates during the analyzed period

1.3 STATEMENT OF THE PROBLEMS

As the selling price of aromatics is made up by the mechanism of the world market price, the method to conduct the business in the present declined economic trend is to reduce costs, or make effort to increase profit.

Products	Amount (Metric Ton)	Value (US\$ million)
Main Products	1,270,000	304,330,000
By-products	689,000	69,905,000
Total	1,959,000	374,235,000

Source: Planning & Commercial Department, The Aromatics (Thailand) Public Co.,Ltd

From the above table, one question is what ATC should do to gain higher benefit from the by-products which actually make low revenue for the company. So, what to do to make greater revenue. One method to be adopted is to upgrade the by-products, by passing them through another new process to gain new main products which can be sold at higher prices.

Furthermore, because of the long-term sales contract with the fixed customer, sometimes ATC cannot produce on-time schedule. Thus the company is short of products to serve the customer according to the agreement, and is forced to import main products for sale. This results in a higher cost that might even make loss on ATC. However, if ATC can produce more main products, there should be no more problem of this kind.

All the above-stated factors give inspiration to study on the decision making to select technology for upgrading by-products.

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1.4 OBJECTIVE

To select an appropriate technology in converting ATC by-products into main products based on economical factors.

1.5 SCOPE

The study will cover the following areas:

1. For this thesis main products consist of Benzene, Toluene, Paraxylene, Orthoxylene, Mixed Xylene, Condensate Residue, Heavy Aromatics. And by-products consist of LPG, Light Naphtha, Raffinate.
2. Doing the technical analysis of available technologies that can use ATC by-products as feedstock to produce ATC main products.
3. Doing the economic analysis of the technically screened technology by using incremental revenue analysis so as to make the most appropriate choice to increase the revenue of the company.
4. Type of Technology
 1. AROMAX
 2. RZ-100
 3. CYCLAR
 4. ALPHA
 5. Z-FORMER

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1.6 PROCEDURES AND METHODOLOGY OF RESEARCH

1. Study the history and the situation of petrochemical industry, with emphasis on aromatics products.
2. Study related literature and theory.
3. Study and collect primary data for marketing research on the tendency of demand volume to use aromatics products.
4. Collect data of each technology to be selected which mainly are :
 - ❖ General process description
 - ❖ Description of feedstock requirements
 - ❖ Estimated cost
5. Study and analyze the result in two parts :
 - 5.1 Technical analysis that the heavy emphasis will be placed on the compatibility of each process with the existing ATC operation and facilities. These will consider such items as :
 - ATC feedstock availability and quality
 - ATC infrastructure and utilities availability
 - Existing configuration and operation plan
 - 5.2 Economic analysis that will analyze the expenses incurred in the investment on every technology that has been studied on technical suitability, as well as installation expenses, maintenance expense details. The analysis will use the concept of incremental revenue.
6. Conclusion and assessment of decision making, by finding the best selection.
7. Compiling the thesis.
8. Issue and present the final report.

1.7 EXPECTED BENEFIT

1. Increase profit for ATC.
2. Reduce import volume of aromatics products, resulting in saving of foreign exchange and increasing of competitive advantage.
3. Technological development which introduce new technology.

1.8 LITERATURE SURVEY

1. Tuan Vo-Dinh, Chemical Analysis of Polycyclic Aromatic Compounds (Chemical Analysis : A Series of Monographs on Analytical Chemistry and Its Applications), John Wiley & Sons, 1991.

“Polycyclic aromatic compounds represent the largest class of suspected chemical carcinogens. This book reviews established and new techniques for analysis of PAC's, including both homocyclic and heterocyclic species, and PAC mixtures. Presented are the latest experimental procedures, along with new developments in instrumentation. Topics covered include photoionization spectroscopy, photothermal spectroscopy, and immunoadsorbant techniques.”

2. Malcolm Sainsbury, Aromatic Chemistry, Oxford University Press, 1992.

“This book concerns with the chemistry of aromatic compounds is part of many aspects of chemistry and other similar subjects. As such the chemistry of benzene and its related compounds is an intergral part of all undergraduate chemistry courses. This primer covers the vast majority of information needed for a thorough understanding of aromatic chemistry in a clear and readable fashion. The book gives careful consideration to bonding, the concept of aromaticity (Huckel's rule), the major reactions undergone by aromatic compounds along with the orientation of substituents in aromatic reactions, modern synthetic methods, such as the use of organometallic reagents, and examples of other arenes.”

3. David T. Davies, Aromatic Heterocyclic Chemistry (Oxford Chemistry Primers, No. 2), Oxford University Press, 1991.

“The emphasis of this book for undergraduate study is on synthetic aspects rather than properties: it covers the essential details and basic principles with reference to all the important classes of heterocyclic compounds, illustrating them with many modern examples of drug synthesis. Annotation copyright Book News, Inc. Portland.”

4. Marilyn K. Pelosi, Theresa M. Sandifer, Doing Statistics for Business With Excel: Data, Inference, and Decision Making, John Wiley & Sons, 1999.

“This text teaches readers the basic techniques for analyzing data to make business decisions. Each chapter of the book begins with a "story". The story tells of a business problem that needs to be solved and describes the data that were collected to help solve the problem. The exercises which are presented in the chapter are tied to that story and are threaded throughout the chapter. The reader is then left to finish the analysis for the story problem. Sample output from Excel, as well as keystroke and menu instructions are featured throughout the book.”

5. W. J. Fabrycky, G. J. Thuessen, D. Verma, Economic Decision Analysis, 3 edition, Prentice Hall, 1997

“This book has been updated and presents methods for analyzing the economic alternatives and outcomes of technical and managerial decisions. The book focuses on practical applications giving readers a thorough understanding of how to use evaluation methods necessary for decision making. The book also includes a new chapter discussing loans, bonds, working capital, exchange rates and equity.”

6. Kanwalroop Kathy Dhanda, Anna Nagurney, Padma Ramanujam, Environmental Networks: A Framework for Economic Decision-Making and Policy Analysis, Edward Elgar Publishing, 1999.

“This book presents a new basis for environmental policy-making: environmental networks. This framework graphically simplifies the analysis of environmental problems and emphasizes the spatial nature of economic activity and pollution dispersion. The book first discusses the foundations of environmental economics before going on to apply the environmental network approach to different firm structures. The authors then extend the analysis to incorporate multiple products and pollutants, the presence of transaction costs, the availability of investment in production technologies, and the issue of noncompliance versus compliance. They also apply the network approach to pollution caused by

transportation and assess the success of permits in limiting this. The authors then formulate integrated models, analyzing the use of permits and taxes in firms, producers, and consumers, as well as transportation and trade routes.”

7. David W. Conklin, Comparative Economic Systems : Objectives, Decision Modes, and the Process of Choice, Cambridge University Press, 1991

“This book discusses an alternative objectives and decision modes are considered in a comparative exploration of diverse economic systems and the choices societies must face in determining the systems best suited to specific needs.”

8. Paul D. Newendorp , Decision Analysis for Petroleum Exploration, Planning Press, 1 edition, 1998

“This book is an introduction to the application of statistical decision analysis concepts to the analysis of risk and uncertainty in petroleum exploration investment decisions. Topics covered in the book represent a composite of current attitudes and practices throughout the world for analyzing drilling prospects, as well as several ideas and concepts published first in this book. Although decision analysis can be applied to any type of business investment decision the emphasis in this book is on the application of these new quantitative analysis methods to petroleum exploration decisions. The book will be of special interest to anyone involved in the evaluation of drilling prospects: petroleum geologists, engineers, geophysicists, and management decision makers. A mathematical or statistical background is not required to follow the practical, applications-oriented discussions.”

9. Marilyn Kourilsky, William Dickneider, David Kaplan, victo Tabbush Arnold, John, Economics and Making Decisions,3 edition, Prentice-Hall, 1996.

“This book presents : The role of management accounting -- Accounting and decision making -- Wealth and wealth maximization in decision making -- Risk and uncertainty in decision making -- Costs and benefits for decision -- Cost behavior and estimation -- Cost recording and product costing -- Cost-volume-profit analysis -- Relevant information for operating decisions -- The effect of scare resources on short-term decisions -- Dual prices and opportunity costs -- Long-term decisions :the net present value rule -- Long-term decisions :internal rate of return and other methods -- The budgeting proceed -- The master budget and the cash

budget -- Variance analysis and standard costing -- Divisional performance.”

10. Gabriel Hawawini and Claude Viallet, Title Finance for executives :managing for value creation, Cincinnati, Ohio : South-Western, 1998

“This book presents : Financial management and value creation : an overview -- Understanding balance sheets and income statements -- Assessing liquidity and operational efficiency -- Measuring cash flows -- Diagnosing profitability, risk, and growth -- Using the net present value rule to make value-creating investment decisions -- Alternatives to the net present value rule -- Identifying and estimating a project's cash flows -- Raising capital and valuing securities -- Estimating the cost of capital -- Designing a capital structure -- Valuing and acquiring a business -- Making value-creating decisions in an international environment -- Managing for value creation.”



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CHAPTER 2

PETROCHEMICAL INDUSTRY AND AROMATICS PLANT

This chapter discusses how the petrochemical industry starts in Thailand. Details are given on the development of this industry and how The Aromatics (Thailand) Public Company Limited is established. Description is also made of the natural resources of Thailand leading to the creation of the national petrochemical projects phases I and II, hence the establishment of the Thailand's first aromatics plant.

2.1 HISTORY OF THE THAI PETROCHEMICAL INDUSTRY

2.1.1 MEANING AND STRUCTURE

Petrochemical products mean chemicals produced from petroleum, which is a natural product containing crude oil and natural gas. At the beginning, petroleum was only used as fuel. Later, it has been processed into various products, increasing its value. There are many categories of petrochemical products. The downstream products are mainly in the form of plastic pellets, solvent and raw materials for various industries. It can be said that petrochemical products are found in practically all type of industries such as automobile, electronics, textile, medical, insecticide, all light industries.

In Thailand, petrochemical products may be classified in three levels according to the processing:

- 1) Upstream Petrochemical industry which is the first stage production from petroleum separated into two main groups:
 - Olefins group consisting of ethylene, propylene and C4 (butane, butene, butadiene)
 - Aromatics group consisting of benzene, toluene and xylenes
- 2) Intermediate Petrochemical industry which is the processing of upstream products towards the production of downstream

production. The intermediate products are complex and cannot be directly used for manufacturing of goods for consumption. These products are such as vinyl chloride monomer (VCM) styrene monomer (SM), terephthalic acid (PTA), and solvent.

- 3) Downstream Petrochemical industry which is the processing of intermediate products into plastic pellets or various polymers which are used in integrated industries or finished products such as fibres, yarns and others products such as polyester and nylon.

2.1.2 PETROCHEMICAL INDUSTRY DEVELOPMENT IN THAILAND

1) The first stage development

As stated earlier, the downstream petrochemicals are raw materials for almost all type of industries. Thus, the development of petrochemicals in Thailand is a backward integration. The development starts with putting the petrochemicals into forms without complicated processing. This makes it easy to start up factories with ready market. At the beginning, plastic pellets were imported to manufacture various products for local consumption. Later, as the demand increased, intermediate products were imported to locally produce plastic pellets in newly built factories.

In 1970, Union Carbide and Hoechst Chemical were the first companies to begin production in Thailand of Polyvinyl Acetate(PVA). This product is mainly used as raw material to manufacture paints. Later in the same year, Teijin Polyester (Thailand) Co., Ltd. began manufacturing polyester yarns, using imported PTA and EG as raw materials. In 1971, Thai Plastic and Chemical Co., Ltd. began manufacturing plastic pellets, polyvinyl chloride (PVC) using imported vinyl chloride monomer(VCM).

In 1978, Pacific Plastic (Thailand) Co., Ltd., a joint-venture of Siam Cement and Dow Chemical (U.S.A.), built up polystyrene plant to produce PS plastic pellets, using styrene monomer(SM), an intermediate product. All these plants are rather small compared to those in the world market. The objective is to response to the local demand. They are situated in Bangkok and Samutprakarn Province with easy transportation of raw materials from Chaophya River ports.

In 1981, an important step to the development of large petrochemical industry, Thai Petrochemical Industry Co., Ltd. (TPI) built its LDPE plastic pellets (low density polyethylene) plant in Rayong Province, with a production capacity of 65,000 ton/year. The company imported ethylene, an upstream product. The company has heavily invested in building its own port and storage tank terminal to transport raw materials. In 1986, TPI has expanded its production to HDPE plastic pellets (high-density polyethylene), with the production capacity of 60,000 ton/year. In the same year, the first phase of national petrochemical development project has started. At that period, TPI was considered one of the biggest ethylene importers of the world.

2) The Development of National Petrochemical Industry Phase 1 (NPC1)

Although many plastic pellet plants then existed, the development of the industry could not be considered as integrated, as it was only the development at the downstream product level. The development of petrochemical industry really began in 1981 when the natural gas was discovered in the Gulf of Thailand and the pipeline was laid to the gas separation plant situated in Map Ta Phut area of Rayong Province. By the end of 1982, the Eastern Sea Board Development Committee has set up the petrochemical industry project in Thailand, having the main objective to use the available natural resources to the highest benefit and to serve the local demand. The NPC1 project consists of the following production units:

Upstream Units National Petrochemical Corporation has the capacity to produce ethylene at 315,000 ton/year and propylene 105,000 ton/year, using ethane and propane as raw materials from the gas separation plant. The Corporation is a joint venture of the Petroleum Authority of Thailand and private companies who are downstream manufacturers.

Intermediate and Downstream Units

1. Thai Petrochemical Industry Co. Ltd. who earlier produced LDPE plastic pellets and expanded its capacity to produce HDPE plastic pellets; the expansion being part of the NPC1, enlarging the company's total production capacity to 125,000 ton/year.

2. Thai Polyethylene Co., Ltd., producing HDPE and LDPE plastic pellets at the capacity of 137,500 ton/year.
3. H.M.C. Polymer Co., Ltd., producing polypropylene (PP) plastic pellets at the capacity of 100,000 ton/year
4. Thai Plastic and Chemical Co., Ltd. The company produces PVC plastic pellets in Samutprakarn at the capacity of 120,000 ton/year. As part of the NPC1, the company has its plant in Rayong, producing vinyl chloride monomer at the capacity of 140,000 ton/year and polyvinyl chloride at the capacity of 60,000 ton/year.

At the end of 1986, the NPC1 project began to build its plants, which all started up production in 1990. All the plants enjoyed the highest level of the promotional privilege of the Board of Investment (BOI), and were built in the same area at Map Ta Phut Industrial Estate in Rayong Province. This project has the production capacity balance between the upstream units and the downstream units, and all utilized the upstream raw materials from Thailand - the natural gas.

3) The Development of National Petrochemical Industry Phase 2 (NPC2)

At mid-1987, the Eastern Sea Board Development Committee had drawn up the policy to develop the second phase of the petrochemical industry. The Committee issued the master plan in January 1988 and assigned the Board of Investment to select operators for the intermediate and downstream industries, and the Petroleum Authority of Thailand (PTT) to lead in the upstream units.

The NPC2 is another integrated development of petrochemical industry, as it comprises olefins and aromatics industries having altogether 15 main products divided into 13 projects and all projects are granted the BOI promotional privilege. The total investment was 79,000 Million Baht as shown in Table 2.1.

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Table 2.1
Petrochemical Product Manufacturers in NPC2 Project

Project	Product	Capacity (Ton/Year)	Investment (M. Baht)
Upstream Units			
1. Thai Olefins Co., Ltd.	Propylene	210,000	17,850
	Ethylene	350,000	
	Mixed C4	100,000	
2. Aromatics (Thailand) Co., Ltd.	Benzene	234,000	18,000
	Paraxylene	335,000	
	Toluene	55,000	
	Orthoxylene	29,000	
	Mixed xylenes	16,000	
Intermediate and Downstream Units			
3. Bangkok Polyethylene Co., Ltd.	Polyethylene	140,000	4,700
4. Thai Polypropylene Co., Ltd.	Polypropylene	10,000	2,370
5. Thai Petrochemical Industry	Polypropylene	100,000	3,600
6. Vinythai Co., Ltd.	Vinyl chloride monomer	140,000	12,254
	Polyvinyl chloride	135,000	
7. Thai Petrochemical Industry	Polystyrene	29,000	281
8. H.M.T. Polystyrene Co., Ltd.	Polystyrene	25,000	723
9. Thai Petrochemical Industry	ABS	8,000	1,028
10. Thai Rayon Co., Ltd.	EG	136,000	3,820
11. Thai Acrylate Co., Ltd.	Linear alkyl benzene	40,000	1,900
12. Tuntex Petrochemical Co., Ltd.	PTA	350,000	8,500
13. Siam Styrene Monomer Co., Ltd.	Styrene monomer	200,000	5,970

Source: BOI Study Report on Petrochemical Industry prepared for the Ministry of Industry.

The NPC2 plants with BOI promotional privilege are all situated at Map Ta Phut Industrial Estate in Rayong Province. The NPC2 upstream industry project is the joint venture of the PTT and downstream producers who will be the users.

The production of the NPC2 petrochemical units is fluid-based using Naphtha as raw material. This production process is used worldwide. At present, the quantity of Naphtha produced locally is not sufficient to meet the demand and has to be imported in the first stage.

4) Development of Integrated Petrochemical Industry

The first and second phases of the petrochemical industry development, entail continued large investment in this industry. The companies which are granted the BOI promotional privilege may be summed up in Table 2.2.

Table 2.2

Manufacturers of Integrated Products in NPC Project

Unit : Ton per year

Project	Product	Capacity
1. Pacific Plastic Co., Ltd.	Polyol	25,000
2. Thai Petrochemical Industry	Polyol	25,000
3. H.M.T. Polystyrene Co., Ltd.	Expandable PS	15,000
4. Thai Petrochemical Industry	Expandable PS	15,000
5. Pacific Plastic Co., Ltd.	Synthetic Latex	20,000
6. TOA Co., Ltd.	Phthalic Anhydride	30,000
7. Thai Chemical Co., Ltd.	Phthalic Anhydride	30,000
8. Siam Solvent Co., Ltd.	Condensate Splitter	1,000,000
9. Thai Petrochemical Industry	Condensate splitter	500,000
10. Thai Petrochemical Industry	Propylene Oxide	20,000
11. Thai Petrochemical Industry	Caprolactam	100,000

12. Thai Petrochemical Industry

Polypropylene

120,000

Source: BOI Study Report on Petrochemical Industry prepared for the Ministry of Industry.

2.1.3 THE SITUATION OF LOCAL DEMAND

1) Local Demand and Average Increase Rate As shown in Table 2.3:

Table 2.3
Demand in Plastic Pellets in 1992-1997

(Unit : Ton)

		PE	PP	PVC	PS	ABS/AS
1992	Production	65,000	-	97,600	25,400	2,400
	Importation	82,360	97,450	16,900	4,400	-
Less	Exportation	2,300	30	600	1,300	-
	Total	145,060	97,420	113,900	28,500	-
1993	Production	129,350	-	106,600	25,900	2,400
	Importation	74,000	101,350	19,500	7,000	-
Less	Exportation	2,050	250	600	2,000	-
	Total	201,300	101,100	125,500	30,900	-
1994	Production	126,600	-	85,250	25,700	2,400
	Importation	69,000	89,850	24,550	11,000	13,250
Less	Exportation	3,100	4,700	1,200	5,100	-
	Total	192,500	85,150	108,600	31,600	15,650
1995	Production	129,800	-	97,000	37,900	5,900
	Importation	92,930	110,200	31,700	11,400	17,900
Less	Exportation	13,000	5,700	6,250	4,800	-
	Total	209,730	104,500	122,450	44,500	23,800
1996	Production	200,000	42,700	157,500	47,300	7,750
	Importation	101,200	143,550	49,400	24,900	28,500
Less	Exportation	11,000	4,200	17,200	8,800	1,150
	Total	290,200	182,050	189,700	63,400	35,100
1997	Production	259,000	156,900	177,950	46,900	16,600
	Importation	78,400	53,500	75,500	27,900	30,700
Less	Exportation	30,850	46,450	17,150	12,150	2,600

Total	306,550	163,950	236,300	62,650	44,700
Percentage Rate of Increase per Year	16.14	10.97	15.71	17.06	41.88

Source: BOI Study Report on Petrochemical Industry prepared for the Ministry of Industry

2) Demand Expansion Tendency

2.1) The rate of petrochemical consumption per capita has increased

As it is forecasted that the consumption of plastic pellets or petrochemical products will increase by 2-3 times the GDP growth, the local consumption of plastic in 1987 compared to other countries, developed countries such as Japan and the USA, have much higher consumption rate than Thailand. Moreover, the development of Thailand on the industrial side has increased, pulling up along side the demand in plastic.

Table 2.4

Consumption of plastic compared to other countries in 1997

Unit: kg./year/person

Country	Type of Plastic				
	PE	PP	PVC	PS	Total
Thailand	2.23	1.44	1.17	0.64	5.48
Singapore	14.00	12.00	16.80	19.00	61.80
Malaysia	4.90	2.30	2.70	0.70	10.60
Indonesia	1.10	1.10	0.60	0.15	2.95
Philippines	1.00	0.60	1.00	0.50	3.10
South Korea	9.50	6.20	11.00	6.00	32.70
Taiwan	17.80	6.00	41.00	7.50	72.30
Japan	17.00	11.00	12.80	13.00	53.80
U.S.A.	31.20	8.80	13.60	9.00	62.60

Source: BOI Study Report on Petrochemical Industry prepared for the Ministry of Industry

2.2) The demand in high technology products tends to increase

The development and the economic and industrial expansion in the last decade have led to new forms of plastic utilization. For example, in agriculture, plastic is used to seal the bottom of water reserves, production of dispensable nappies, and various other industries.

Development of plastic application is much advanced, particularly in replacement of natural resources which are becoming scarce such as wood metal, cement, etc. Plastic has the advantage of having light weight. In the development of high technology, plastic is used in engineering to produce parts for automobiles, airplanes, and other engines. This part of application is less developed in Thailand. In the past, plastic was mainly used to produce commodity products. Therefore, the potential of development and expansion of plastic is very high. As shown in Table 2.5, the annual growth of main engineering plastics was 30-200 %.

Table 2.5
Volume of imported engineering plastic pellets

Product and Code	Volume (ton)				Increase (%)
	1993	1994	1995	1996	
Polyacetal (39.07.10.008)	1,683	2,552	3,833	3,811	31.16
Polycarbonate (3907.400.003)	982	1,191	1,804	2,202	34.55
Polyethylene Terephthalate (3907.600.007)	220	823	2,014	3,088	257
Polyamide -6; -11; -12; -6, 6; -6, 9; -6, 10; -6,12 (3908.10.003)	2,787	2,944	4,276	4,768	28.5

Source: BOI Study Report on Petrochemical Industry prepared for the Ministry of Industry

2.1.4 THE STRUCTURE OF TAX ON PETROCHEMICAL PRODUCTS IN THAILAND

1) The structure of tax on petrochemical products before 1992 comprised two rates:

-20% for upstream and intermediate products. The Ministry of Finance reduces the rate to 7-10% for some intermediate products.

-40% for most of down stream products.

The details concerning import duties of petrochemical products are shown in Table 2.6.

Table 2.6

Petrochemical Tax Structure

GROUP	Downstream	Tax %	Intermediate	Tax %	Upstream	Tax %
POLYOLEFINS	PP	40	VCM	20	Propylene Ethylene	20 20
	PE	40	SM	20		
	PVC	40	VAM	20		
	PS	40	EDC	20		
	PVAc	40	EB	20		
	POLYOL	40	Acetic Acid	20		
			PO	20		
AROMATICS	PET	40	EG	7	Ethylene Paraxylene Benzene Orthoxylene	20 20 20 20
	Nylon	40	PTA	7		
	Alkyd Resin	40	Caprolactum	7		
			PA	20		
			EO	20		
			Cyclohexane	29		
C4	MTBE	15	MMA	20	Mixed C4	20
	BR	30	MEK	20		
	PMMA	40	SM	20		
	Paint	20	I-C4/MEOH	20		
	SBL	25	BD	20		
			I-C4	20		
			B-2	20		
			B-1	20		
			BD	20		

Source: BOI Study Report on Petrochemical Industry prepared for the Ministry of Industry.

2) In compliance with the stipulation of AFTA, the Ministry of Finance had to adjust the tax rate of petrochemical products in September 1992, with tax reduction plan spanning over 10 years as shown in Table 2.7.

- Import tax rate over 20% must be reduced to 20% within the 1st January 1998, and to 0-5% within the 1st January 2003.

- Import tax rate of 20% or under must be reduced to 0-5% within the 1st January 2000.

What the Ministry of Finance will do will greatly affect the survival of the Thai petrochemical products, as Thailand remained the dumping field for developed countries such as the USA, Europe and Japan, including Taiwan and Korea. These countries had the advantage of operating cost from the size of integrated production.

Table 2.7

AFTA Tax Reduction Plan for Petrochemical Products

Type of Product	1994	1995	1996	1998	2000	2002	2003
	%	%	%	%	%	%	%
Upstream	20	20	15	10	5		
Intermediate	20	20	15	10	5		
Downstream	40	30	25	20	15	10	5
Plastic Products	60	30	25	20	15	10	5

Source: BOI Study Report on Petrochemical Industry prepared for the Ministry of Industry

AFTA tax adjustment would strongly affect local manufacturers who have just started their operation, particularly the aromatics plant which was due to start in 1996.

2.1.5 RAW MATERIALS USED IN PETROCHEMICAL INDUSTRY

The upstream raw materials of petrochemical industry are crude oil and natural gas. Generally, the upstream material obtained from refinery at the separation stage is Naphtha which is about 17-25 % depending on the source of the crude. Naphtha is the upstream raw material to produce

petrochemical products. As for natural gas, it is composed of methane, ethane, propane, butane and pentane. When these gases are separated, they can be used as upstream raw materials for petrochemical products.

1) Source of Raw Materials in Thailand

Naphtha in Thailand comes mainly from local oil refineries. In 1991, the three local refineries: Thai Oil, Esso, and Bangchak had a total production capacity of 250,000 barrels/day, which could still not satisfy the local demand for fuel. Also Naphtha was not yet required, and was all returned to the process to produce fuel oil. Later, Shell and Caltex refineries began to operate and Naphtha would be available as raw materials for petrochemical.

Naphtha can also be obtained from condensate which was available at 22,000 barrels/day. This condensate could produce 250,00-300,000 ton/year. However, Naphtha available in Thailand was not enough because each of the upstream petrochemical units required about 1 million ton/year.

The local natural gas is sufficient to feed the National Petrochemical Corporation. But due to limited reserves and high cost, it is not suitable to be used as upstream raw materials for petrochemical in the future.

2) Source of Raw Materials Overseas

The biggest producers of Naphtha were the U.S.A., the Middle East, and South East Asia including Singapore. As all these producers had high refinery capacity, there was no problem in procuring Naphtha. However, the production capacity in Asia was expanding, particularly Korea. This would raise the demand for Naphtha that could affect the prices in the future.

The raw materials for intermediate and downstream are ethylene, propylene, which could be produced in Thailand. But the volume could not satisfy the local demand. However, as there was surplus products overseas with favourable prices, there was no problem of raw materials procurement both in quantity and sources of importation. The only problem is the ethylene which required a particular storage tank and port of unloading.

2.1.6 PRODUCTION TECHNOLOGY

Petrochemical industry is a complex industry which requires high technology. In the early stage, Thailand has not much developed the technology of this industry, and relied on buying foreign technology at high cost. The important sources of this technology were the USA, European countries, and Japan.

When the NPC1 project started, Thai engineers began to acquire more experience in managing industrial plants, such as the plant of National Petrochemical Corporation producing propylene from propane. This plant was the first in the world to use the latest technology of UOP (U.S.A.). Thai staffs were then considered well capable of handling the technology in managing an industrial plant.

To develop its own technology, Thailand still needed a little more time. Thailand still relied on technology from foreign countries both in the form of joint-venture, licensing, or turn key projects, which made the operation cost about 25 % higher compared to the investment of the technology's owner. That was the weak point of this industry development.

2.1.7 PROBLEMS AND OBSTACLES

Limitation and problems which were obstacles to the development of petrochemical industry in Thailand were:

1) Technology

As stated earlier, Thailand lacks technology at the designing stage and has no technology of its own. Therefore, petrochemical plants in Thailand have to rely on foreign technology, resulting in high expenses and production cost.

Nevertheless, the beginning of NPC1 development allows Thailand to gain experience in production technology at a level, which would promote the development of other technologies in the future.

2) Staff

Petrochemical industry is a new industry in Thailand. Experienced personnel in this field are limited. Manpower is important to support the development of this industry. Educational institutions both public and private are giving importance in creating personnel in petroleum and

petrochemical fields. Particular the Petroleum and Petrochemical School of Chulalongkorn University has course for postgraduates including organization of seminars and research work. Another research body is the Petroleum and Petrochemical Research Centre of the Faculty of Engineering, Chulalongkorn University, which conducts similar works. Private institutions such as the Petroleum Institute of Thailand give support in personnel and technological development of petroleum and petrochemical industries.

3) Infrastructures and Basic Facilities

Petrochemical industry heavily relies on the readiness of infrastructures such as deep-sea ports for transportation of raw materials, storage tanks and silos, electricity, water, transportation system, and telecommunications, as well as utilities. The lack of readiness on this side would result in higher cost of production compared to other countries which are more prepared than Thailand. Although the public sector has invested or encouraged investment in infrastructures and basic facilities, there is tendency that the service fees will be high compared to other countries. The lack of preparedness is a great handicap to petrochemical development.

4) Raw Materials

Thailand has a disadvantage on the raw material side of this industry, that is petroleum. Although Thailand has some petroleum, the large part of which is natural gas, and the volume cannot meet the demand. Also, the petroleum fields are offshore making high drilling cost. Therefore, it can be said that this industry has to rely on imported petroleum. Problems would arise from the volume and prices in the world market that is changing according to the market trend. Moreover, the importation of raw materials is costly because of the shortage of equipment to facilitate the importation.

5) Government Policy

The public sector still has conditions and limitation for the investment in this industry. In the past, the Government designed the outline for the development and joined in the proceeding. On the one hand, this would promote the development of petrochemical industry. On the other hand this would limit the development, because the government required the budget for other plans and could not assign the budget for the full development of the petrochemical industry. This prevented the growth of the industry to be compatible with neighbouring countries which had full support of their government.

Another important problem of the development of this industry is that the production processes are not integrated, and cannot adjust itself to the world market trend. The development of this industry in foreign countries expands to large size and integrated production. Thus the industry had less business risk of losses as it can transfer prices of one product to another from the upstream to the downstream. This would help the business to survive during economic changes or moving market.

2.1.8 SUGGESTIONS

1) The Public Sector

1.1) As the government is the authority to design the plan for the petrochemical industry development, including assigning the producers and prices at each step, when any of the producing units has problem, the state authority concerned should join in to solve the problem quickly, so that other units are not affected by the event. In fact it must be admitted that the government system has many restrictions which hamper as quick actions as the private sector is able to take. Therefore, the government should only support and issue policy for the private sector, and let the industry grow naturally.

1.2) The state should give full support to reduce production cost, by granting promotional privilege as follows:

1.2.1) Granting the highest benefits from taxes, be it exemption of income tax for eight years, or exemption of import duties for mechanical equipment. In the short term, the state will lose large income from taxes, but in the long term, the industry will be firm and will help other integrated industries to be more competitive. Particularly, the return to the government will be much higher than the taxes lost in the earlier stage.

1.2.2) In case of unfair competition from foreign producers, tax measure should be immediately taken to protect the local industry, or coordinate with the authority concerned with anti-dumping.

1.3) There should be more personnel who have experience in petrochemical industry on top of education. This includes government personnel who should receive training in or outside the country, so that they gain deep understanding to help them in the development of petrochemical industry.

2) The Private Sector

2.1) The lack of utilities including storage tanks that should be provided by the State requires heavy investment from the private sector which has to help itself. The expenses incurred make the production cost higher than foreign countries.

2.2) The government policy is not steady, and changes are made without clear detailed study in the long term. This affects the industry, particularly for the projects already invested that are in the course of proceeding.

2.3) Dumping comes from outside Thailand, particularly from big producers of each product. The aim of the dumping is to bar out local projects from existence, which is an obstacle for the development of this industry, and the government has no effective measures to improve this situation.

2.4) The production capacity of some products is higher than the local demand, which increases the competition, especially in case of promotional privilege.

3) Tendency of Future Development

3.1) This industry has the tendency towards higher competition in East Asia. Therefore, the petrochemical industry in Thailand must develop its efficiency to gain strength to compete with foreign countries in the long term. One way to strengthen the industry is the development towards integration including development in conjunction with the oil refinery industry in Thailand, so as to create a stable source of raw materials.

3.2) Upstream raw materials also directly affect the production. Therefore, there should be flexibility in using various raw materials for further development, when prices and volume change, particularly for upstream petrochemical units.

2.2 HISTORY OF THE AROMATICS (THAILAND) PCL

CHRONICLE OF EVENTS

December 25, 1989 Establishment of the Aromatics (Thailand) Co., Ltd. At first, shareholders included the Petroleum Authority of Thailand with 25%, Thai Oil Co., Ltd.

with 40% and Exxon Chemicals Eastern Co., Ltd. with 35%.

- January 7, 1992* The government approves the amendment of the original Aromatics project design to include the reformer unit. The Cabinet also approves the Petroleum Authority of Thailand's assumption of 100% share in the venture.
- November 4, 1993* Securities One Public Co., Ltd. is contracted as an advisor to transform the company into a public company and for its eventual listing in the Stock Exchange of Thailand, in accordance with the government policy.
- February 1, 1994* Commencement of construction of the Aromatics and the Reformer units, Thailand's first aromatics production complex at Map Ta Phut Industrial Estate with a completion time of 36 months.
- September 27, 1994* Formal signing of the construction agreement with contractors group – Asia Badger Inc. of the United States, Sunkyong Engineering and Construction Ltd. of Korea and Nissho Iwai Corp. of Japan to build the aromatics and reformer units.
- October 28, 1994* The company sign the US\$453.3 million loan agreement for the cost of the project construction.
- December 29, 1994* Sale of 29.5% of the original shares of the company's registered capital of 2,000 million Baht to three institutional partners, as follows: 15% to Siam Cement Public Co., Ltd.; 9.5% to Ban Pu Public Co., Ltd. and 5% to The Bureau of the Crown Property.
- March 24, 1995* Increasing registered capital from 2,000 million Baht to 4,000 million Baht and transforming the company into a public company with the name of The Aromatics (Thailand) Public Company Limited (ATC).
- May 24, 1995* Sale offer of 51 million shares at par value of 10 Baht per share to institutional investors at 25 Baht per share.

- October 17, 1995* The Securities Exchange Commission grants approval for the company to sell the newly issued ordinary shares to the public.
- November 8-10, 1995* The Company sells 54.05 million shares at 30 Baht per share to the public. Shareholders include the Petroleum Authority of Thailand 44%, Siam Cement Public Co., Ltd. 15%, Ban Pu Public Co. Ltd., 9.5%, The Bureau of the Crown Property 5%, Institutions 12.75% and the public 13.75%.
- January 25, 1996* The Stock Exchange of Thailand grants permission for the company to list 399,050,000 shares with a par value of 10 Baht per share in the Stock Exchange of Thailand in the Chemical and Plastic Sector.
- July 9, 1996* The Board of Directors of the company passes resolution approving the company's 34% equity participation in a joint-venture with Rayong Petrochemical Corporation Ltd. to produce Styrene Monomer and also to expand output capacity of the aromatics plant through a debottlenecking process. The Debottlenecking program will cost approximately 1,900 million Baht and is designed to increase the plant's capacity by 20-30%.
- July 31, 1996* The plant passes the 20 million man hours of construction work mark without a single accident, a world construction safety record which has been entered into the Korean Guinness Book of Records.
- October 17, 1996* Construction completes at the aromatics and reformer units. The company issues Certificate of Provisional Acceptance to construction contractors. The plant is ready for test-run.
- November 25, 1996* Enters into a joint-venture agreement for the establishment of Rayong Petrochemical Corporation Ltd. (RPC) to produce Styrene Monomer. RPC has a registered capital of 875 million Baht.
- Signs agreement to sell 160,000 metric tons per year of Benzene to the Rayong Petrochemical Corporation Ltd. for a term of 10 years in which

120,000 metric tons per year is under a Take or Pay agreement.

January 31, 1997 Takes delivery of the finished Aromatics and Reformer plant by issuing Certificate of Acceptance to construction contractors.

2.2.1 THE DEVELOPMENT OF ATC

When natural gas was discovered in commercial quantity in the Gulf of Thailand in 1980, the Thai government envisaged a master plan to maximize its utilization to the fullest extent for the development of the national economy. As a result, plans for the development of the National Petrochemical Complex 1 (NPC1) and thereafter the National Petrochemical Complex 2 (NPC2) were respectively implemented. NPC2 was divided into the Upstream, Intermediate and Downstream phases. The Upstream phase consists of the Thai Olefins Co., Ltd. and the Aromatics (Thailand) Public Co., Ltd. which are bound under a long-term sale contract to supply each other with certain by-products of their individual outputs, for feedstocks.

The Aromatics (Thailand) Public Co., Ltd. was established, with government support, on December 25, 1989 with the objectives of producing and selling Aromatics, the Upstream raw materials to be used as feedstocks for the Intermediate and Downstream industries for the manufacture of a multitude of essential products for everyday uses. The government, therefore, designated The Aromatics (Thailand) Public Co., Ltd. as a project of the National Petrochemical Complex 2 in the National Economic Development Plan.

The company began construction of Thailand's first Aromatics production plant, which consists of the Aromatics and Reformer units, on February 1, 1994. The construction progresses according to plan with meticulous efficiency. The company issued the Certificate of Provisional Acceptance to the construction contractors on October 17, 1996 attesting that the installation of all machinery, equipment and controlling systems had been certified as consistent with the prescribed specification in the contractual agreement and ready in all respects for a trial run.

The contractors had effectively conducted the statutory performance test run from which the output had been established as meeting the specified quality, quantity and process efficiency according to the contract specifications and the Technology Patent Agreement in all respect.

Upon the successful performance test run, the company issued the Certificate of Acceptance to the contractors on January 31, 1997. Every aspect of the plant therefore met the design specification and the plant began to produce Aromatics product in commercial quantity.

The construction time of the plant was set at 36 months after its start on February 1, 1994 under a Lump Sum Turn Key contract, at a cost of US\$ 4,466.30 million with a contingency provision of US\$ 448.55 million for a total budgeted cost of US\$ 514.83 million. The actual cost of construction came to US\$ 488.80 million, a saving of US\$ 426 million or 5.06% below budget.

Working closely with consulting engineers, the company kept construction works in progress under effective supervision and as a result, the project achieved a world records of perfect construction safety, with over 23 million man hours of work and not a single accident that caused a disruption in work schedule.

As the founding objective of the Aromatics (Thailand) Public Co., Ltd. is to set up and operate Thailand's first Aromatics plant, under the master plan to develop the National Petrochemical Complex 2 in the Eastern Sea Board Development Project. The company's Mission Statement is:

“Fulfilling the country and the regional growth for the needs of aromatics products as part of the national petrochemical industry development by emphasizing efficiency, profitability and social responsibility.”

In accordance with the Mission Statement under the prevalent economic and social environment, the company has set its Corporate Vision and Direction to the company's mission statement with the goal of maximizing its earning potentials to provide favourable returns on investment for its shareholders, as follows:

Corporate Vision

Concentrate upon expansion and investment projects that are interdependent which will result in the progressive reduction of production cost

Promote the use and development of new technologies to increase management and production efficiency.

Direction

Become aromatics producer with low cost in production

Utilize high technology in production and management process.

Development organization into an elite world class corporation.

Engage in business that would promote growth of the company and reduce risk of revenues fluctuation

Create business synergy between companies in the shareholder group.

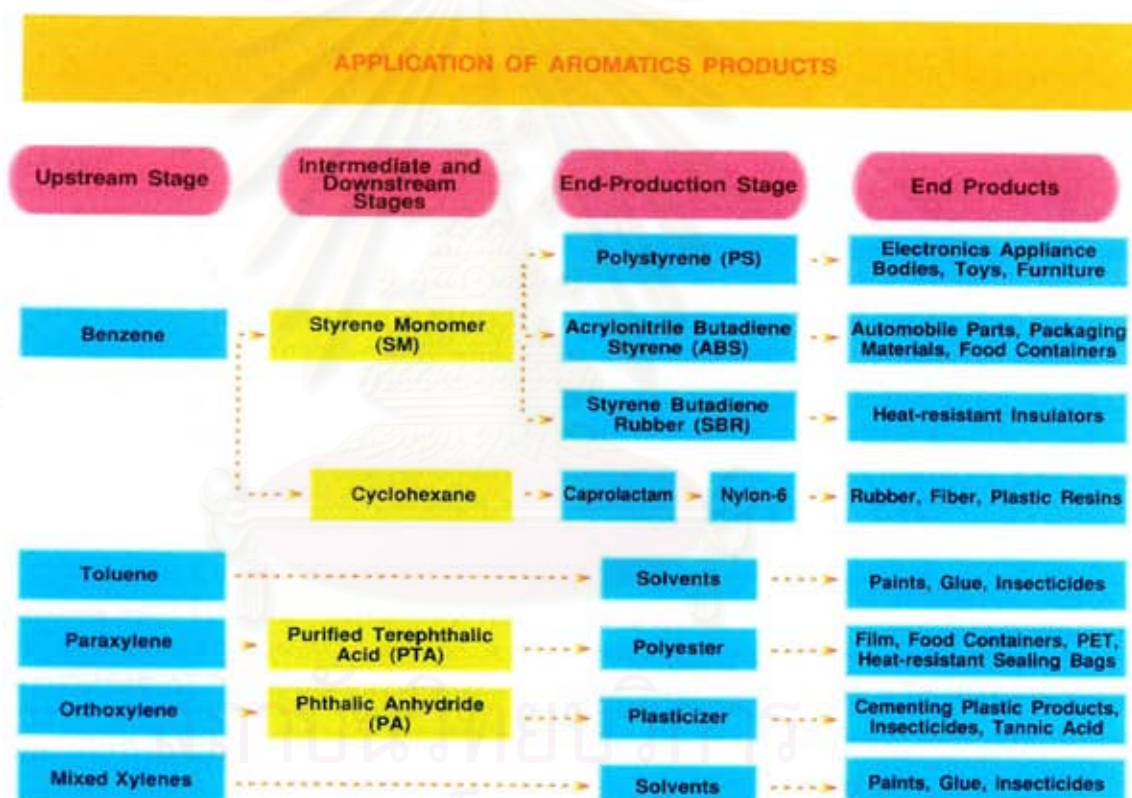
Become the leader in quality of products and service.

Expand business base into a fully integrated petrochemical producer.

Increase revenue with value-added processing on products.

Figure 2.1

Application of Aromatics products



Source: Company Profile of ATC, 1996.

2.2.2 OPERATION RESULTS

The year 1996 has proved to be another year of accomplishment for the company. It was the year the company had successfully completed the construction of Thailand's first aromatics and reformer plants to commence commercial production in 1997. Management of the company's finance had achieved highly satisfactory results. The project to expand the production capacity has already been initiated according to plans. The company had also started a joint venture to produce Styrene Monomer, an Intermediate industry which uses aromatics as raw material, to consummate the industrial cycle: investment, Production and offtake. At the same time, personnel and technological development programmes as well as the formulation of investment and marketing plan have proceeded according to plan. Operational activities to be reported are:

1. Finance
2. Production
3. Sales and Distribution
4. Development Plans of the Future

Finance

The company had conducted its financial activities in line with the loan agreement with lending institutions in effecting the draw downs of the US\$420.3 million credit facilities for construction work in 1996 under the terms of the construction and loan agreements. Additionally, the firm had obtained consent from lending institutions to invest in other projects such as the joint venture for the establishment of a Styrene Monomer plant with Rayong Petrochemical Corporation Ltd. The company has also acted as coordinator in arranging a financial package for RPC.

As for the company's capital fund, after becoming a public company in 1995, the company listed its shares in the Stock Exchange of Thailand on January 25, 1996. Afterward, the company had effected the distribution of 950,000 shares of the company's directors and management on May 27, 1996. The registered capital of the company now stands at 4,000 million Baht.

In our financial management, during 1996 the company had made judicious investment, with consent from its lending syndicate, with funds from capital increase and loans which were earmarked as payment for plant construction, but not yet due. Thus, the company gained 370 million baht in revenue from interest earned. Accordingly, accrued losses were completely eliminated in the third quarter of 1996 and in turn the company has now realized an accrued profit of 20 million Baht.

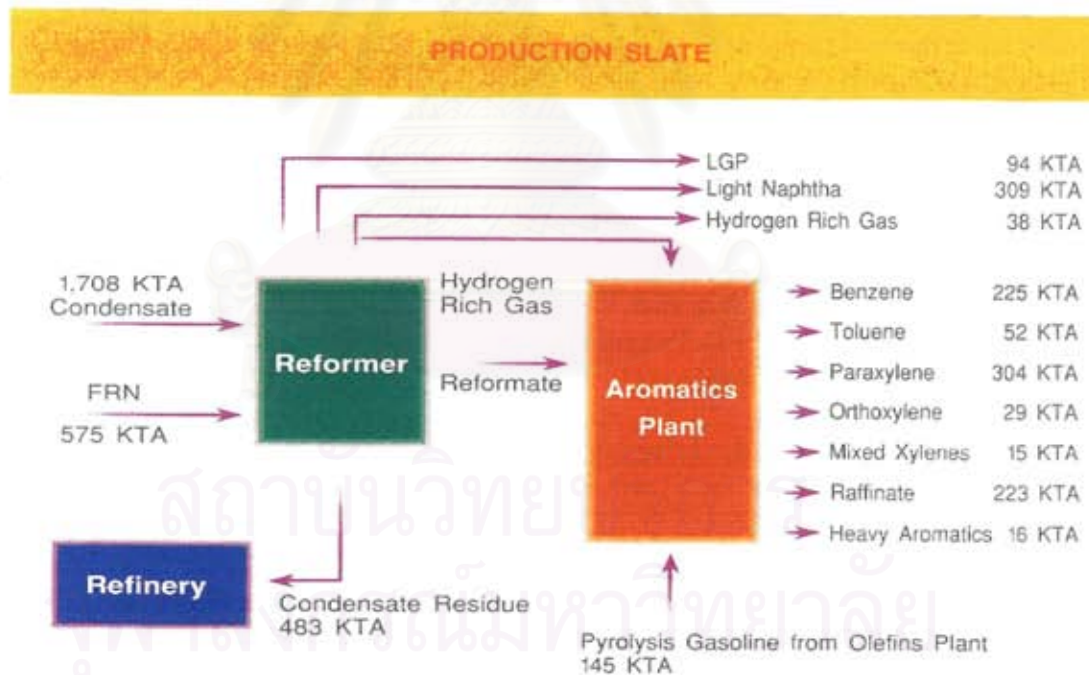
Production

Construction of the production plant was completed on October 17, 1996. After a successful trial run, some products have been delivered to customers since December 1996. Commercial production is to begin by February 1997, with an output rate of 85% and 90% of capacity in 1997 and 1998, respectively. From 1999 onward, output rate will be increased to 95% of capacity.

The production range includes Benzene, Toluene, Paraxylene, Orthoxylene and Mixed Xylenes. The by-products group consists of Light Naphtha, Raffinate, LPG, Hydrogen-Rich Gas, Condensate Residue and Heavy Aromatics. The products and by-products are the raw materials for Intermediate and Downstream producers. Meanwhile, the main raw materials for ATC plant are Condensate from the Gulf of Thailand, Full Range Naphtha from domestic oil refineries or imports and Pyrolysis Gasoline from Thai Olefins Co., Ltd.

Figure 2.2

Production Slate of ATC



Note: Figures show production capacity according to design specification [unit : 1,000 tons per year]

Source: Company Profile of ATC, 1996.

The advanced technology used by the Aromatics (Thailand) Public Co., Ltd. is another strong point of the country's first aromatics processing plant. The plant incorporates two individual petrochemical plants— the Aromatics and the Reformer units— which have complementary processes. The Reformer Unit transforms chemical properties of Hydro-Carbon in various formations in the raw materials into a more aromatics rich state. In the next phase, the Aromatics Unit takes over to further enrich the aromatics properties of the output from the Reformer Unit and then separates the various aromatics derivatives into different products.

All the technical processes at the plant, except for the Mercury Removal Unit which employs the French IFP Technology, use the well proven technology of UOP Inc. Both firms are respected leaders in petrochemical industry technology. The whole production process system of the company is fully integrated, characterized by built-in flexibility which enables the choice of raw materials for a particular production batch: either condensate, or Naphtha, or a combination of the two, whichever offers the most cost-effective output.

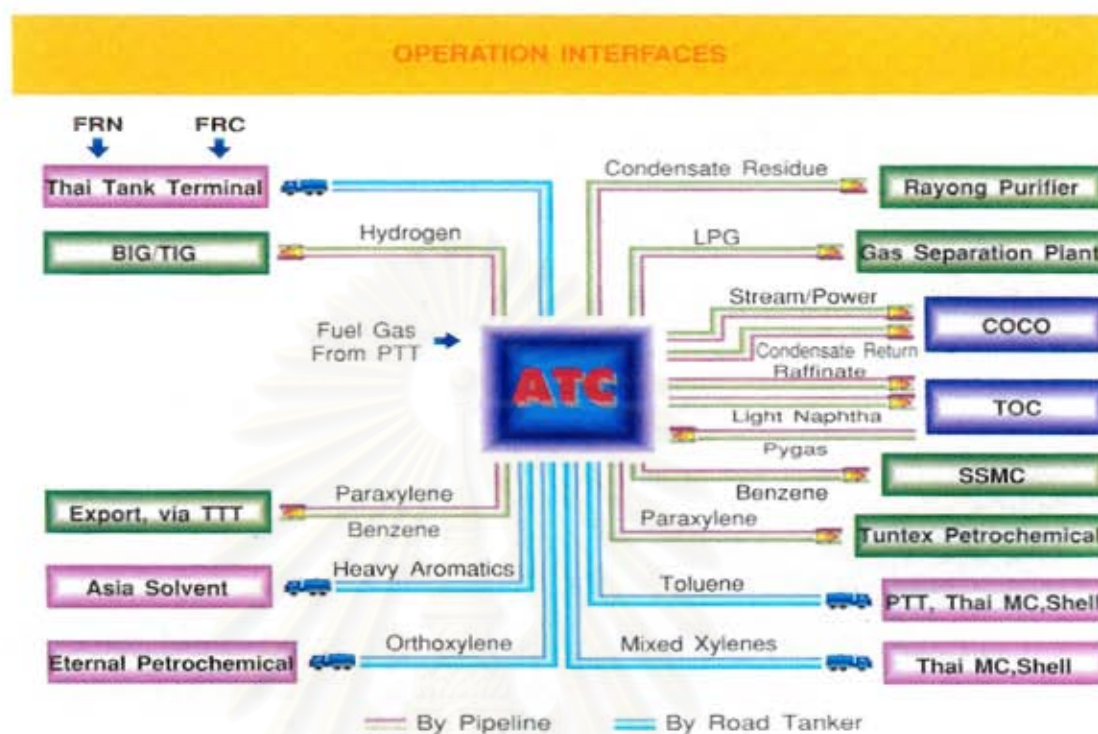
Sales and Distribution

Sales of the main products of The Aromatics (Thailand) Public Co., Ltd.— Benzene, Paraxylene, Orthoxylene and Mixed Xylenes— are made through the Petroleum Authority of Thailand under fixed contract. The company will sell the products to the Petroleum Authority of Thailand but will deliver products directly to buyers. The contact is a long-term underwriting agreement, in which the Petroleum Authority of Thailand guarantees to purchase up to 80% of the contracted amount.

For the by-products, the company has made long-term contract for the sale and distribution of Condensate Residue, Light Naphtha and Liquefied Petroleum Gas through the Petroleum Authority of Thailand with ATC making direct delivery to the PTT's customers. For other by-products, a sale contract has been made with the Asia Solvent Co., Ltd. for the sale of Heavy Aromatics and with Thai Olefins Co., Ltd. for the sale of Raffinate.

During the plant trial runs, since October 1996, the company was able to sell a limited amount of aromatics products to end users. These include Light Naphtha, Raffinate and LPG. The deliveries, made in the middle of December, totalled 6,286 metric tons with a value of 35million Baht.

Figure 2.3
Operation Interfaces of ATC



Source: Company Profile of ATC, 1996.

In January 1997, the company started producing standard quality aromatics products in every category. Approximately 59,810 metric tons or 411 million Baht of aromatics products were sold to local and foreign buyers.

To prepare for the increased output of Condensate Residue, the aromatics by-product, which will come from the increased use of Condensate as the raw material for production ahead of original plan, the company has carried out negotiations with prospective buyers to arrange for the sale of the increased stock. In addition, a transportation arrangement had been made with Thai Tank Terminal Co., Ltd. to deliver Condensate Residue by tanker trucks to buyers to increase delivery flexibility.

The company had communicated with other companies in the Petroleum Authority of Thailand group to find potential opportunities to

promote group synergy. As a start, a guideline has been established for the joint utilization of storage tanks, delivery pipeline, spare parts and human resource. This includes coordinated corporate expansion plan.

Table 2.8
PRODUCT OFFTAKERS

Type	Production	Offtakers
Benzene	234,000	Siam Styrene Monomer Co., Ltd.
Toluene	55,000	The Shell Company of Thailand Thai MC Co., Ltd.
Paraxylene	335,000	Tuntex Petrochemical Co., Ltd.
Orthoxylene	29,000	Eternal Petrochemical Co., Ltd.
Mixed Xylenes	16,000	The Shell Company of Thailand Thai MC Co., Ltd.
Condensate Residue	586,000	Rayong Purifier Co., Ltd.
Light Naphtha	375,000	Thai Olefins Co., Ltd.
Raffinate	230,000	Thai Olefins Co., Ltd.
Heavy Aromatics	17,000	Asia Solvent Co., Ltd.
LPG	89,000	Petroleum Authority of Thailand

Source: ATC's Annual Report 1996

Development Plans of the Future

The year 1997 saw the first step in the proud beginning of the Aromatics (Thailand) Public Co., Ltd. to become the first aromatics producer of Thailand under the NPC2 project, and to have a major role in pushing the development of the country's petrochemical industry towards world market capability. While current competitive conditions have intensified to a high pitch in all fronts, be it trade restrictions, tariff adjustments and even petrochemical industry liberalization at home, the company has set its corporate vision and direction and laid a dynamic policy for expansion and development.

In the past year, the company has initiated several expansion and development projects as follows:

□ **Expansion project of output capacity by modifying present production system**

Demand growth for aromatics in Thailand and the region continues to rise, estimated by the Petroleum Institute of Thailand at 10% to 15% per year up to 2002. To meet this projected demand, and in accordance with the company's strategy as a low-cost producer to increase raw material supply for various prospective projects of the company, the company is planning to raise production capacity by 20-30% through a debottlenecking project. The company has contracted a consulting firm to conduct a feasibility study and prepare the detailed plan. Implementation of the debottlenecking project is targeted to be completed for full operation in the first quarter of 1999.

□ **Styrene Monomer Production Project**

Styrene Monomer is an important downstream product of Benzene. It is used as the raw material to produce Plastic Polystyrene pellet and many derivatives for the manufacture of a wide variety of items used in daily life.

The demand for Styrene within the Southern Asian region, will grow at 6% per year from 1995 to 2000. And although half of the world's output lies within the region, the total demand will not be fully met until 2005. For Thailand, the growth per year has been rising continuously and expected to be 25.5% from 1995 to 2000. And even with the opening of Styrene Monomer plants – firstly Siam Styrene Monomer company, with an output capacity of 200,000 metric tons a year and scheduled production in 1997, and secondly the Industrial Petrochemical Thai Co., Ltd. with a capacity of 180,000 metric tons in 1998 – the combined output is still not sufficient to supply local demand. Thus the situation highly warrants the opening of a third plant.

The Aromatics (Thailand) Co., Ltd. is a producer of Benzene, which is the main raw material for Styrene Monomer production. With its policy to expand vertically into full line production of Upstream and Intermediate petrochemical products, on May 25, 1996, the company entered into an agreement with Rayong Petrochemical Corporation Ltd. (RPC) to construct a Styrene Monomer plant with an output capacity of 200,000 metric tons per year, starting in 1999.

RPC has a registered capital of 875 million Baht. Shareholders include the Aromatics (Thailand) Public Co., Ltd. with 34%, the Sri Thep Thai (STT) Group with 24%, TOA Co., Ltd. with 24%, Grand Pacific Petrochemical Corp. with 14% and the United Machinery Co., Ltd. with 4%. Additionally, ATC signed a contract to deliver 160,000 metric tons of Benzene a year to RPC for ten years starting when RPC begins production.

The project is fundamentally a co-operation for mutual interest between Raw Material Supplier and Product Offtaker. The project not only constitutes a major distribution outlet for ATC's benzene production in the lead-in to the petrochemical industry liberalization in 1999 when the company's output capacity will also be expanded. Additionally, the increased domestic production of Styrene Monomer will help reduce import expenditures and, in a way, also strengthen the competitive position of the Thai manufacturing industry. This project is a reflection of the company's vision and the first step in its objectives to go into a full line of aromatics production with the highest efficiency, to serve the demand of the country and be a contributing factor in turning the Thai petrochemical industry into an exporter in the world markets.

□ PTA Production Project

One way to strengthen the competitiveness of a petrochemical industry is to achieve a fully integrated line of production. Therefore, apart from the production project of Styrene Monomer, which is a Benzene based product, with RPC, the company has planned to produce PTA. Similar to Styrene Monomer, PTA is an important petrochemical product in the economic development of the country as it is the raw material for various industries producing articles for various uses in everyday life.

PTA is used to make Polyester, a feedstock for various industries such as polyester fibres, packaging material, film sheet, and plastic for mould. Currently, the supply of locally produced PTA is still below local demand. Therefore, the company is planning to set up a PTA production project to help reduce imports and provide Thai industry with a firm raw material source to strengthen their competitiveness. This project is yet another step towards its objectives to complete a fully integrated line of business. Presently, the company has contracted Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public,Co.,Ltd., Chem Systems, 1996-1997. Inc. to conduct a feasibility study for the project.

2.2.3 BUSINESS, MARKETING AND DISTRIBUTION

1. Situation of Aromatics in 1998

➤ World Situation

In 1998, the worldwide aromatics industry including the Asian markets slowed down continuously from last year. The direct cause was the impact of the economic and finance crisis of the countries within the region since late 1997. This has resulted in a prolonged drop in demand for intermediate and downstream products. Notwithstanding, the world industry kept up its production level. Furthermore, a number of new aromatics plants in South Korea and Indonesia began their production in the fourth quarter, thus resulting in a great excess of aromatics products for the world markets. For Paraxylene alone, the annual production grew at an average rate of 12.40% during 1996-1998. Apparently, decisions for the new projects to expand capacity and set up new plants have been based on past economic, marketing, cost and profitability scenario. Moreover, demand growth has been on a continuous decline at the annual rate of 8.50% which is substantially lower than estimated. Consequently, the price of Paraxylene fell sharply.

The prices of aromatics products declined considerably in 1998 from the first to the third quarters. In the fourth quarter there was a slight rise in Benzene price in the U.S. Gulf Coast (USGC) and Southeast Asian markets because of the technical problems which affected the former aromatics plants production in USGC. This has resulted in a shortage in the spot market causing Southeast Asian prices to rise.

As for Paraxylene, the demand for Polyester, its downstream product, also declined. Consequently, resulting in the depressed demand for PTA products in general. In fact, PTA plants as well as downstream plants in the Polyester group cut production by 75% and under 70% respectively in 1998. Under the circumstances, prices of both PTA and Paraxylene, the upstream raw material for polyester, sank to a low level.

In addition, Southeast Asian markets saw a glut of Paraxylene due to the output of new plants in the region. Two new plants in South Korea began full production early in the year. The two were Sangyoung with an annual output capacity of 600,000 metric tons, and Hyundai Chemical with an annual output capacity of 400,000 metric tons.

It is anticipated that the price trend of the two main aromatics products would remain unchanged in 1999 due to continued economic and financial crisis in the region, despite full-scale joint efforts by all the countries in the area to resolve problems.

However, various commercial consulting institutions forecast that petrochemical product prices will take a turn upward early in the year 2000.

➤ Domestic Situation

The financial crisis that enveloped Asia in 1997 has suddenly altered the course of various economies in the region, including Thailand's, from a high growth trend to a deep recession. From the middle of 1997 to the present period, production and private investment have contracted sharply, as were the demand for plastic and chemical products. As a consequence, various expansion projects of the petrochemical industry had to be put on hold. Production was kept only at a level to meet anticipated domestic demand. The remaining surplus was exported to countries where there were still some demand for the products.

According to the predictions of several commercial consulting institutions, a general improvement will be seen in the early part of the year 2000. Investment projects which have been put on hold or shelved would be reviewed for activation. It is anticipated that by then expansion plans and new investment projects will be undertaken by the Thai petroleum industry.

As for the demand for aromatics products in Thailand, the growth rate has slowed down in 1998. Prevailing economic conditions have discouraged domestic downstream producers from pursuing expansion plans.

As a result, total consumption of Paraxylene in Thailand in 1998 was 257,000 metric tons, a 4.90% increase from 1997. Total Paraxylene output in Thailand in 1998 was 337,000 metric tons with The Aromatics (Thailand) PCL. Being the sole producer.

As for Benzene, the total domestic demand in 1998 came to 326,000 metric tons, an increase of 44.25% over the figure for 1997. This was due to the start up of the Styrene Monomer plant belonging to the Thai Petrochemical Industry Public Company Limited (TPI) which utilized Benzene as the main raw material. The TPI plant has an output capacity of 200,000 metric tons a year. There are two Benzene producers in Thailand – ATC and TPI – with a combined annual production in 1998 of 329,000 metric tons.

In 1998, Thailand was a net exporter of Paraxylene and Benzene to the Asian countries where demand existed. The countries were Taiwan, South Korea and Malaysia.

In 1999, Thailand should remain a net exporter of Benzene to the Asian countries considering that the newly opened Rayong Olefin Company Limited (ROC) has started production, while the domestic downstream industry will not increase production.

As for Paraxylene, Thailand is expected to remain a net importer. While the PTA plant of Siam Mitsui PTA Co., Ltd. has started commercial production, The Aromatics (Thailand) PCL. and the Exxon Chemical Thailand Co., Ltd. are the only two Paraxylene producers in the country. Paraxylene is expected to come from Japan, Singapore and South Korea.

2. Raw Materials Sourcing

Total raw materials required for the Company's production process in 1998 amounted to 1,396,632 metric tons at a total cost of US\$194.7 million. Of the total, 61.2% was sourced domestically and 38.8% externally. External sources included Indonesia, Yemen, Egypt and Iran, all of which supplied 64% of the raw materials under long term contracts with the remainder coming from spot markets.

2.2.4 CUSTOMER BASE EXPANSION

The Company proceeded with a customer expansion plan to raise product value, increase ways and means of product transportation and reduce impact on plant operating plans, i.e.:

- The Company signed a purchase and sale agreement with the Siam Mitsui PTA Co., Ltd. (SMPC) on April 30, 1998 for an annual total of 50,000 metric tons of Paraxylene.
- The Company discussed an agreement on the sales of Benzene with Siam Styrene Monomer Co., Ltd.

CHAPTER 3

AROMATICS COMPOUNDS & AROMATICS PROCESS

This chapter discusses the aromatics used since the old time. We will see in this chapter the discovery of aromatics various application reaching industrial scale, including synthetic dyestuffs marking the new era of synthetic products in replacement of natural products. Description is also given on the development of the sources of aromatics products.

3.1 AROMATICS COMPOUNDS

Aromatic compounds are defined as cyclic hydrocarbons in which the carbon skeleton is linked by a specified number of conjugated π -bonds. During the early days of industrial aromatic chemistry in the mid-19th century, the structure of aromatic compounds had not yet been elucidated. The name of this class of compounds is historically-based since the first members were obtained from aromatic, i.e. pleasant-smelling resins, balsams and oils; examples of this are benzoic acid, which was obtained from gum benzoin, toluene from tolu balsam and benzaldehyde from oil of bitter almonds.

The history of aromatic chemistry was closely linked to the development of coal carbonization to produce coke, gas and tar. Coke was mainly used as a substitute for charcoal in the production of pig iron, coal gas was used for lighting, and coal tar initially replaced wood tar for impregnating timber used in ship-building.

As early as 1584, the Duke of Brunswick recommended the application of 'desulphurized' coal as an alternative to charcoal for the production of salt. The first patent for the production of coke for use in blast furnaces for iron smelting was granted to Dud Dudley in England in 1622.

The first large-scale attempts to manufacture lighting gas were initiated by the French engineer Philippe Lebon in 1790. He degasified wood chippings in an iron retort on the grate of a kitchen stove and fed the resultant gas by pipe to other rooms, where it was burned in lamps. His discovery, which he called "Thermo-lamp", aroused great interest but never found practical application.

The real founder of gas engineering was the Scotsman William Murdoch, who carried out experiments in 1792 on the degasification of

hard coal. He lit his house with gas which he brought daily from the factory in containers.

The German philosopher and chemist, Johann Becher, is considered to be the discoverer of coal tar. In 1691, together with the Englishman Henry Serle, he obtained the English patent no.214 for the production of pitch and tar from coal.

The German privy councilor Winzler, known in England as Windsor, was particularly successful in marketing the idea of using coal gas for lighting and founded a number of gas companies. In London in 1813, Westminster Bridge was lit by gas from the *London & Westminster Chartered Light & Coke Co.*, established by Windsor. In 1819, he introduced gas lighting to Paris. Lighting with coal gas began in Germany in 1824 in Hanover, and 1826 in Berlin. The first gas works in the USA was already operating in Baltimore in 1802; gas lighting was introduced into New York in 1824.

The first distillation of gas-work tar from coal carbonization was carried out at Leith in Scotland in 1822. The tar oil was used in timber impregnation, while the distillation residue, called pitch, was employed in coal briquetting.

The key factor in the development of the tar industry was the accelerated growth of the railroad system. Tracks were laid on wooden sleepers, which were impregnated with coal tar oil to preserve them from rapid decay. The first railway lines started operation in England in 1825, and in Germany in 1835.

In spite of the demand for impregnation oil, by the mid-19th century, owing to the rapid growth in the production of gas for lighting and the tremendous development of the iron and steel industry, there was a considerable over-supply of coal tar. Although some of the tar could be used in the production of roofing tar felts and in carbon black manufacture, these applications were not sufficient to absorb all the tar being produced.

The first estimates of annual tar production from gas works in Europe date from 1884. Great Britain led the way with a production of 450,000 ton, followed by Germany (85,000 ton), France (75,000 ton), Belgium (50,000 ton) and the Netherlands (15,000 ton).

The parent compound of aromatics is benzene that was first discovered by Michael Faraday in 1825 in the condensed part of a lighting gas derived from whale oil and obtained some years later by Eilhard Mitscherlich by decarboxylation of benzoic acid (as calcium benzoate).

The occurrence of benzene in coal tar was first described by August Wilhelm v. Hofmann in 1845. John Leigh had already demonstrated to the British Natural Research Conference in 1842, that benzene is present in coal tar; this claim was not immediately published, however. Even before the discovery of benzene, Ferdinand Runge had found aniline and phenol in coal tar in 1834.

The composition of the aromatic mixture, coal tar, was still largely unknown up to the middle of the 19th century. As tar production grew, so analytical investigations increased.

In 1845, Hofmann went to London as Principal of the newly-founded Royal College of Chemistry, to continue his investigations at the original source of coal tar. Hofmann gathered a number of young chemists around him, who concentrated on investigating the reactions of tar components. London thus became the central point of aromatic chemistry.

One of the principal objectives of Hofmann's work was to synthesize quinine, at that time the only known agent effective against malaria. William Henry Perkin, one of Hofmann's youngest students, devoted a great deal of imagination to the synthesis of quinine. In 1856, Perkin tried to synthesize quinine by oxidation of N-allyltoluidine, but instead he obtained only a red-brown precipitate. As a model reaction Perkin chose to investigate the treatment of aniline sulphate with potassium dichromate.

On working-up the reaction mixture he produced a violet dyestuff; Perkin had synthesized the first tar-derived dyestuff, the mauveine. Within barely 18 months, together with his father and brother, he set up a factory in Greenford Green to manufacture aniline dyes, the first time that coal-tar dyestuffs had been produced on an industrial scale. By 1860, there were already five companies in England engaged in the production of synthetic dyes. Apart from Perkin, *Read & Holliday* should be mentioned among the founders of English companies, as they established the first subsidiary in the USA in 1861. Synthetic dyestuffs found a ready market, since to satisfy growing demand from the textile industry, 750,000 ton of natural dyes were imported annually into Great Britain alone.

Production of coal-tar dyes developed dramatically on the European continent too, following Perkin's discovery. In Lyons, France, in 1895, François Emanuel Verguin produced the red-violet fuchsin (Basic Violet 14) by oxidation of technical aniline, a mixture of aniline and toluidines. This dyestuff provided the basis for the production of coal-tar dyestuffs in France, and it is still important today. At the World Exhibition in London in 1862, the coal-tar dyestuffs industry celebrated great triumphs. The

thirteen prize winners were almost exclusively English and French dye manufacturers.

Following the pattern of England and France, new manufacturing facilities were set up in Germany for production of synthetic dyes. The first were established by existing natural-dye traders. In 1860, the dyestuff merchant Friedrich Bayer set up a fuchsin factory in Elberfeld. In 1863, Meister, Lucius and Bruning also began the production of fuchsin in Hoechst.

The growing demand from the dyestuffs industry for aromatics was met by the rapidly developing tar industry. The basis of tar refining was fractional distillation, firstly used by Charles Blachford Mansfield in 1847, for the production of benzene from coal tar on a large scale.

Lively competition developed among the European dyestuff producers. The race to produce alizarin was particularly dramatic. In 1867, Adolphe Wurtz and August Kekule had discovered that the sulphonic acid group in aromatics could be replaced by a hydroxyl group by alkali fusion. Perkin used this process to manufacture alizarin from anthraquinone, which up to this time was produced from madder. When he applied for a patent on his process, he learned that Carl Graebe and Carl Liebermann had already submitted an application for this product on 25th June 1859, just one day earlier than himself. However, Perkin did not give up, but developed a new process, which subsequently led to an exchange of licenses. In 1873, he produced 435 ton of alizarin, while German alizarin production had already reached 1,000 ton.

Just as madder extracts were used for red colouring, so indigo had been used since the old times as a blue colouring agent, especially in India. The source of indigo was woad, which was cultivated in Germany, mainly in Thuringia. In the 16th and 17th centuries, there were large woad plantations found in the area around Gotha, Erfurt and Weimar, which were abandoned when imports of indigo from India took over. Production of natural indigo was around 8,200 ton/year in 1885, with over half this dyestuff being produced in Bengal by biochemical decomposition from *Indigofera tinctoria*.

Synthesis of indigo was a particular challenge for dyestuff chemists in the second half of the 19th century. Adolf von Baeyer first successfully synthesized indigo in 1869, starting from o-nitrocinnamic acid. Since Baeyer's work was more directed to the elucidation of the structure of indigo, the synthesis he had discovered could not be applied economically on a large scale. Karl Heumann, at the Federal Polytechnic in Zurich, discovered a method of synthesis which was based on phenylglycine, which can be produced from aniline and chloroacetic acid. The yield from

this process, however, was still unsatisfactory. Heumann's second proposal used phenylglycine-o-carboxylic acid, obtained by first oxidizing naphthalene to phthalic anhydride.

The oxidation of naphthalene was carried out with chromic acid and chromates, regenerated by electrochemical reoxidation. This method was first used by the Farbwerke Hoechst. In 1891, it was accidentally discovered at BASF that naphthalene could be oxidized by concentrated sulphuric acid in the presence of mercury. In 1897, BASF introduced the first synthetic indigo to the market, followed shortly thereafter by Farbwerke Hoechst. Synthetic indigo rapidly replaced the natural product in the market in spite of harsh competition of the producers of natural indigo, especially of the Provence, France.

As a result of intensive research in the dyestuff sector by the turn of the century, around 15,000 dyes had already been patented in Germany. The largest portion were azo-dyes, obtained by coupling diazotized amines with suitable organic compounds.

Peter Griess, a student of August Wilhelm von Hofmann, living in England, discovered diazotization in 1857. In 1861, the first azo-dye, aniline yellow (Solvent Yellow 1) appeared on the market in England. A further milestone in the development of azo-dyes was Congo red, a substantive dye discovered by Paul Bottiger in 1884.

Production of dyestuffs initially followed empirical methods, but academic research established the scientific bases which gave a power to the German dyestuffs industry. Already by 1880, the German share in world dyestuffs production had reached one-half and in 1900 it exceeded 80%.

Concurrent with the rather haphazard discovery of the first coal-tar dyes, important scientific knowledge was being accumulated, which significantly advanced the understanding of the chemical reactions involved in the production of dyestuffs. In 1865 Professor Friedrich August Kekule of Bonn University proposed the ring formula for benzene, which provided the basis for understanding the essentials of aromatic chemistry.

On the basis of this progress in fundamental research in organic chemistry, the German dyestuff industry also enjoyed great success in the new field of synthetically-produced pharmaceuticals. Products discovered at the beginning of this development, and worthy of mention, are the antipyretics antipyrine (1-phenyl-2,3-dimethylpyrazolin-5-one) and phenacetin (p-thoxyacetanilide), as well as aspirin (acetylsalicylic acid).

Initially, coal-derived raw materials were the almost exclusive source of aromatics. However, beginning in the 1930's, the growth of the automobile industry brought petroleum to the forefront in ever-increasing quantities as a source of raw materials for monocyclic aromatics.

Alongside pyrolytic processes for the production of aromatics, this new development was accompanied by the introduction of catalysis. Even today, catalytic and purely thermal processes still complement each other in the production of aromatics.

3.2 AROMATICS OF ATC

Among the aromatics, three main products are processed by ATC which are benzene, toluene and xylenes. Each of these products has been known and used since early 19th century. The following is a brief narration of the products:

3.2.1 Benzene

Benzene was discovered in 1825 by Michael Faraday during the pyrolysis of whale oil. Although benzene aromatics were being used as solvents for rubber as early as the 19th century, the development of the industrial use of benzene began when Michael Faraday treated benzene with nitric acid and produced nitrobenzene, a base material for aniline-derived dyestuffs such as Perkin's mauvine. A further milestone in the history of industrial applications of benzene was the production of phenol, which was used during World War I as a feedstock for picric acid, an explosive. However, picric acid is now of little commercial importance.

Of far-reaching and more lasting importance for the industrial use of benzene was the commencement of the production of styrene in 1929, and the hydrogenation of benzene to cyclohexane as a feedstock for nylon production, after the discovery of nylon synthesis from hexamethylenediamine and adipic acid by Wallace H. Carothers of *Du Pont* in 1935.

3.2.2 Toluene

Like benzene, toluene was also discovered in the pyrolysis of a renewable raw material, by Pierre J. Pelletier and Philippe Walter in 1837, during investigations into the by-products from the manufacture of illumination gas from pine resin. The name is derived from the small harbour-town of Tolu in Columbia, where Tolu balsam is produced. Henri

Saint-Claire Deville was the first to produce toluene, by destructive distillation of this renewable raw material in 1838.

Although the presence of toluene is detected in coal tar in 1849, it had only limited application at first as a chemical raw material. However, this changed in World War I, when toluene was used in the production of the explosive trinitrotoluene (TNT). Up to the turn of the century, coal tar and coke-oven benzole remained the only source of toluene, but during the World War I it was also produced by fractional distillation of aromatic crude oils from the Far East.

3.2.3 Xylenes

Xylenes were also first discovered during pyrolysis of renewable raw materials, by Auguste Cahours in crude wood spirit, in 1850. The name of xylene was therefore taken from the Greek word for wood. In 1855 H. Ritthausen and A.H. Church found xylenes in coal tar.

The importance of xylenes as major industrial chemicals began with the rise of the plastics industry in the 1920's and 30's, when polyesters were developed from paraxylene. From mid-1950's orthoxylene also gained prominence as a raw material in the production of phthalic anhydride, alongside coal-derived naphthalene. Before these developments, xylenes were mainly used as solvents or as components of fuels.

After introduction of the aromatics products, now we will discuss the complex production process used by ATC to produce its main products. Description is also made of ATC reformer plant for treatment of raw materials to increase aromatics.

3.3 ATC PRODUCTION PROCESS

ATC production process consists of 2 main units: Reformer units and Aromatics units.

3.3.1 REFORMER UNIT

Here the structure of hydrocarbon group components (paraffins and naphthenes) is transformed to increase aromatics. The hydrocarbon

obtained is called reformat and will be used as raw material for aromatics plant.

Raw Materials

Condensate	1,180,020	ton/year
Naphtha	450,650	ton/year

Products

Reformat	761,900	ton/year
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Other products obtained are LPG, hydrogen rich gas, light naphtha and condensate residue.

Reformer unit consists of five main units.

1. Mercury Removal Unit (MRU)

The condensate from the Gulf of Thailand contains a high level of mercury, which is harmful to the catalyst used in the production process. The mercury decreases the quality and shortens the life of the catalyst. Therefore, the mercury must be removed before entering the production process.

Mercury removal is carried out in two steps. At first, the hydrogenolysis reaction is introduced to transform the mercury from ionic and organic into elementary state which can easily be removed by absorption at the second step.

2. Feed Fractionation Unit

At this unit, heat is used to split mercury-free condensate and full range naphtha into various products. The fractionation is carried out on the principle of the difference in the boiling points of the product components. The products obtained respectively from the head down to the bottom of the fractionation column are LPG, light naphtha, heavy naphtha and condensate residue.

3. Heavy Naphtha Hydrotreating Unit

At this unit, the naphtha quality is improved by introducing hydrogen into the product. Hydrogen reacts directly to sulphur on the

catalyst packed bed in the reactor and produces hydrogen sulphide mixed in the off-gas that can be used in the plant as a fuel. The hydrotreated heavy naphtha will then be transferred to the platforming unit.

4. Platforming Unit

This is the process to change the structure to increase aromatics by using catalyst. The resulted reaction is heat absorption. As this requires high temperature, four reactors are built one on top of the other, with heaters installed between the four reactors. The product obtained is called platformate containing high volume of aromatics and hydrogen rich gas for use in the reformer and aromatics plants.

5. Continuous Catalytic Regeneration (CCR) Unit

This is part of the platforming. Its function is to adjust the quality of the used catalyst in a continuous manner. The generator is divided in 4 zones:

- 1) The burning zone where the coke accumulated on the surface of the catalyst is burnt out by hot gas with low oxygen.
- 2) The chlorination zone where the catalyst chloride balance is adjusted by feeding chloride together with heat, moving in the cross direction with the catalyst flow.
- 3) Drying zone where the hot dry air moving in the cross direction with the catalyst flow, in order to removed steam (humidity) resulted from the burning.
- 4) Reduction zone is to stimulate the catalyst in the purified hydrogen rich gas ambience, to render the catalyst proper for the use.

Hydrogen rich gas is used to transfer the catalyst between the reactors and the adjustment column. The catalyst flows into the reactors by force of the earth gravity.

3.3.2. AROMATICS UNIT

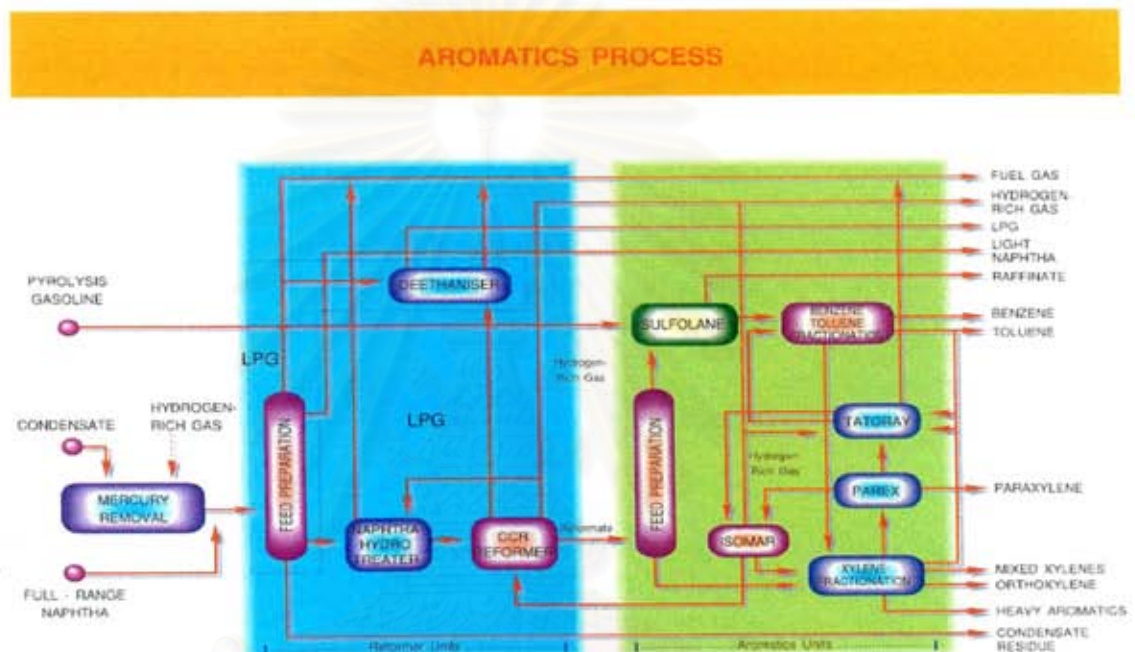
Aromatics units consist of seven main units.

1. Feed Preparation Unit

This unit separates reformat in two parts. One part is hydrocarbon lighter than C8 that has been treated from various oxygen components before transferring to sulpholane unit to protect against damage to catalyst and sulpholane, another part is hydrocarbon from C8 upward that has been treated at Clay Tower before going to Xylene Fractionation.

Figure 3.1

Production Process of ATC



Source: Company Profile of ATC, 1996.

2. Sulpholane Unit

This unit separates aromatics (benzene, toluene and xylenes) from pyrolysis gasoline and reformat from raw materials receiver unit. The separation is made by extraction with sulpholane to obtain raffinate which is a by-product to be sent to olefins plant. The aromatics obtained from extraction is then treated at the clay tower before going to benzene-toluene fractionation unit.

3. Benzene-Toluene Fractionation Unit

This unit separates pure benzene and pure toluene from xylene mixture. The fractionation is made by steam heat. Part of the toluene obtained serves as feedstock to tatoray unit, while xylenes and heavy hydrocarbon are sent to xylenes fractionation unit.

4. Tatoray Unit

This unit upgrades benzene and xylenes by changing the structure of toluene and C9 aromatics using heat from fired heater. This generates reaction on the bed of catalyst, in a hydrogen atmosphere transferred from Reformer Plant, forming benzene, xylene and heavy hydrocarbon which are then returned to benzene-toluene fractionation unit.

5. Xylene Fractionation Unit

By heat from fired heater, this unit separates the product in mixed xylenes, orthoxylene, and heavy aromatics which is a by-product for oil refinery. Moreover, this unit also prepares feed for parax unit and tatoray unit.

6. Parax Unit

The parax unit separates paraxylene from xylenes by absorbing paraxylene from a bed of absorbent. Then paraxylene is extracted from the absorbent with desorbent. Subsequently, the desorbent is extracted to obtain paraxylene.

7. Isomar Unit

This is a unit to upgrade of paraxylene by readjusting the balance of xylene and changing the structure of ethylbenzene, in a hydrogen atmosphere transferred from the tatoray unit and the reformer plant, on a bed of catalyst. The reaction results in the increase in paraxylene. The substance is then transferred to the clay tower to remove dirt and sent back to xylene fractionation unit.

CHAPTER 4

FEEDSTOCKS, MAIN PRODUCTS AND BY-PRODUCTS

This chapter discusses the various raw materials that ATC uses as feedstocks in its production process. Description is made on the characteristics of each of the raw materials, how they are obtained, what are their sources of procurement. Then each main product and by-product is explained in details.

4.1 FEEDSTOCKS USED BY ATC IN THE AROMATICS PRODUCTION PROCESS

Since the discovery of natural gas in the Gulf of Thailand in 1970, the development of petrochemical industry has been given more importance. This development is in response to the domestic demand of plastic products in various forms, synthetic fibres and other petrochemical products, which increases every year. Moreover, this will save billions of Baht in foreign exchange lost in importing raw materials.

As for the aromatics and reformer plant which is part of the second phase of the petrochemical industry development project – NPC2, this is an upstream petrochemical industry that produces aromatics for intermediate stream and downstream industries which produce end products for consumption.

Generally, aromatics derive from various raw materials:

1. Pyrolysis Gasoline (Pygas) which is a by-product hydrocarbon obtained from Ethylene and Propylene processing by Olefins plants.
2. Catalytic Reformate which is a hydrocarbon obtained from reformer unit which processes naphthenes and paraffins to produce aromatics by using catalyst.
3. Naphtha which is a hydrocarbon obtained from oil refinery.
4. Coal Tar and Coke-oven light oil.

For ATC, the analysis result of the different components of the full range comes from two companies:

- JGC Assay (1993)

- Unocal Assay (1993)

ATC has designed the process according to JGC Assay, but UOP has guaranteed the production efficiency by relying upon Unocal Assay.

Four cases of Designed Process have been undertaken:

Case A	JGC Assay	-	Condensate Plus Naphtha
Case B	JGC Assay	-	Condensate Only
Case A	Unocal Assay	-	Condensate Plus Naphtha
Case B	Unocal Assay	-	Condensate only

For ATC, the company utilizes three categories of materials for feedstock:

1. Condensate from the natural gas fields in the Gulf of Thailand
2. Full Range Naphtha (FN) and
3. Pyrolysis Gasoline (Pygas) from TOC Olefins Plant

1. THAI CONDENSATE

The condensate used by ATC is Thai condensate from the Gulf of Thailand, supplied by UNOCAL Thailand Co., Ltd. This condensate is produced on the offshore platform and conveyed by undersea pipeline to the floating storage off-loading unit (FSO). Then it is transported by tankers to the Thai Tank Terminal (TTT) at Map Ta Phut for storage in huge condensate tanks. The condensate for ATC is conveyed from the TTT condensate tanks to ATC tank farm, ready for use. The storage capacity at ATC tank farm is about 5,250 tons enough for about 24-44 hours of continued operation depending on the production capacity.

One weak point in the Thai condensate is that it bears about 2000 ppb of mercury and 90 ppb. arsenic. Mercury Removal Unit (MRU) must remove these materials, before going into the process. ATC uses the IFP Mercury Pretreatment Unit to separate Hg and As from the condensate.

The composition of the condensate before entering the MRU is shown in Table 4.1.

Table 4.1

Composition of Thai Condensate Ex-TTT Tank Farm

Component	Mol. Wt.	Kg mol/hr	Vol %	Kg/hr
H ₂	2.02			
C ₁	16.04			
C ₂	30.07			
C ₃	44.09	12.35	0.87	544.51
i-C ₄	58.12	46.03	3.26	2675.26
n-C ₄	58.12	85.77	6.07	4884.95
i-C ₅	72.15	90.44	6.40	6525.25
n-C ₅	72.15	85.60	6.06	6176.04
C _{5N}	70.13	10.82	0.77	758.81
C _{6P}	86.17	139.5	9.88	12020.72
Methyl-C _{5N}	82.14	45.89	3.25	3769.40
C _{6N}	82.14	37.58	2.66	3086.82
C _{6A}	78.11	49.94	3.54	3900.81
Dimethyl Pentane	100.20	6.64	0.47	665.33
Methyl Nexane	100.20	28.59	2.02	2864.72
3-Ethyl Pentane	100.20	1.77	0.13	177.35
n-C _{7P}	100.20	49.85	3.53	4994.97
Di-methyl Cyclopentane	98.18	43.98	3.11	4317.96
Methyl Cyclohexane	98.18	76.47	5.41	7507.82
Ethyl Cyclopentane	98.18	14.97	1.06	1469.75
Toluene	92.13	70.51	4.99	6496.09
C _{8P}	114.22	61.64	4.36	7040.52
C _{8N}	112.21	60.70	4.30	6811.15
C _{8A}	106.16	83.57	5.92	8871.79
n-C _{9P}	128.25	50.02	3.54	6415.07
C _{9N}	126.24	26.24	1.86	3312.54
C _{9A}	120.19	2.64	0.19	317.30
C ₁₀₊	189.00	230.84	16.34	43628.76
TOTAL			100.00	149333.69

Source: Aroma Magazine, vol.7 November-December 1995.

The composition of condensate after entering the MRU is shown in Table 4.2

Table 4.2

Composition of Thai Condensate (post Mercury Removal)

Component	Mol. Wt.	Kg mol/hr	Vol %	Kg/hr
H ₂	2.02	11.62	0.81	23.43
C ₁	16.04	1.82	0.13	29.19
C ₂	30.07	3.91	0.27	117.57
C ₃	44.09	16.68	1.16	735.42
i-C ₄	58.12	46.03	3.21	2675.26
n-C ₄	58.12	85.77	5.987	4984.95
i-C ₅	72.15	90.44	6.30	6525.25
n-C ₅	72.15	85.60	5.97	6176.04
C _{5N}	70.13	10.62	0.74	744.78
C _{6P}	86.17	139.50	9.73	12020.72
Methyl-C _{5N}	82.14	45.89	3.20	3769.40
C _{6N}	82.14	37.58	2.62	3086.82
C _{6A}	78.11	49.94	3.484	3900.81
Dimethyl Pentane	100.20	6.64	0.46	665.33
Methyl Nexane	100.20	28.59	1.99	2864.72
3-Ethyl Pentane	100.20	1.77	0.12	177.35
n-C _{7P}	100.20	49.85	3.48	4994.97
Di-methyl Cyclopentane	98.18	43.98	3.07	4317.96
Methyl Cyclohexane	98.18	76.47	5.33	7507.82
Ethyl Cyclopentane	98.18	14.97	1.04	1469.75
Toluene	92.13	70.51	4.92	6496.09
C _{8P}	114.22	61.64	4.30	7040.52
C _{8N}	112.21	60.70	4.23	6811.15
C _{8A}	106.16	83.57	5.83	8871.79
n-C _{9P}	128.25	50.02	3.50	6438.15
C _{9N}	126.24	26.24	1.83	3312.54
C _{9A}	120.19	2.64	0.18	317.30
C ₁₀₊	189.00	230.84	16.10	43628.76
TOTAL			100.00	149703.85

Source: Aroma Magazine, vol.7 November-December 1995.

- The condensate is composed of several different kinds of hydrocarbon.
- C₄-C₁₀ paraffins, naphthenes and aromatics are found in the condensate, as well as a little of hydrogen, methane, ethane and propane.
- The condensate for reforming process is "topped" and "tailed" to naphtha that must be heart cut for reforming

Topping is C₅ and lighter compounds

Tailing is C₉ and heavier compounds

- If the condensate is used alone without fullrange naphtha, heart cutting of heavy naphtha will obtained heavy naphtha with the following quality and composition:

Table 4.3

**Composition and Quality of Heavy Naphtha
(after heart cutting of fullrange naphtha)**

Composition Vol %	Paraffins P	Naphthenes N	Aromatics A	Total
C5	0.31	0.17	-	0.48
C6	10.64	8.44	3.88	22.96
C7	12.64	17.36	7.45	37.45
C8	9.93	8.72	10.23	28.88
C9	6.26	2.89	0.25	9.40
C10	0.51	0.32	-	0.83
TOTAL	40.29	37.90	21.81	100.00

Source: Aroma Magazine, vol.7 November-December 1995.

From the above data, it can be seen that condensate is a composition of several kinds of hydrocarbon. If condensate is a single composition material, it would be easier to fix the boiling point.

2. FULL RANGE NAPHTHA (FRN)

Naphtha is supplied by both domestic oil refineries and importation.

ATC designed process is based upon the composition of full range naphtha as shown in the following table:

**Table 4.4
Composition of Full Range Naphtha**

Component	Mol. Wt.	Kg mol/hr	Vol %	Kg/hr
H2	2.02		0.00	0.00
C1	16.04		0.00	0.00
C2	30.07		0.00	0.00
C3	44.09	0.91	0.12	40.12
i-C4	58.12	7.82	1.06	454.50
n-C4	58.12	72.23	9.76	4198.01

i-C5	72.15	19.60	2.65	1414.14
n-C5	72.15	55.42	7.49	3998.55
C5N	70.13	4.84	0.65	339.43
C6P	86.17	199.22	26.92	17166.79
Methyl-C5N	82.14	4.85	0.66	398.38
C6N	82.14	4.12	0.56	338.42
C6A	78.11	2.23	0.30	174.19
Dimethyl Pentane	100.20	10.18	1.38	1020.04
Methyl Nexane	100.20	44.12	5.96	4420.82
3-Ethyl Pentane	100.20	2.76	0.37	276.55
n-C7P	100.20	76.98	10.40	7713.40
Di-methyl Cyclopentane	98.18	9.76	1.32	958.24
Methyl Cyclohexane	98.18	16.91	2.28	1660.22
Ethyl Cyclopentane	98.18	3.32	0.45	325.96
Toluene	92.13	24.21	3.27	2230.47
C8P	114.22	64.32	8.69	7346.63
C8N	112.21	25.42	3.43	2852.38
C8A	106.16	24.08	3.25	2556.33
n-C9P	128.25	48.73	6.58	6249.62
C9N	126.24	13.12	1.77	1656.27
C9A	120.19	4.98	0.67	598.55
C10+	142.28	0.00	0.00	0.00
TOTAL			100.00	68387.99

Source: Aroma Magazine, vol.6 September-October 1995.

The quality and composition of full range naphtha used by ATC are as follows:

Table 4.5

The Quality and Composition of Fullrange Naphtha

Composition	Paraffins	Naphthenes	Aromatics	Total
Vol %	P	N	A	
C3/C4	8.20			8.20
C5	8.70	0.50		9.20
C6	26.30	1.00	0.20	27.50
C7	19.80	3.90	2.60	26.30
C8	10.50	3.70	3.00	17.20
C9	8.80	2.10	0.70	11.60
TOTAL	82.30	11.20	6.50	100.00

Source: Aroma Magazine, vol.6 September-October 1995.

Full range naphtha contains more hydrocarbon than the Thai condensate and will enter the feed fractionation unit as a reformer feedstock which has a lot of naphthene and C₆-C₈.

3. PYROLYSIS GASOLINE (Pygas)

Pyrolysis gasoline is a by-product hydrocarbon obtained from the production of ethylene and propylene by Thai Olefins Co., Ltd. (TOC)

ATC uses pygas as a feedstock which contains aromatics at 80% by wt. The pygas is supplied by Thai Olefins Co., Ltd. (TOC). The substance is a by-product carbon of TOC obtained from the processing of ethylene and propylene, as shown in the following table:

Table 4.6
Composition of Feed Streams to Sulpholane

Composition	Mol.Wt.	Sulpholane Feed		Platformate Splitter to Sulpholane		Pyrolysis Gasoline	
		Kg mol/hr	Kg/hr	Kg mol/hr	Kh/hr	Kg mol/hr	Kg/hr
I-C4	58.12	3.58	208.07	3.58	208.07	0.00	0.00
n-C4	58.12	17.99	1045.58	14.88	864.83	3.11	180.75
I-C5	72.15	70.29	5071.42	30.73	2217.17	39.56	2854.25
n-C5	72.15	60.95	4397.54	21.37	1541.85	39.58	2855.70
C5N	70.13						
C6P	86.17	84.95	7320.14	66.90	5764.77	18.05	1555.37
Methyl-C5N	82.14						
C6N	82.14	15.38	1263.31	3.21	263.67	12.17	999.64
Benzene	78.11	196.53	15350.96	158.04	12344.50	38.49	3006.45
Dimethyl Pentane	100.20						
Methyl Hexane	100.20						
3-Ethyl Pentane	100.20						
n-C7P	100.20	58.25	5836.65	52.94	5304.59	5.31	532.06
Di-methyl Cyclopentane	98.18	5.27	517.41	1.38	135.49	3.89	381.92
Methyl Cyclohexane	98.18						
Ethyl Cyclopentane	98.18						
Toluene	92.13	386.22	35582.45	364.18	33551.90	22.04	2030.55
C8P	114.22	6.75	770.99	5.62	641.92	1.13	129.07
C8N	112.21	1.32	148.12	0.52	58.35	0.80	89.77
C8A	106.16	20.29	2153.99	3.45	366.25	16.84	1787.73
n-C9P	128.25	4.64	595.08			4.64	595.08
C9N	128.24	2.94	371.15			2.94	371.15
C9A	120.19	3.51	421.85			3.51	421.87
C10+	142.28						
Indane	118.17	0.91	107.53			0.91	107.53
TOTAL		939.77	81162.25	726.80	63263.35	212.97	17898.90

Source: Aroma Magazine, vol.5 July-August 1995.

The TOC's pygas has passed the cracking process from TOC plant. If the py-gas contains unsaturated material such as olefin alkene, it will result in high acid wash value in aromatic products.

4.2 ATC'S MAIN PRODUCTS OBTAINED FROM ITS PRODUCTION PROCESS

ATC's main products obtained from its production process are called BTX grouping Benzene, Toluene and Xylenes. Xylenes consist of paraxylene, orthoxylene and mixed xylenes. The xylenes are separated at the xylene fractionation unit.

1. Benzene (C₆ H₆)

At room temperature, benzene is a clear liquid substance, highly inflammable, easily vapourized, and has a particular odour. It is an essential raw material for many industries such as medicine, chemical, petrochemical, and plastic. Benzene is harmful and should not be directly in contact with the body or breathed. But this does not mean that all manufactured products including plastic such as polystyrene, ABS or other plastic products which are produced from this raw material are all toxic.

Benzene is refined from crude oil at the temperature 20 to 135°C. Before the World War II, benzene was mainly used to mix in gasoline. The reason is that benzene yields high octane and helps the engine to start easier. Later during the World War II, benzene was introduced in chemical industry which expanded quickly. After the World War II, the demand for benzene in chemical industry increased drastically. Therefore, benzene was gradually reduced in gasoline and replaced by tetraethyl lead. As the demand for benzene in chemical industry increases, this leads to the change and development towards the separation of aromatics.

Benzene is used in petrochemical industry as raw material for the preparation of organic chemicals such as cyclohexane, ethylbenzene, alkylbenzene, cumene and many others. Moreover, these organic chemicals can also be used as raw materials for the production of monomer, polymer and other chemicals.

The major markets of benzene are the U.S.A., Europe and the Far-East. There are two methods of pricing: Contract Price and Spot Price that may be Spot FOB or C&F depending on the agreement between the seller and the buyer. There are two factors that influence the price: Demand and Supply.

Demand depends on the requirement of the producers of derivatives such as producers of styrene, monomer, ABS and caprolactum.

Supply depends on the volume of goods available in the market, and the production capacity of the plants that can response to the market demand. Generally, the problems are mainly from the inability of the plants in a particular region, which cannot produce due to emergency shutdown or annual turnaround, resulting in tight avails to the markets.

2. Toluene ($C_6H_5CH_3$)

Toluene is a colourless liquid smelling like benzene. Its density is 0.866 at 20/4°C, freezing point at -94.5°C, boiling point at 110.7°C, igniting point at 44°C, inflaming point at 997°C. It dissolves in alcohol, gasoline and ether, but does not dissolve in water. Toluene is obtained from catalytic reforming of petroleum and fractional distillation of coal-tar light oil. It is a highly inflammable substance. It can be absorbed through the skin. It is toxic if swallowed or breathed. Its TLV in air is 100 ppm.

Toluene has a wide range of usage. It serves many purposes, for instance, as solving agent in paint and coating industry, as component of insecticides, as fuel for aeronautical engines, and as octane booster.

Toluene price is affected by petroleum world price, because, like other aromatics, it is an octane booster that can be added into gasoline pool to increase octane. Nevertheless, the Clean Air Act (CAA) of the U.S.A. to solve the air pollution problem reduces the requirement of aromatics in gasoline.

The market price of toluene is divided in two main categories:

1. The price of nitration grade toluene (99%) used as raw material to produce benzene and trinitrotoluene (TNT).
2. Industrial grade toluene (95 to 98%) used as raw material to produce benzene or solvents.

In the Far East, Korea is the major exporter of toluene. The export is forecast to increase due to oversupply from production.

3. Xylenes (C_8H_{10})

Xylenes produced by ATC comprise paraxylene, orthoxylene and mixed xylenes. ATC plant has been designed as a fully integrated plant. It has not only a xylene fractionation unit, but also purifying tower to produce orthoxylene and mixed xylenes.

1. Paraxylene

Paraxylene is a colourless liquid, crystallizes at low temperature, soluble in alcohol and ether but insoluble in water. It is flammable, dangerous fire risk. It is separated from orthoxylene and mixed xylenes at the xylene fractionation unit. It is then conveyed to parex unit by absorption-desorption method to separate pure paraxylene. Moreover, TAC has isomar unit which, by isomerization, processes orthoxylene and metaxylene to obtain the maximum quantity of paraxylene.

Paraxylene is an essential raw material for intermediate petrochemical industry for the production of DMT² (dimethyl terephthalate) or PTA³ (purified terephthalic acid). The latter materials are used to produce PET⁴ (polyethylene terephthalate) to be used as raw material for downstream petrochemical industry. It is particularly used for the manufacturing of polyester fibres to compensate for cotton-fibres in the textile industry, and the manufacturing of bottle chips to replace PVC and glass in the food and beverage industries.

2. Orthoxylene

It is a clear, colourless liquid, soluble in alcohol and ether, but insoluble in water. Orthoxylene is combustible with moderate fire risk. It is free of hydrogen sulphide and sulphur dioxide.

It is used to manufacture phthalic anhydride, vitamin and pharmaceutical syntheses, dyes, insecticides, motor fuels and plasticizer for PVC pipes.

3. Mixed Xylene

Mixed xylene is a clear colourless liquid, soluble in alcohol and ether, but insoluble in water. It is flammable with moderate fire risk. It is used as solvent, intermediate for dyes and organic synthesis, especially isophthalic acid, insecticides, aviation fuel.

PRODUCTS REQUIREMENTS

The product requirements are consistent with the facilities presently being built and are (in order of preference): paraxylene, orthoxylene, benzene, toluene, mixed xylenes.

The required product purity for each of the aromatics products are shown in Table 4.7.

Table 4.7**Product Purity Specifications
(percents)**

Product	Purity
Paraxylene	99.8 min.
Orthoxylene	98.0 min.
Benzene	99.9 min.
Toluene	98.5 max
Mixed xylenes	Not applicable

Source: Aroma Magazine, vol. 13 January-February, 1997.

4.3 ATC'S BY-PRODUCTS OBTAINED FROM ITS PRODUCTION PROCESS

Three major by-products from the world scale aromatics plant presently being built as an integral part of the NPC2 complex have been identified to be potential sources of additional aromatics production. These are light naphtha, raffinate and LPG.

TABLE 4.8**Typical Properties of Light Naphtha**

Item	Specification
Distillation, degrees C	
IBP	32
10%	47
30%	52
50%	67
70%	70
90%	73
EP	79
Gravity	
API	81.3
Specific	0.66
Molecular weight	79.1
Reid vapour pressure, kg/cm ²	0.7733
RONC	69

MONC	67
Impurities	
Water, wt. Ppm	<5
Sulphur, wt. Ppm	<200 ¹
Mercury, wt. Ppb	<5 ²
Arsenic, wt. Ppm	Nil
COS, wt. Ppm	Nil
Chlorides, wt. Ppm	<0.5 ³
PONA analysis, wt. %	
Paraffins	85.4
Olefins	0
Naphthenes	10
Aromatics	4.6

Source: Aroma Magazine, vol.9 March-April, 1996.

Notes:

- ¹ Figure is based on typical value. The actual sulphur content will depend on FRC and FRN sulphur content.
- ² Mercury content will depend on the performance of the mercury removal unit (MRU). If the MRU performs as expected, the light naphtha should contain less than 5 wppm mercury.
- ³ Figure is based on typical value. The chloride content will depend on FRC and FRN chloride content.

TABLE 4.9

Typical Properties of Raffinate

Item	Specification
Component, wt. %	
I-Butane	0.70
n-Butane	3.88
I-Pentane	12.25
n-Pentane	11.02
Methylpentane	0.04
n-Hexane	26.83
Methylcyclopentane	4.02

Benzene	0.08
n-Heptane	26.76
Ethylcyclopentane	1.99
Toluene	0.49
C8 paraffins	5.35
C8 naphthenes	1.03
Ethylbenzene	0.17
Paraxylene	0.04
Mixed xylene	0.11
Orthoxylene	0.06
C9 paraffins	0.37
C9 naphthenes	0.23
Methylethylbenzene	0.86
Trimethylbenzene	0.44
Indans	0.03
C10 paraffins	0.03
C10 aromatics	3.09
Gravity	
API	78.2
Specific	0.6748
Impurities	
Water, wt. Ppm	Nil
Sulphur, wt. Ppm	Nil
Mercury, wt. Ppb	Nil
Arsenic, wt. Ppm	Nil
COS, wt. Ppm	Nil
PONA analysis, wt. %	
Paraffins	87.23
Olefins	0.01
Naphthenes	7.3
Aromatics	5.46

Source: Aroma Magazine, vol.11 July-August, 1996.

Table 4.10
Typical Properties of LPG

Item	Specification
Vapour pressure, kg/cm ² (g)	9.50 max
C2 and lighter, vol. %	0.01 max
Volatile residue	
Evap. Temp., 95 vol. %	2.2 max
C5 and heavier, vol. %	2.0 max
Residue on evap., 100 ml	0.05 max
Copper strip corrosion @ 37.8 C, 1 hr	No. 1 max
Sulphur (unstretched) @ 15.6 c, 1.03 kg/cm ² , g/m ³	0.343 max
Free water	None

Source: Aroma Magazine, vol.10 May-June, 1996.

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CHAPTER 5

DETAILED PROFILE OF FIVE BY-PRODUCT UPGRADING TECHNOLOGY AVAILABILITY

This chapter discusses the presently available technologies for upgrading aromatics by-product from ATC's production process. Each of the five technologies is described in detail in order to compare the suitability and possibility of the production processes in response to ATC's requirement.

5.1 BACKGROUND

It has long been known that aromatics are formed in low yields when any hydrocarbons from methane upward are subjected to high temperature pyrolysis. Such conversions are, however, accompanied by a high degree of degradation to carbon and hydrogen. Hence, lower paraffins, defined as methane through pentane, although normally having a lower value than liquid streams in the C6-C9 range, have not previously been regarded as economic feedstocks for aromatics.

Conventional catalytic reforming, which operates at much lower temperatures, involves a complex mixture of reactions, including isomerization of paraffins and naphthenes, dehydrocyclization of paraffins, dehydrogenation of naphthenes, and hydrocracking. In general, the formation of cracked products is not reversible, since oligomerization does not occur to any significant extent. Because cyclization is not the dominant reaction, it is preferable to choose naphthenic naphthas as feedstocks to conventional aromatics reformers. However, for this study evaluation will be made on developing technologies specific to paraffinic feeds.

Developments in recent years have been directed toward:

- ⇒ Modification of the thermal cracking process in order to produce higher yields of aromatics rich liquid products from lower paraffins.
- ⇒ Extension of the catalytic hydroforming process to promote oligomerization/dehydrocyclization of the lower paraffins. This may or

may not be combined with a sizeable amount of cracking to lower olefins.

A number of technologies that produce aromatics are in the development stages or close to commercialization. In most cases, the emphasis is on process routes to aromatics from novel, low value feedstocks, such as LPG or paraffinic naphthas.

Amortization of ethane is being investigated by Mobil and UOP/BP (using the CYCLAR process). Neither process shows any significant yield of xylenes, indicating they are best suited from benzene and toluene production rather than xylenes as the main product.

Several processes that are still in the development stages or are just being commercialized are discussed in the body of the report, including:

- 1) BP's CYCLAR catalytic process developed with UOP. This process can be applied to ethane, propane, butane, or light naphtha feedstocks (C5s and below), although an LPG feedstock seems the most likely to be economical. This process has been proven in a 1,000 barrel per day demonstration-scale unit, and there are plans for a commercial unit to be installed in Saudi Arabia by 1998, using an LPG feedstock.
- 2) UOP's RZ-100 process employs a catalyst with a high selectivity to convert light paraffins to aromatics. The catalyst is operated in a semi-regenerative, fixed-bed mode. Commercial demonstration involved the revamp of an existing semi-regenerative unit.
- 3) Asahi Chemical Industry Co., an affiliate of Sanyo Petrochemical Co., recently announced the commercialization of the ALPHA process to produce aromatics from olefins. This process will also work using paraffinic feedstocks, although a significant increase in catalyst consumption will be required.
- 4) Chevron's AROMAX process employs a highly selective reforming catalyst capable of producing high yields of benzene from light (C5-C6) paraffinic naphthas. This process has recently been commercialized at Chevron's Pascagoula, Mississippi facility.
- 5) Mitsubishi/Chiyoda's Z-FORMER Process has been proven in a 200 barrel per day demonstration unit, using LPG and light naphtha feedstocks.

ATC has available LPG, raffinate and light naphtha by-products which could be converted into higher value aromatics products. Reflecting these feeds, five aromatics processes have been reviewed in this study.

In order to determine the availability of each process, and its potential for use, using ATC's specific available feedstocks, the information obtained from the above licensors included:

- 1) a general process description
- 2) capital cost estimate
- 3) operating cost
- 4) feedstock requirements
- 5) a discussion of the process' level of commercialization

In the case of UOP's CYCLAR process, Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public,Co.,Ltd., Chem Systems, 1996-1997. was sent general information on the process.

For the Chevron AROMAX, a general discussion was held. However, Chevron was reluctant to share detailed information specific to ATC's feedstocks without first discussing the possibility of a joint venture arrangement, since Chevron no longer licenses the process.

For the UOP RZ-100, Mitsubishi/Chiyoda Z-FORMER, and Asahi ALPHA processes, secrecy agreements were signed by both Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public,Co.,Ltd., Chem Systems, 1996-1997.s and ATC, in order to obtain the best available information. Mitsubishi/Chiyoda revised the investment and utility requirements several times during the evaluation period as they "optimized" the process. Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public,Co.,Ltd., Chem Systems, 1996-1997.s evaluation was based on the last information provided by Chiyoda.

1) **BP/UOP's CYCLAR PROCESS**

BP built a commercial-sized demonstration plant in Grangemouth, Scotland due to the availability of LPG feedstock from the North Sea. The design incorporated full-scale process equipment, including stacked reactors and a Continuous Catalyst Regeneration (CCR) section. The aromatics distribution attained closely matched predicted yields based on pilot plant tests.

A CYCLAR-based aromatics facility is currently under construction in Yanbu, Saudi Arabia to be operated by SABIC. Start-up is scheduled for 1998. This plant is the first to be built under a CYCLAR license from UOP.

The process is currently available for license worldwide by UOP, which offers design and performance guarantees.

2) UOP'S RZ-100 PROCESS

The commercial demonstration of the RZ-100 process involved the revamp of a semi-regenerative unit that had previously processed untreated naphtha over a monometallic reforming catalyst. The existing unit was extensively contaminated with sulphur and sulphide-containing scale. UOP provided a patented plant cleanup procedure developed for RZ-100 that effectively removed the sulfur. According to UOP, commercial operations met expectations for catalyst activity, conversion, and yield. However, the unit is no longer in operation due to a change in the refiner's corporate organization.

To date, UOP has licensed two RZ-100 units to unspecified producers. The first unit is expected to start up in late 1997, according to UOP.

3) ASAHI CHEMICAL ALPHA PROCESS

Sanyo's ALPHA plant in Mizushima, Okayama, Japan (Sanyo Petrochemical is a subsidiary of Asahi) has commercialized the ALPHA process. The feedstock employed is an olefin-based raffinate (C4-C5) from an ethylene plant. A pair of swing reactors in adiabatic reaction are used in this plant. In Sanyo's case, the liquid product is fed directly to the HDA unit. However, the toluene fraction and xylene fraction may be fed to a TDP unit and xylene isomerization unit, respectively. The plant has been in stable operation since 1993.

Asahi Chemical Industry Co., Ltd. is the licensor of the ALPHA process.

4) CHEVRON'S AROMAX PROCESS

The AROMAX process has been commercialized in both Chevron's refinery in Pascagoula, Mississippi and, in Phillips' facility in Guayama, Puerto Rico. Two other plants are planned for Saudi Arabia and Japan. In Pascagoula, an AROMAX unit was added to an existing refinery because of the availability of feedstock and the need for additional H₂ production. The plant went on line in early 1994 and has been a commercial success.

The Saudi plant is based on a naphtha feedstock more commonly used as ethylene cracker feedstock, an unrealistic feed for a conventional reformer, but likely similar to the feedstocks proposed by ATC.

Chevron does not license the AROMAX process, but will consider sharing the technology as part of a joint venture arrangement.

5) MITSUBISHI/CHIYODA Z-FORMER PROCESS

Mitsubishi Oil and Chiyoda Corp. have jointly developed a new process for manufacturing BTX and hydrogen from LPG and light naphtha, called the "Z-FORMER" process. Operation of a demonstration plant for the Z-FORMER process began in November 1990, and was completed in December 1991. The operation was deemed successful by the licensors, and data generated by the pilot plant was used in the design of a commercial plant. No plants employing the Z-FORMER process are currently in operation or are being built at this time.

5.2 BY-PRODUCT UPGRADING TECHNOLOGIES

A. BP/UOP's CYCLAR PROCESS

1. General Process Description

The CYCLAR process can produce petrochemical-grade aromatics from C3 and C4 alkanes (i.e., LPG). UOP indicates that the distribution of the butane species in the C4 feedstock is inconsequential. Components lighter than propane should be minimized since they act as inert diluents. C5 and C6 components should be limited to less than 20 and 2 weight percent, respectively, to minimize coke formation in the process. Butane feedstocks produce a product that is leaner in benzene and richer in xylenes than that produced from propane. The aromatics yield is slightly higher with an all-butane feed as opposed to an all-propane feed.

The catalyst is a sphere consisting of a proprietary zeolite incorporated with a non-noble metal promoter in an inert binder. The zeolitic component in the catalyst provides acidity, and the metal promoter combines with the zeolite to provide dehydrogenation. The inert binder and shape-selective properties of the zeolite retard the formation of coke. UOP claims that 30 percent less catalyst is required with the second generation.

UOP offers two alternative designs: the low pressure design that produces the maximum aromatics yield; the high pressure design (but still less than 100 psig) requires only half the catalyst and therefore has a lower investment (approximately 25 percent less) and lower operating costs. However, the high-pressure design produces about 20 percent less aromatics than the low-pressure design. UOP's Continuous Catalyst Regeneration (CCR) technology is employed for the reactor design. A process flow diagram for the CYCLAR process is shown in Figure V.A.1.

Fresh feed is combined with a small recycle stream consisting of unconverted feed. After being heated to the required reactor inlet temperature, the stream is converted to aromatics in a series of four reactors with interstage heating. This configuration allows high conversion despite the highly endothermic nature of the CYCLAR reaction. The reactors are low-pressure drop, radial flow, and stacked to allow gravity flow of the catalyst between reactors, as in the UOP Platforming process and the CCR system. The effluent from the fourth reactor exchanges heat with the combined feed, is cooled, and partially condensed liquid from the low pressure separator is recovered and fed to a stripper where C6 and heavier aromatics are recovered as a bottoms product.

Aromatics from the stripper bottoms are sent to a conventional, three-tower BTX distillation train where individual cuts of benzene, toluene, and mixed xylenes are distilled overhead. C9+ aromatics are recovered from the xylene tower bottoms. The combined toluene and C9s could be sent to a toluene disproportionation (e.g. Tatoray) unit which would convert these to mixed xylenes. The mixed xylenes could further be processed in a Parex-type unit to produce para-xylene.

Vapour from the low-pressure separator is compressed and sent to a gas recovery section where hydrogen and light by-products are separated from the unconverted feed. The unconverted feed is recycled to the reactors along with the stripper overheads. The small amount of aromatics that are recovered in the gas separation section is also sent to the stripper.

The hydrogen stream could be recovered in several ways, depending on the purity desired, as well as the economics:

1. An absorber-stripper system producing a 65 mole percent hydrogen product.
2. A cold box producing 95 mole per hydrogen.
3. An absorber-stripper system combined with a Pressure Swing Absorption (PSA) unit, producing 99 mole percent hydrogen.
4. A cold box combined with a PSA unit is usually more attractive if large quantities of 99+ mole percent hydrogen is desired.

Catalyst flowing from the final reactor is transferred by lift gas to the top of the regeneration tower where it is separated from the lift gas and proceeds by gravity flow through the regenerator. Operating conditions that fully restore catalyst performance and protect the catalyst from hydrothermal damage are established. Regenerator catalyst inventory is limited to a small fraction of that required in the reactor.



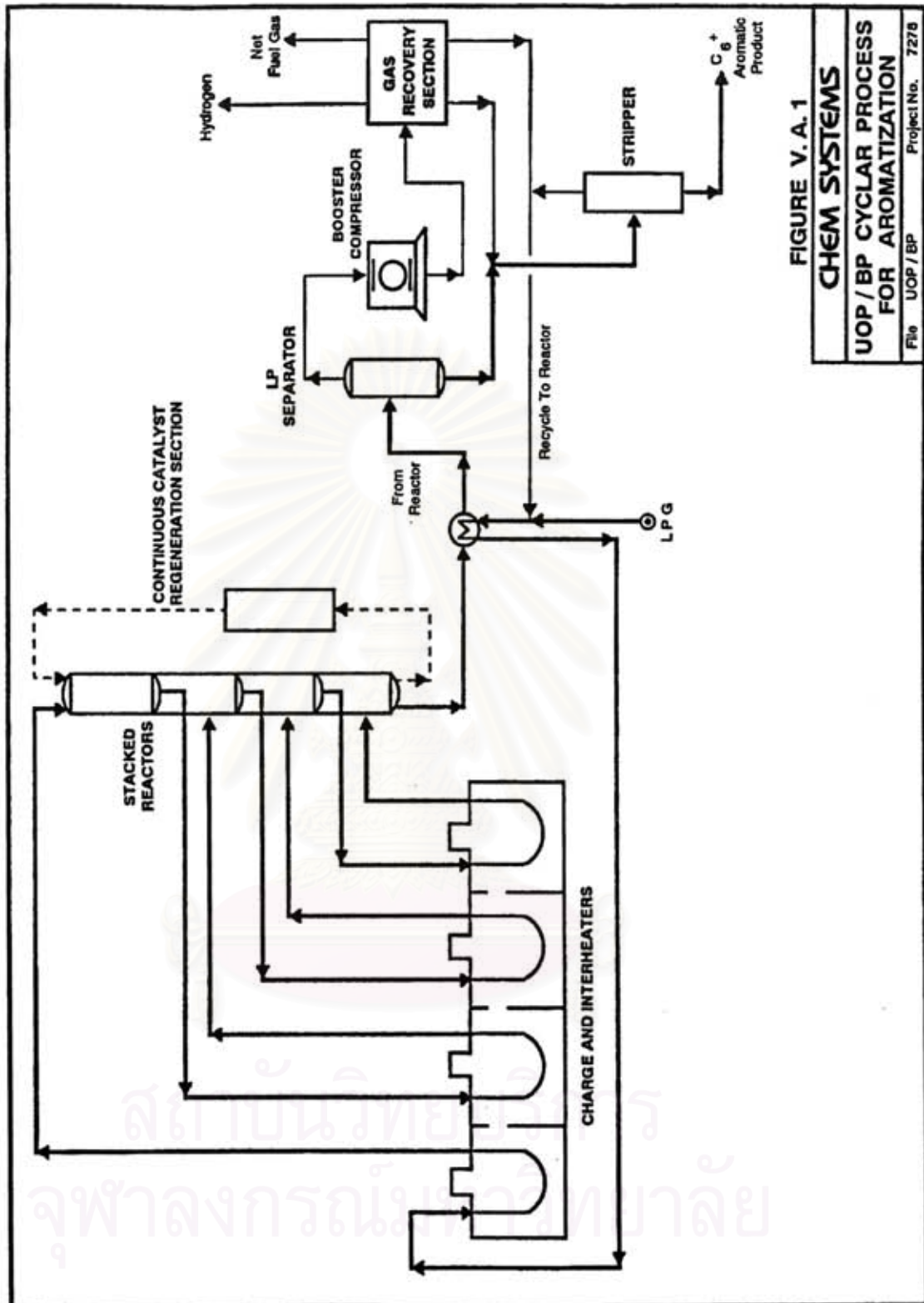


FIGURE V. A. 1

CHEM SYSTEMS

UOP / BP CYCLAR PROCESS
FOR AROMATIZATION

File UOP / BP

Project No. 7278

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

The regenerated catalyst proceeds through small transfer lines into flow control and surge hoppers and finally into the regenerator lock hopper. Lift gas then transports the catalyst back to the top of the first reactor in the stack, thus completing the catalyst circuit. Catalyst movement is very gradual, with the rate controlled at the outlet of the regeneration tower. From this control point, all catalyst transfers are regulated by level control devices. The catalyst from the fourth reactor allows a constant and high level of catalyst activity and selectivity to be maintained in the reactors. This steady-state catalyst condition eliminates the need for changes in process temperatures to compensate for catalyst deactivation that might be typical of a SR type reformer.

The desired conversion level, yield, and product quality are continuously maintained. The regenerator section is sized to be compatible with a wide range of plant capacities while maintaining the desired optimal steady-state catalyst quality in the reactor.

The reactor and regenerator are independent. Each operates at its own ideal set of conditions. Individual reactors do not cycle between reaction and regeneration conditions. This simplifies metallurgy, heater sizing, and hydraulics, since these can be designed for specific duties.

The CCR system was first commercialized in 1971 in the UOP Platforming process, where high octane, gasoline-blending stock is produced by catalytic reforming of naphtha. At present there are at least 124 units on stream worldwide, with more than 42 in the design or construction phase. The design of the CYCLAR CCR equipment is essentially the same as the design of a Platforming CCR unit.

Although the amortization reaction sequence involves some exothermic steps, the preponderance of dehydrogenation and cracking reactions causes the overall sequence to be highly endothermic. The reaction product is separated into hydrogen and light by-product (for fuel) with unconverted alkanes recycled to extinction. In this example, the hydrogen purity of the net hydrogen stream is 95 percent (via a cold box). The aromatics product is very rich in BTX. Typically, the level of nonaromatics is less than 0.1 percent. This means that solvent extraction is not needed to meet most product specifications.

The estimated material balances for the CYCLAR using ATC's LPG as feedstock is shown in Table 5.A.1. UOP has stated that LPG yields can be estimated by interpolation based on published yields from pure propane and butane feeds.

The estimated conversion to BTX is 59.9 percent for the low-pressure case, using only the LPG as feedstock.

Table 5.A.1
CYCLAR Process Material Balance
(metric tons per year)

Feed Case	LPG, Low Pressure case	LPG, High Pressure case
Feedstock	89,000	89,000
Products		
C6+ Cut	-	-
Net Feed to Cyclar	89,000	89,000
Benzene	13,386	8,776
Toluene	25,569	21,053
Xylenes	14,343	13,437
C9+ Aromatics	5,089	5,452
Fuel Gas	24,587	36,368
H ₂	6,025	3,914

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

2. Strengths and Weaknesses

The CYCLAR process is proven on a small scale to achieve selective conversion to BTX in a single step from propane and butanes. The process is an economically attractive alternative to conventional naphtha reforming.

The process can also use pentanes as a feedstock component, although this results in more coke formation than pure LPG feedstocks, and the flexibility to handle these components could be incorporated into the reactor and regenerator design. However, UOP has stated that considerable research and engineering would be required to design a CYCLAR unit to handle the heavier C5 feeds; UOP does not wish to pursue this option with ATC due to the small scale of the project. Feedstocks richer in butane produce a product leaner in benzene and richer in xylenes than that produced by propane feedstocks.

Olefins should be limited to less than 10 percent of the feed. Higher concentrations of olefins require hydrogenation of the feed. This should not be a concern to ATC based on the proposed feeds.

On-stream efficiency of the units is expected to be about 95 percent, similar to a UOP CCR reformer.

UOP currently offers two alternative designs: the low-pressure and high-pressure designs provide flexibility in terms of a trade-off between investment and yield. For ATC, the low-pressure case, which provides higher aromatics yields, is suggested, based on ATC's objectives.

UOP's proven Continuous Catalyst Regeneration (CCR) technology is employed for the reactor design. Aromatics production is relatively simple because of minimal feed-pretreatment and product-purification requirements.

A CYCLAR unit could be combined with an RZ-100 unit or an AROMAX unit. The C6 and heavier hydrocarbons off the depentanizer could be processed through an RZ-100 or AROMAX unit to produce additional aromatics.

3. Capital Investment

The low-pressure design that produces one maximum aromatics yield; the high-pressure design (but still less than 100 psig) requires only half the catalyst and therefore has a lower investment (approximately 25 percent less) and lower operating costs. For ATC's case, it is assumed that the maximum aromatics yield is desired.

Estimated capital cost of a Cyclar unit is \$27.8 million. Details are shown in Table 5.A.2.

Table 5.A.2

**Estimated Capital Cost, CYCLAR Installation
(\$MM)**

Feed Case	LPG
Total equipment cost	24.3
Engineering and design ₁	
Royalties ₂	
Catalyst ₃	1.0
Total inside battery limits	25.3
Modifications to existing plant	0.0
Outside battery limits	0.0
Total plant capital	25.3
Owners' costs	2.5
Total capital investment	27.8

₁ Included in total equipment cost

- ² Information not available
³ Expected catalyst life is two years

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem System Inc.

4. Operating cost

The low-pressure design produces the maximum aromatics yield; the high pressure design (but still less than 100 psig) requires only half the catalyst and therefore has lower operating costs. For this study, it is assumed that ATC desires the maximum aromatics yield.

Utility requirements for normal plant operation are shown in Table 5.A.3. In this analysis, the fuel gas produced by the plant has been shown as a by-product in the material balance, and no credit for the fuel value has been taken in the utilities.

Table 5.A.3

CYCLAR Normal Operating Requirements

Utilities	Units	Per Ton BTX
Electricity	kWh	71.29
HP Steam	metric tons	(0.7609)
LP Steam	metric tons	0.0387
Boiler Feed Water	metric tons	0.8509
Cooling Water	metric tons	74.388
Fuel gas	metric tons	0.2013

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

The estimated cash cost of production, shown in Table 5.A.4 per ton of BTX, is \$383 per metric ton of BTX. This is the third lowest estimated cost of production of all the options under consideration, on a BTX basis.

TABLE 5.A.4
TOTAL CASH COST OF PRODUCTION ESTIMATE FOR : BTX
PROCESS : CYCLAR

Plant start-up	2001	CAPITAL COST	MILLION US \$
Analysis date	19980	ISBL	25.3
Location	THAILAND	OSBL	0.0
Capacity	53.3 Thousand MT/yr	Total Plant Capital	25.3
		Other Project Costs	2.5
		Total Capital Investment	27.8
Throughput	48.0 Thousand MT/yr		

PRODUCTION COST SUMMARY		UNITS	PRICE	US \$	ANNUAL	US \$
		Per MT	US \$ /	Per MT	COST MM	Per Lb
		Product	Unit		US \$	
RAW MATERIALS	LPG, MT	1.6698	266.0000	444.17	21.31	
	Catalyst & Chemicals	-	11.6600	11.66	0.56	
	TOTAL RAW MATERIALS			455.83	21.87	0.
	C9+aromatics, MT	0.0955	278.0000	(26.55)	(1.27)	
	Fuel gas, MT	0.4613	260.0000	(119.94)	(5.75)	0.
	Hydrogen - reformer, MT	0.1130	260.0000	(29.38)	(1.41)	
	TOTAL BY-PRODUCT CREDITS			(175.87)	(8.44)	(0.080)
	NET RAW MATERIALS			279.95	13.43	0.127)
UTILITIES	Power, kWh	71.2939	0.0626	4.46	0.21	
	Cooling Water, MT	74.3881	0.0349	2.60	0.12	
	Steam, LP, MT	0.0387	13.4700	0.52	0.02	
	Steam, HP, MT	(0.7606)	14.8700	(11.31)	(0.54)	
	Boiler Feed water, MT	0.85096	0.4968	0.42	0.02	
	Fuel, MT	0.2103	260.0000	52.33	2.51	
	TOTAL UTILITIES			49.02	2.35	0.222
	NET RAWMATERIALS & UTILITIES			328.98	15.78	0.149
	VARIABLE COST			328.98	15.78	0.149
DIRECT FIXED COSTS	Labor, 15 Men	16.15 Thousand	US \$	5.05	0.24	
	Foremen, 6 Men	32.38 Thousand	US \$	4.05	0.19	
	Super., 1 Men	72.80 Thousand	US \$	1.52	0.07	
	Maint., Material & Labour	3.00 % of ISBL		15.82	0.76	
	Direct Overhead	45 % Labour & Supervision		4.78	0.23	
	TOTAL DIRECT FIXED COSTS			31.22	1.50	0.014
ALLOCATED FIXED COSTS	General Plant Overhead	65 % Labour & Maintenance		17.19	0.82	
	Insurance, Property Tax	1.0 % Total Plant Capital		5.27	0.25	
	TOTAL ALLOCATED FIXED COSTS			22.46	1.08	0.010
	TOTAL CASH COST			382.66	18.36	0.174

Source : A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co., Ltd., 1996-1997, Chem Systems Inc.

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Propane and butanes should be the major components in the feedstock to a CYCLAR unit. C1 and C2 saturates should be minimized as these components are inert diluents.

Olefins should be limited to less than 10 percent of the feed. Higher concentrations of olefins require hydrogenation of the feed. This should not be of concern to ATC.

C5 and C6 components increase the rate of coke formation in the process and should be limited to less than 20 wt percent and 2 wt percent respectively in CYCLAR units designed for LPG service. CYCLAR units can be designed to process significantly higher amounts of C5 and C6 materials if necessary, although UOP admits that considerable design time would be required to include engineering and testing of C5 feeds.

The feed contaminant limits recommended by UOP are given in Table 5.A.5.

Table 5.A.5

**CYCLAR Process UOP Recommended
Feedstock Contaminant Limits**

Sulphur	<20 -ppm
Fluorides	<0.3 mol-ppm
Water	No free water
Oxygenates	<10 wt-ppm
Basic Nitrogen	<1 wt wt-ppm
Metals	<50 wt-ppb

Source: Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

6. Experience List

Between 1989 and 1991, BP operated a 1,000 BPD demonstration unit at its Grangemouth, Scotland refinery. The design incorporated full commercial-scale process equipment, including the stacked reactors and the CCR section. Two catalyst formulations were evaluated: first-generation catalyst and second-generation catalyst with even higher activity. Commercial performance dated was obtained using propane and mixed LPG feedstocks. The process performance closely matched expectations based on pilot plant performance.

mixed LPG feedstocks. The process performance closely matched expectations based on pilot plant performance.

Saudi Basic Industries Corporation (SABIC) has recently signed a letter of intent with UOP for use of the CYCLAR process in an aromatics unit to be built at Yanbu, Saudi Arabia. This plant is expected on stream in late 1997 or early 1988 with a capacity of 300,000 metric tons per year of para-xylene, 45,000 tons per year of ortho-xylene, 35,000 tons per year of metaxylene, and more than 300,000 tons per year of benzene.

7. Integration with Existing Facilities

The integration of the relatively small CYCLAR unit with the existing facilities can be accomplished relatively easily. The production of additional aromatics would have the largest effect on the benzene column and Tatoray unit. The capacities for these units would increase about 10 percent, which is considered easily achievable at no additional cost.

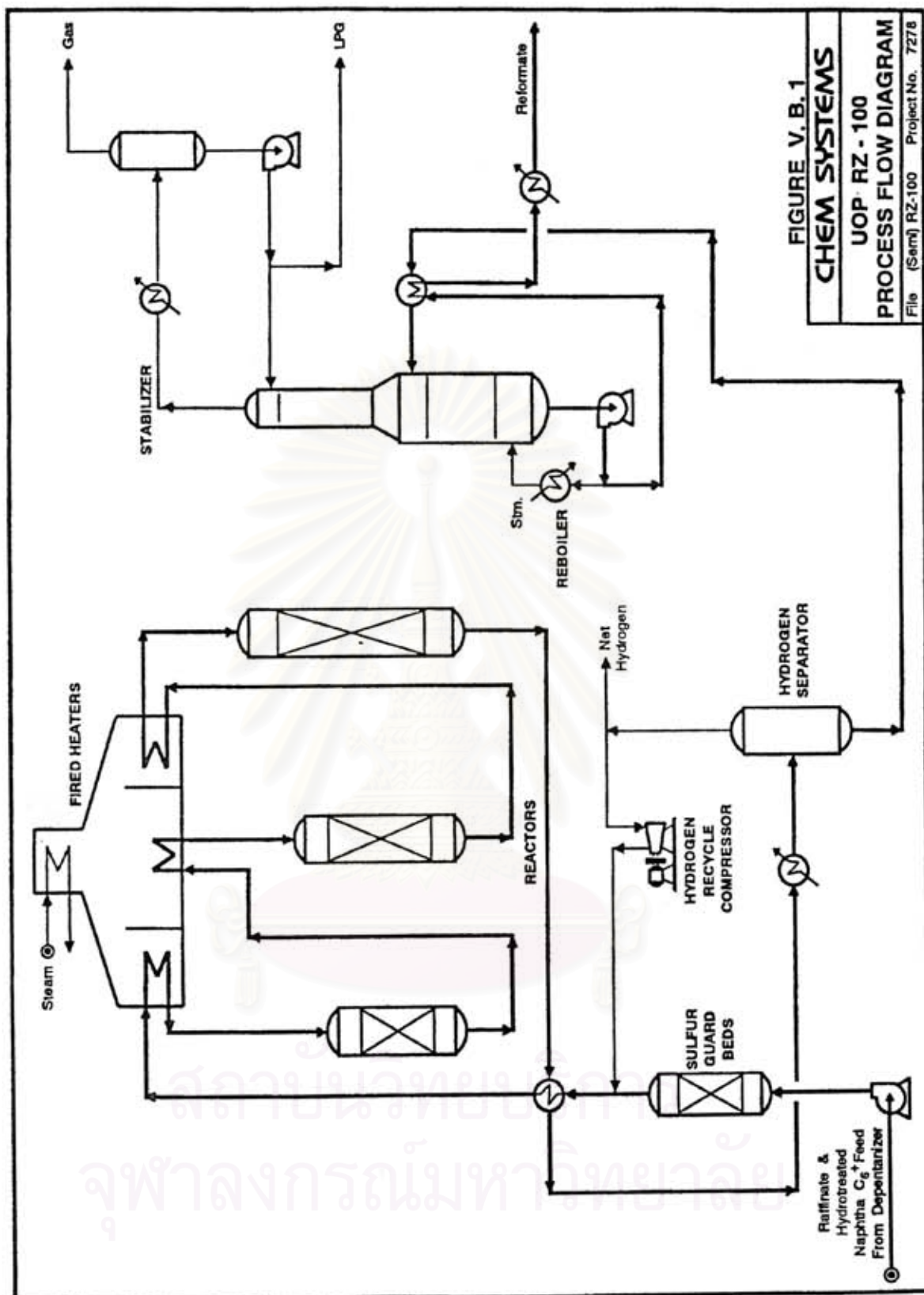
At present, ATC has two plots of land. The first has 98 rais (1 rai equals to 2 in 5 acres) on which are built the warehouses and various tanks. On this plot, ATC has reserved an area of about 17 rais for future expansion. Opposite this plot of land is the second plot of 157 rais where offices and production process area are situated. On this latter an area of 36 rais is reserved for future expansion, while CYCLAR Unit requires just 9 rais. Therefore, CYCLAR Unit can easily fit into one of the two plots of land available on site.

From Table 5F, it can be seen that the utility consumption rate of CYCLAR increases very little comparing to the utility volume remained from existing process of ATC each year. For instant, the electrical power of ATC can be available up to 204,000,000 kWhr/yr, while the consumption rate is around 153,000,000 kWhr/yr. Therefore, there remains up to 51,000,000 kWhr/yr of electricity, while CYCLAR uses only 3,799,614 kWhr/yr. Moreover, all CYCLAR processing equipments, be it HP steam, LP steam, Boiler feed water, Cooling water or Fuel gas, use less electricity than the rate that the existing utilities can supply. Therefore, the additional utilities required by the CYCLAR Unit can easily be met by the existing utilities without any further investment.

B. UOP'S RZ-100 PROCESS

1. General Process Description

The RZ-100 Platforming catalyst is a fixed-bed, regenerable catalyst system that UOP has worked on for over ten years. It has the



Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

ability to convert C6 and C7 paraffins to aromatics, and is particularly well suited for producers who require large amounts of benzene.

Feedstocks to the reforming unit using the RZ-100 catalyst can range from extraction unit raffinates to BTX naphthas. In ATC's case, the feedstocks used will be their by-product light naphtha and raffinate streams. Both streams will require depentanizing to remove the C5s before processing in the RZ-100 unit. Within certain limitations, these C5s can be fed to a CYCLAR unit.

Figure V.B.1 shows a process flow diagram the UOP's RZ-100 process.

Table 5.B.1 shows the required operating conditions, using ATC's available feedstocks of raffinate and light naphtha.

Table 5.B.1
RZ-100 Operating Conditions

Feed Case	Raffinate	Raffinate and Light Naphtha
C5+ Reformate, RONC	88.50	86.60
Average Reactor Pressure, psig	50.00	50.00
Separator Pressure, psig	35.00	35.00
Net Gas Pressure, psig	300.00	300.00
LHSV hr ⁻¹	1.12	1.12
H ₂ /HC Ratio	3.60	3.70
Number of Reactors	3.00	3.00
Catalyst Cycle Length, Months	10.00	11.00
Ultimate Catalyst Life	Three regenerations	

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

An RZ-100 unit can be used in parallel with a second conventional reforming unit to optimize the production of desired aromatics by processing different fractions of the hydrotreated feed. In such cases, the conventional reformer can be dedicated to processing the heavier feed fraction, taking advantage of its ability to produce xylenes.

The light naphtha stream, which is rich in C6 and C7 components, can be routed to the RZ-100 unit, where selectivity for converting light

paraffins to benzene and toluene is greater. The raffinate stream could also be recycled to the RZ-100 unit.

Feed from the hydrotreater and raffinate from the Sulfolane unit are depentanized before being treated in a sulphur guard bed. Then the feed is combined with recycle hydrogen, preheated by exchange with reactor effluent, heated to reaction temperature by a charge heater, and passed to the first reactor.

Since endothermic reactions cause the temperature to decrease, the effluent is reheated to reaction temperature and sent to the second reactor. Effluent from the second reactor is reheated and sent to the third reactor. Three reactors are required for the proposed RZ-100 Platforming unit proposed to ATC. Effluent from the third reactor is cooled before passing to the products separator drum.

Products separator gas, which is hydrogen-rich, is compressed, and combined with fresh feed to the unit. Net gas is taken from the products separator and compressed in a two stage counter-current recontacting scheme which maximizes recovery of C5+ liquids to the fractionation section. This also increases the purity of the by-product hydrogen stream.

Unstabilized reformat from the counter-current recontacting section is preheated by exchange with debutanizer column bottoms before being fed to the debutanizer column. The debutanizer column is reboiled by the fired heater convection section and a fired trim heater. Overheads from the column are partially condensed in the debutanizer condenser and collected in the debutanizer overhead receiver. Uncondensed vapours are recycled to the recontacting section. Some of the liquid is returned to the column as reflux and the remaining overhead liquid product is sent to the battery limits for recovery of LPG. The stabilized reformat product bottoms are cooled against the column feed and then the products cooler before being sent to the battery limits. Estimated yields from ATC's available light naphtha and reformat streams are shown in Table 5.B.2. Estimated conversion of the raffinate stream is 41.4 percent to BTX, while conversion to BTX of the combined light naphtha/raffinate stream increases slightly, to 43.0 percent, based on recycling raffinate from the aromatics unit to extinction.

2. Strengths and Weaknesses

RZ-100 is well suited for producers who desire benzene and toluene production over xylenes. ATC could convert their available raffinate and light naphtha streams to aromatics using an RZ-100 unit, then convert the toluene to xylenes using the existing Tatoray unit; the capacity and debottlenecking capabilities of the Tatoray unit should be confirmed

before proceeding further with this option. The RZ-100 technology is suitable for revamping existing or mothballed semi-regen reformers.

A small RZ-100 could be designed to process only the raffinate stream, or a larger one designed to process the combined raffinate and light naphtha stream.

3. Capital Investment

The estimated capital cost of an RZ-100 unit is \$108.7 million. Details are shown in Table 5.B.3. The total equipment cost includes a reformer, feed depentanizer, product stabilizer, and hydrotreater for the naphtha feedstock.

Table 5.B.2
RZ-100 Process Material Balance
(metric tons per year)

Feed Case	Raffinate	Raffinate and Light Naphtha
Feed to depentanizer:		
Feedstock	200,000	595,000
Additional recycle from aromatics unit	105,558	253,409
C5s- cut	67,374	237,890
Heavies – cut	9,791	9,181
Feed to RZ-100 unit	248,393	601,338
Products:		
Benzene	55,154	211,023
Toluene	41,846	41,555
Xylenes	5,911	4,865
C9+ aromatics	4,859	2,535
Fuel gas	7,040	15,951
H ₂	24,471	55,683
Light ends	9,066	20,521
Nonaromatics	100,046	248,305

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd, 1996-1997, Chem Systems Inc.

Table 5.V.B.3
RZ-100 Estimated Capital Cost
(SMM)

Feed Case	Raffinate + Light Naphtha
Total equipment cost	52.7
Engineering and design ¹	
Royalties ²	
Catalyst and platinum ³	18.3
Absorbent ⁴	0.3
Total inside battery limits	71.3
Modifications to existing plant	15.9
Outside battery limits	11.6
Total plant capital	98.8
Owner's project costs	9.9
Total capital investment	108.7

¹ Included in total equipment cost

² Information not available

³ Expected catalyst life is 2.5 years

⁴ Expected absorbent life is one year

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

4. Operating Costs

Estimated utility requirements for the RZ-100 unit are shown in Table 5.B.4.

Table 5.B.4

RZ-100 Estimated Utility Requirements

Feed Case	Raffinate + Light Naphtha	
Utilities	Units	Per Ton BTX
Electric power	kWh	137.3880
HP Steam (export) ¹	metric ton	(0.0281)
MP Steam	metric ton	0.7244
Boiler Feed Water	metric ton	0.7193
Fuel gas	metric ton	0.1375
Cooling Water	metric ton	31.5631
Hydrogen	metric ton	0.0021

1 "Export" indicates net production of HP Steam

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

TABLE 5.B.5
TOTAL CASH COST OF PRODUCTION ESTIMATE FOR : BTX
PROCESS : RZ-100

Plant start-up	2001	CAPITAL COST	MILLION US \$
Analysis date	1998	ISBL	71.3
Location	THAILAND	OSBL	11.6
Capacity	255.9 Thousand MT/yr	Total Plant Capital	82.9
		Other Project Costs	8.3
		Total Capital Investment	91.21
Throughput	230.3 Thousand MT/yr		

PRODUCTION COST SUMMARY		UNITS	PRICE		ANNUAL	
		Per MT	US \$ /	US \$	COST MM	US \$
		Product	Unit	Per MT	US \$	Per Lb
RAW MATERIALS	Light Naptha, MT	1.4986	268.0000	401.62	92.50	
	Raffinate (Bz extraction), MT	0.8045	268.0000	215.61	49.66	
	Catalyst & Chemicals		28.6000	28.06	6.59	
	TOTAL RAW MATERIALS			645.83	148.75	02.93
BY-PRODUCT CREDITS	C5 – cut	0.9208	268.0000	(246.77)	(56.84)	
	C9+aromatics, MT	0.0098	278.0000	(2.73)	(0.63)	
	Fuel Gas, MT	0.0617	260.0000	(16.05)	(3.70)	
	Hydrogen – reformer, MT	0.2149	260.0000	(55.87)	(12.87)	
	Heavy ends, ton	0.0163	268.0000	(4.37)	(1.10)	
	Light ends, MT	0.0794	260.0000	(20.64)	(4.75)	
	TOTAL BY-PRODUCT CREDITS			(346.44)	(79.79)	(0.157)
	NET RAW MATERIALS			299.39	68.96	0.136
UTILITIES	Power, kWh	137.5286	0.0626	8.61	1.98	
	Cooling Water, MT	31.5631	0.0349	1.10	0.25	
	Hydrogen-reformer, MT	0.0021	260.0000	0.56	0.13	
	Steam, MP, MT	0.7244	13.7600	9.97	2.30	
	Steam, HP, MT	(0.0281)	14.8700	(0.42)	(0.10)	
	Boiler Feed water, MT	0.7193	0.4968	0.36	0.08	
	Fuel, MT	0.1375	260.0000	35.74	8.23	
	TOTAL UTILITIES			55.91	12.88	0.025
	NET RAWMATERIALS & UTILITIES			355.30	81.84	0.161
	VARIABLE COST			355.30	81.84	0.161
DIRECT FIXED COSTS	Labour, 30 Men	16.15 Thousand	US \$	2.10	0.48	
	Foremen, 12 Men	32.38 Thousand	US \$	1.96	0.39	
	Supervisors, 2 Men	72.80 Thousand	US \$	0.63	0.15	
	Maint., Material & Labour	3.00 % of ISBL		9.29	2.14	
	Direct Overhead	45 % Labour & Supervision		1.99	0.46	
	TOTAL DIRECT FIXED COSTS			15.70	3.62	0.007
ALLOCATED FIXED COSTS	General Plant Overhead	65 % Labour & Maintenance		8.91	2.05	
	Insurance, Property Tax	1.0 % Total Plant Capital		3.609	0.83	
	TOTAL ALLOCATED FIXED COSTS			12.51	2.88	0.006
	TOTAL CASH COST			383.519	88.33	0.174

Source : Source : A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co., Ltd., 1996-1997, Chem Systems Inc.

The estimated cash cost of production, shown in Table 5.B.5, is estimated at \$384 per metric ton of BTX. RZ-100 has the second highest cash cost of production of the options under study.

5. Feedstock Requirements

Feedstocks to the RZ-100 Platforming unit can range from BTX extraction unit raffinates, to naphthas. After extraction, the low-value raffinate can be an excellent potential source for additional aromatics and hydrogen when processed by an RZ-100 unit.

Straight-run naphtha fractions can also be effectively processed with the RZ-100 catalyst. The full benefit of the RZ-100 unit is met by processing straight-run naphtha combined with recycled raffinate.

ATC's available light naphtha and raffinate streams are good feedstocks for the RZ-100 unit, after hydrotreating the light naphtha and depentanizing of both feedstreams.

6. Experience List

To date, UOP has licensed two RZ-100 units to unknown producers. The first unit is expected to start up in late 1997.

7. Integration with Existing Facilities

Integration of the RZ-100 unit (including depentanizer and hydrotreater) is somewhat more difficult than for the CYCLAR unit. The Sulpholane unit, which is the current bottleneck within the existing plant, will need to be expanded by about 50 percent. (This may actually be a new unit). The capacity of the benzene column will increase by about 76 percent and will require major revamping (possibly an additional column). Changes in other areas of the existing facilities are minor and can be handled without any significant investment.

As stated in CYCLAR Unit, at present on the second plot of land ATC has reserved a space of 36 rais for future expansion, while RZ-100 Unit needs 29 rais. Therefore, the plot of land available for expansion of the existing facilities is rather tight. UOP estimates that the addition of a semi-regeneration reformer, depentanizer, BTX stabilizer, hydrotreater, new sulpholane unit, additional benzene column will barely fit into the available plot space.

From Table 5F, it can be seen that the utilities will require an expansion of the medium pressure steam distribution that remains at 136,656 MT/yr, while RZ-100 uses 187,143 MT/yr, cooling water system that remains at 6,570,000 MT/yr, while RZ-100 uses 8,154,105 MT/yr, and boiler feed water system that remains at 118,260 MT/yr, while RZ-100 uses 185,826 MT/yr. As for other utilities such as power, Fuel gas are within the capability of the existing plant.

C. ASAHI CHEMICAL ALPHA PROCESS

1. General Process Description

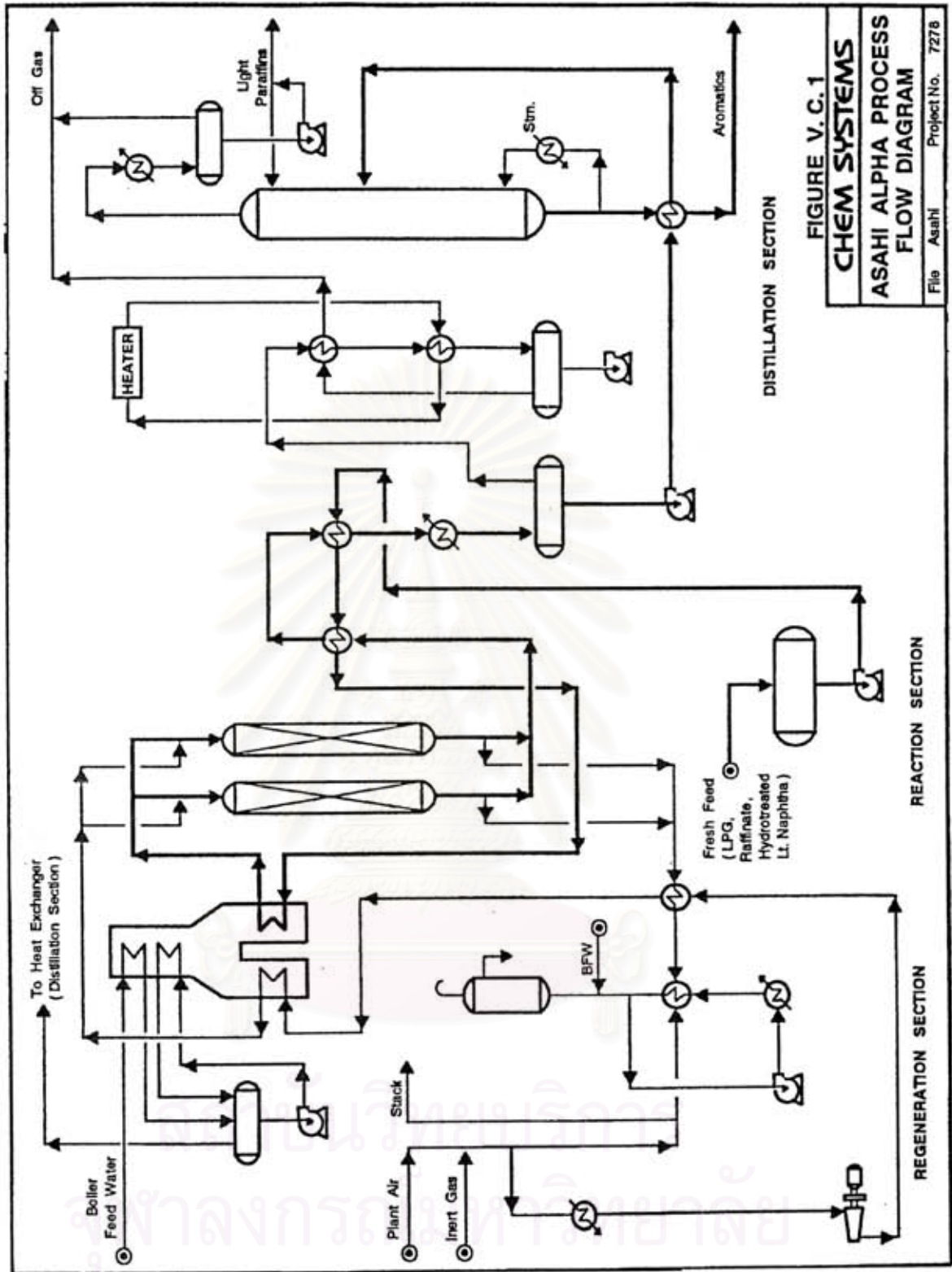
The process is a joint development of Asahi Chemical and its subsidiary Sanyo Petrochemical. It is reported that the acceptable range of feedstocks is from C3 to C8 olefins, although paraffinic hydrocarbons are also an acceptable feedstock.

In the case of light paraffins amortization, a larger volume of catalyst in multistage reactors, along with interstage reheating is required, because of the lower reactivity and larger heat adsorption of paraffins dehydrogenation and hydrocracking. The activity of the catalyst can be adjusted for maximum light naphtha conversion during the pre-conditioning stage, and would be performed by a small laboratory test before a final proposal to ATC.

The cyclization catalyst is a modified ZSM-5 type zeolite. This catalyst shows very high selectivity for amortization and very little coke formation. The cyclization reaction takes place between 490°C and 510°C using a C4/C5 feed, at a pressure of 5 Kg/cm²(g) in a fixed bed reactor.

A simplified process flow diagram is shown in Figure V.C.1. The fresh feed, consisting of LPG, light naphtha and raffinate, as well as a recycle by-product light paraffin stream are fed to the reaction section. The feedstock is pumped to obtain the required system pressure, heated, vaporized and further pre-heated to reaction temperature.

The swing reactor system consists of 4 sets of heaters and reactors connected in series. Catalyst regeneration occurs by periodically switching between reactors. The run length of the catalyst is controlled by adjusting the catalyst characteristics, and is determined by optimizing the investment and regeneration costs to meet the required product specifications. The reaction temperature is approximately 500°C. The reaction is highly exothermic, and Asahi claims that it requires very little external energy. The reactions consist of cracking, dehydrogenation of paraffins, oligomerization, and cyclization.



Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997; Chem Systems Inc

Patent data indicates that conversion of C5-C8 nonaromatics increases with increasing temperature; however, the selectivity to BTX appears to be at its optimum at about 550°C.

Benzene selectivity continues to increase with increasing temperature. Thus if benzene is the primary product sought, operation at a higher temperature may be justified.

Reactor effluent is cooled down by heat exchangers, and aromatics are condensed in a water-cooled condenser. Liquid product is fed to a stabilizer to reject the dissolved light hydrocarbons and the product aromatics are obtained from the bottom.

The major aromatics product in the BTX stream is toluene, the least desirable aromatic. However, with some debottlenecking, this toluene, along with the additional C9s, may be run through the existing Tatoray to produce additional mixed xylenes, which could be further converted in para-xylene, the preferred end-product. The capacities of the existing Tatoray, Sulpholane, and Parex/Isomar units would have to be considered before choosing this option.

Yield data for ATC's feedstocks is shown in Table 5.C.1. The conversion of the light naphtha and raffinate stream to BTX is 44.2 percent.

Table 5.C.1

ALPHA Process Material Balance
(metric tons per year)

Feedstock	
Combined LPG, light naphtha and raffinate	684,000
Products	
C6+ paraffins	4,945
Benzene	80,104
Toluene	134,945
Xylenes	88,015
C9+s	22,086
Off gas	354,356

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

2. Strengths and Weaknesses

One of the major differences between this process and the others under consideration is that an olefinic feed is preferred over paraffinic hydrocarbons. The reactivity and selectivity of olefins are higher than paraffins; thus the use of an olefinic feedstock gives some advantages to the alpha process, primarily in terms of energy requirements.

ATC's advantage of the ALPHA process is that ATC could process all three by-product streams in one Alpha process unit, after hydrotreating of the light naphtha stream.

3. Capital Investment

The estimated capital cost for an ALPHA process based reformer is \$135.2 million. Details are shown in Table 5.C.2. The total equipment cost includes a naphtha hydrotreater and an ALPHA-type reformer.

Table 5.C.2

**ALPHA Process Estimated Installed Capital Cost
(\$MM, Thailand basis)**

Feed Case	Raffinate + Light Naphtha
Total equipment cost	61.9
Engineering and design	1.1
Royalties	4.2
Catalyst ¹	10.7
Total inside battery limits	77.9
Modifications to existing plant	14.3
Outside battery limits	30.7
Total plant capital	122.9
Owner's cost	12.3
Total capital investment	135.2

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

4. Operating Costs

Estimated operating costs are shown in Table 5.C.3.

Table 5.C.3**ALPHA Process Estimated Utilities Consumption**

Feed Case		Raffinate + Light Naphtha
Utilities	Units	Per Ton BTX
Electricity	kWh	73.9360
Cooling water	metric ton	157.7700
Plant air	Nm ³	38.5000
Inert gas	Nm ³ (normal)	0.8684
	Nm ³ (maximum)	5.7890
Fuel gas	metric tons	0.1711
MP Steam	metric ton	(0.1361)
HP Steam	metric ton	0.0327
Hydrogen	metric ton	0.0018
Boiler Feed Water	metric ton	0.0095

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

The estimated cash cost of production, shown in Table 5.C.4, is \$367 per metric ton of BTX. The ALPHA process has the estimated cash cost per ton of BTX of the processes under consideration. However, the major aromatic produced is toluene, the least valuable of the three products.

5. Feedstock Requirements

The ALPHA process was developed to upgrade olefinic C4 raffinate and C5 raffinate which was used for fuel in Asahi's petrochemical complex since the start-up of the naphtha cracking unit. The catalyst was designed to take advantage of the high reactivity and reaction heat of olefins. Olefins are converted to aromatics at high selectivity.

Usually, C4 raffinates after the extraction of butadiene, or raffinate-2 after further extraction of I-butane for MTBE or MMA, and C5 raffinate after the extraction of isoprene and DCPD or after the partial hydrogenation of diolefins are used as feedstock for the ALPHA process. Also, partially hydrogenated C4s can be used as feedstock.

TABLE 5.C.4
TOTAL CASH COST OF PRODUCTION ESTIMATE FOR : BTX
PROCESS : ALPHA

Plant start-up	2001	CAPITAL COST	MILLION US \$
Analysis date	1998	ISBL	77.9
Location	THAILAND	OSBL	30.7
Capacity	302.6 Thousand MT/yr	Total Plant Capital	108.6
		Other Project Costs	10.9
		Total Capital Investment	119.5
Throughput	272.4 Thousand MT/yr		

PRODUCTION COST SUMMARY		UNITS	PRICE	US \$	ANNUAL	US \$
		Per MT	US \$ /	Per MT	COST MM	Per Lb
		Product	Unit		US \$	
RAW MATERIALS	LPG, MT	0.2941	266.0000	78.23	21.31	
	Light Naphtha, MT	1.2392	268.0000	332.11	90.45	
	Raffinate (Bz extraction), MT	0.7270	268.0000	194.84	53.06	
	Catalyst & Chemicals		1107900	11.79	3.21	
	TOTAL RAW MATERIALS			616.97	168.03	0.280
BY-PRODUCT CREDITS	C6+ nonaromatics, MT	0.0163	268.0000	(4.38)	(1.19)	
	C9+ aromatics, MT	0.0730	278.0000	(20.29)	(5.53)	
	Hydrogen/Fuel gas, MT	1.1710	260.0000	(304.46)	(82.92)	
	TOTAL BY-PRODUCT CREDITS			(329.13)	(89.64)	(0.149)
	NET RAW MATERIALS			287.84	78.398	0.131
UTILITIES	Power, kWh	73.93608	0.0626	4.63	1.26	
	Cooling Water, MT	15776592	0.349	5.51	1.50	
	Inert Gas, Nm3	0.8684	0.0472	0.04	0.01	
	Steam, MP, MT	(0.1361)	13.7600	(1.87)	(0.51)	
	Steam, HP, MT	0.0327	14.8700	0.49	0.13	
	Hydrogen-reformer, MT	0.0018	260.0000	0.47	0.13	
	Fuel, MT	0.1711	260.0000	44.47	12.11	
	Boiler Feed water, MT	0.0095	0.4968	0.00	0.00	
	TOTAL UTILITIES			53.74	14.64	0.024
	NET RAWMATERIALS & UTILITIES			341.58	93.03	0.155
	VARIABLE COST			341.58	93.032	0.155
DIRECT FIXED COSTS	Labour, 24 Men	16.15 Thousand US \$		1.42	0.39	
	Foremen, 12 Men	32.38 Thousand US \$		1.43	0.39	
	Supervisor, 2 Men	72.80 Thousand US\$		0.53	0.15	
	Maint.,Material&Labour	3.00 % of ISBL		8.58	2.34	
	Direct Overhead	45 % Labour & Supervision		1.52	0.41	
	TOTAL DIRECT FIXED COSTS			13.49	3.67	0.006
ALLOCATED FIXED COSTS	General Plant Overhead	65 % Labour & Maintenance		7.788	2.12	
	Insurance, Property Tax	1.0 % Total Plant Capital		3.99	1.09	
	TOTAL ALLOCATED FIXED COSTS			11.76	3.20	0.005
	TOTAL CASH COST			366.83	99.91	0.166

Source : Source : A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co., Ltd., 1996-1997, Chem Systems Inc.

LPG can also make a good feedstock for the ALPHA process. If an alkylation unit is not employed to produce marketable LPG, then the ALPHA process can be used to convert the LPG into BTX.

Additionally, C5 and C6 fraction from cracked gasoline make good feedstocks for the ALPHA process for BTX production.

Light paraffins can be employed in the process, using a large volume of catalyst in multistage reactors and interstage reheating, due to the lower reactivity and larger head absorption of paraffins dehydrogenation and cracking.

6. Experience List

Sanyo's ALPHA process has been commercial since July 1993. A 3,500 BPD unit (40,000 metric ton per year of benzene) is located at the company's Mizushima complex in Okayama, Japan, taking C4-C5 feed from the adjacent olefins plant as feedstock. Plant operations have been stable to date.

7. Integration with Existing Facilities

The integration of the ALPHA unit with the existing plant will be more difficult than for either the CYCLAR or RZ-100 processes. As for the others, the Sulpholane unit will either need to be expanded or an additional unit added. The capacity increase for 3 other units (benzene column, toluene column and Tatoray unit) are between 20 and 22 percent. It is expected that these facilities can be debottlenecked.

From the 36 rai of land available, ALPHA unit needs 32 rai. Therefore, fitting the ALPHA Unit (together with a hydrotreater, new sulpholane unit and BTX stabilizer) within the existing plot of land will be tight.

From Table 5F, it can be seen that a significant amount of investment is needed in the utilities area. The additional power requirements will exceed the current capacity, so a new transformer will be required as a minimum. Also, the cooling water system will need to be expanded as well.

D. CHEVRON'S AROMAX PROCESS

1. General Process Description

The AROMAX process is very similar to conventional catalytic reforming, with the exception of extra sulfur removal facilities and the high paraffinicity of the feedstock. The proprietary catalyst is an L-type zeolite synthesized in such a way as to have a high proportion (greater than 80 percent) of large crystals (i.e., larger than 1,000 angstroms). The typical pore size for this type of zeolite is 7 to 9 angstroms. The catalyst is very sensitive to sulphur and water, thus, more sophisticated sulfur removal facilities have been included in the flow scheme. One of the major drawbacks of this process is the high yield of toluene, which is of the lowest commercial value of the three major aromatics. Therefore, it is recommended that the toluene be processed in ATC's Tatoray unit to produce benzene and mixed xylenes. The mixed xylenes could further be processed in the Parex unit produce the desired end product, para-xylene.

A general flow scheme for an AROMAX unit is shown in Figure V.D.1. The feed must be very effectively desulfurized to ensure that catalyst activity is maintained throughout the run. A typical residual sulfur level of less than 0.1 ppm is cited by Chevron. Chevron has developed a two-stage proprietary sulfur-control system that is shown inside the dotted box in Figure V.D.1.

The first stage absorber, containing a supported cupric oxide absorbent, operates at about 300F to absorb residual hydrogen sulfide from the stripped feed; the second-stage reactor/absorber operates at a high temperature in the presence of recycle hydrogen to remove the last traces of sulfur-containing species from the feed naphtha.

The reforming section can be a semiregenerative (SR), cycle, or continuous catalyst regeneration (CCR) type. The refrigeration section has been added to reduce benzene losses in the separator drum overhead gas to an acceptable level. Countercurrent liquid extraction could also be used for this step. The low-pressure operation (100 psig reactor outlet pressure), narrow boiling range of the feedstock, and high hydrogen yield make liquid benzene recovery more difficult. The recycle gas dryer is assumed to also contain a portion of sulfur absorbent material to keep the sulfur content in the recycle as to a very low level.

Recycle gas is circulated by a centrifugal compressor that compresses the gas to suitable pressure for recontacting in the upstream absorber/deethaniser for BTX and LPG recovery. The separator liquid is sent to a debutanizer where the C4 material is separated and sent overhead

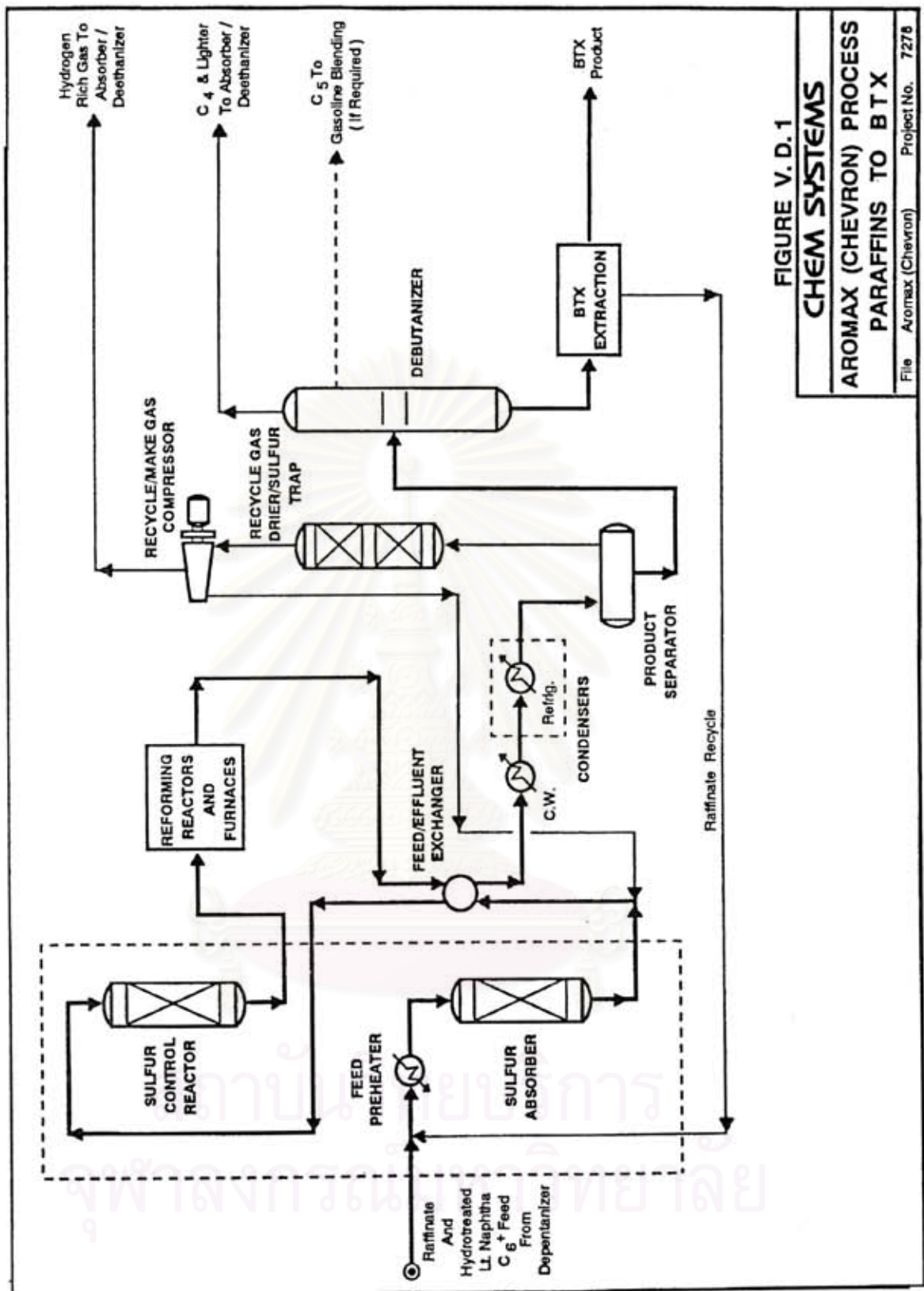


FIGURE V. D. 1

CHEM SYSTEMS

AROMAX (CHEVRON) PROCESS
PARAFFINS TO BTX

File Aromax (Chevron) Project No. 7278

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

to the absorber/deethaniser for LPG recovery. A C5-rich sidestream may also be withdrawn here to purge out any accumulation of C5 material that may be present either because it was not recovered in the upstream fractionation facilities or generated via cracking reactions in the reaction section.

The debutanizer bottoms stream is routed to the BTX extraction unit where product is extracted and unconverted paraffins are recovered for recycle to the AROMAX reformer.

A summary of the design parameters used in the process are shown in Table 5.D.1.

Table 5.D.1

AROMAX Reforming Design Parameters

Average reactor pressure, psig	150
Reactor temperature, °F	850-950
Recycle gas rate, SCF/bbl (based on total feed)	6,300
Recycle gas ratio, H ₂ :HC	5:1
LHSV, hr ⁻¹	1.5

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

Approximate yields from ATC's available feedstocks are shown in Table 5.D.2. Conversion of the combined light naphtha/raffinate feed to benzene and toluene is estimated at 44.2 percent of the available, feed, or 70.0 percent after removal of unusable C5s and below in the feedstream. However, the AROMAX does not produce many xylenes, and ATC would have to process the toluene in their existing Tatoray unit to convert this toluene to mixed xylenes.

Table 5.D.2

AROMAX Process Material Balance
(metric tons per year)

Feedstock

Combined raffinate and light naphtha	595,000
C5s – cut	215,345
Feed to aromax	379,655

Products	
Benzene	231,246
Toluene	49,722
Xylenes	8,574
C9+ aromatics	2,384
Fuel gas	28,637
H2 21,566	
Nonaromatics	37,475

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

2. Strengths and Weaknesses

The AROMAX is a good aromatics conversion process for the production of BTX, (approximately 76 percent of the fractionated light naphtha and raffinate feedstock). Using ATC's available feedstocks, benzene is the primary product. To produce xylenes the toluene should be fed to ATC's Tatoray Unit.

Chevron no longer licenses the process. It is available only as part of a joint-venture agreement.

The relative size of the AROMAX unit for ATC would be small in comparison with a larger-world scale size unit. (This may be true for all of ATC's options).

Additional capital expenditure is required for a depentanizer to separate the C5s and lighter hydrocarbons from the raffinate and light naphtha streams for feed to the AROMAX. Also, the added expense of a naphtha hydrotreater is required.

The AROMAX unit is designed to process high paraffinic naphthas, which is the type of feedstock ATC has available.

3. Capital Investment

The estimated capital cost for an AROMAX unit, Thailand basis, year 2000, is \$107.6 million. Details are shown in Table 5.D.3. Total equipment cost includes a depentanizer, stabilizer, naphtha hydrotreater, and an AROMAX reformer.

Table 5.D.3
AROMAX Estimated Capital Cost
(\$MM, Thailand Basis)

Feed	Raffinate + Light Naphtha
Total equipment cost	57.5
Engineering and design	11.5
Royalties ¹	
Catalyst ²	4.1
Total inside battery limits	73.1
Modifications to existing units	17.0
Outside battery limits	7.7
Total plant capital	97.8
Owner's cost	9.8
Total capital investment	107.6

¹ Unknown, since Chevron no longer licenses the process

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem System Inc.

4. Operating Costs

Estimated utilities costs are shown in Table 5.D.4.

Table 5.D.4
AROMAX Process Estimated Utilities Consumption
(per ton of BTX produced)

Utilities	Units	Per Ton BTX
Power	kWh	217.5700
HP Steam	metric tons	0.8442
MP Steam	metric tons	0.4268
Cooling water	metric tons	99.8400
Fuel gas	metric tons	0.2177
Hydrogen	metric tons	0.0019
Boiler feed water	metric tons	0.0099

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

TABLE 5.D.5
TOTAL CASH COST OF PRODUCTION ESTIMATE FOR : BTX
PROCESS : AROMAX

Plant start-up	2001	CAPITAL COST		MILLION US \$		
Analysis date	1998	ISBL		73.1		
Location	THAILAND	OSBL		7.7		
Capacity	289.6 Thousand MT/yr	Total Plant Capital		80.8		
		Other Project Costs		8.1		
		Total Capital Investment		88.9		
Throughput	260.6 Thousand MT/yr					
PRODUCTION COST SUMMARY						
		UNITS	PRICE	US \$	ANNUAL	US \$
		Per MT	US \$ /	Per MT	COST MM	Per Lb
		Product	Unit		US \$	
RAW MATERIALS	Light Naphtha, MT	1.2949	268.0000	347.04	90.45	
	Raffinate (Bz extraction,) MT	0.7597	268.0000	203.60	53.06	
	Catalyst & Chemicals		4.71930	4.72	1.23	
	TOTAL RAW MATERIALS			555.36	144.74	0.252
BY-PRODUCT CREDITS	C5 – cut	0.7436	268.0000	(199.28)	(51.94)	
	C9+ aromatics, MT	0.0082	278.0000	(2.29)	(0.06)	
	C5-C6 Raffinate, MT	0.1294	268.0000	(34.68)	(9.04)	
	Fuel gas, MT	0.0989	260.0000	(25.71)	(6.70)	
	Hydrogen, MT	0.0745	260.0000	(19.36)	(5.05)	
	TOTAL BY-PRODUCT CREDITS			(281.33)	(73.32)	(0.128)
	NET RAW MATERIALS			274.03	71.428	0.124
UTILITIES	Power, kWh	217.5712	0.0626	13.62	3.55	
	Cooling Water, MT	99.8402	0.349	3.49	0.91	
	Hydrogen-reformer, MT	0.0019	260.0000	0.49	0.13	
	Steam, MP, MT	0.4268	13.7600	5.87	1.53	
	Steam, HP, MT	0.8442	14.8700	12.55	3.27	
	Boiler Feed water, MT	0.0099	0.4968	0.00	0.00	
	Fuel, MT	0.2177	260.0000	56.61	14.75	
	TOTAL UTILITIES			92.64	24.14	0.042
	NET RAWMATERIALS & UTILITIES			366.67	93.039557	0.166
	VARIABLE COST			366.67	95.572	0.166
DIRECT FIXED COSTS	Labour, 30 Men	16.15 Thousand US \$		1.86	0.48	
	Foremen, 12 Men	32.38 Thousand US \$		1.49	0.39	
	Supervisor, 2 Men	72.80 Thousand US \$		0.56	0.15	
	Maint., Material & Labour	3.00 % of ISBL		8.41	2.19	
	Direct Overhead	45 % Labour & Supervision		1.76	0.46	
	TOTAL DIRECT FIXED COSTS			14.08	3.67	0.006
ALLOCATED FIXED COSTS	General Plant Overhead	65 % Labour & Maintenance		8.01	2.09	
	Insurance, Property Tax	1.0 % Total Plant Capital		3.10	0.81	
	TOTAL ALLOCATED FIXED COSTS			11.11	2.90	0.005
	TOTAL CASH COST			391.86	102.13	0.178

Source : Source : A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co., Ltd., 1996-1997, Chem Systems Inc.

The estimated cash cost of production for the AROMAX process, shown in Table 5.D.5, is \$392 per metric ton of BTX. This is the highest cash cost of product of the options under study.

5. Feedstock Requirements

AROMAX is designed to process highly paraffinic light naphtha feedstocks.

ATC's light naphtha and raffinate are good feedstocks for the AROMAX, after removing the C5 and lighter hydrocarbons via a depentanizer. The light naphtha stream also requires hydrotreating to remove excess sulfur. The LPG stream is not a suitable feedstock.

6. Experience List

Chevron's project in its Pascagoula refinery was started up in late 1993. The facility has a capacity of 150 million gallons per year (500,000 metric tons per year) of benzene. The facility can also produce toluene and xylenes from a low quality naphtha feedstock. The project included significant modifications to the existing fractionation section as well as the addition of the AROMAX unit.

7. Integration with Existing Facilities

The integration of the AROMAX unit with the existing facilities will be similar to that of the RZ-100 unit discussed previously in this report. As for the RZ-100 unit, major renovations will be required to the Sulpholane unit and benzene column (or new, parallel units added). The OSBL will require slightly less modification.

On the available 36 rai plot of land, AROMAX unit needs around 28 rai. Therefore, the space requirement is the same as for the RZ-100 Unit.

As for the utilities, only HP steam and cooling water system need to be expanded, while the electricity, MP steam, boiler feed water, fuel gas and hydrogen are still within the capacity of the exiting utilities.

E. MITSUBISHI/CHIYODA Z-FORMER PROCESS

1. General Process Description

The major reaction steps of the Z-Former process of Mitsubishi Oil Co. and Chiyoda Corp. are dehydrogenation of paraffins followed by oligomerization and dehydrocyclization. This process can be used to convert LPG, light naphtha, and raffinate into aromatics, in the presence of a zeolite based catalyst. The zeolite catalyst is formed from metallosilicate and a specialized binder.

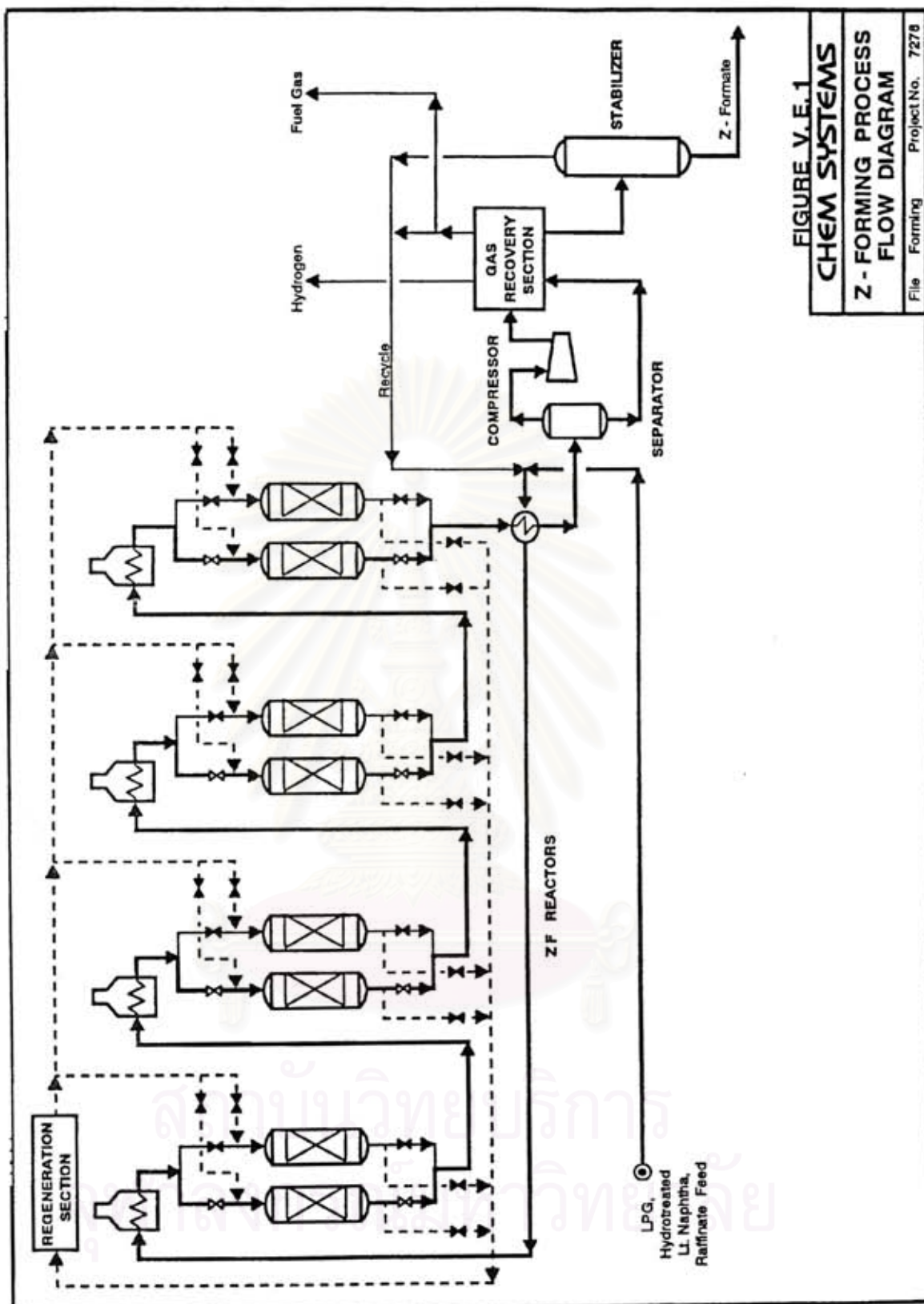
A process flow scheme of the Z-Former process is shown in Figure V.E.1. The reactor section uses a fixed bed switching reactor system. Four reactors are arranged in series. The multistage reactor is used because the reaction is highly endothermic. Heat is supplied by interheaters located between the reactors. Regeneration is accomplished by burning off the coke deposited on the catalyst. Two reactor trains are provided so that one can be regenerated while the other is in normal operation. Since catalyst activity is adversely affected by water, a dryer is required to remove water resulting from coke combustion, to keep the circulation gas dry.

ATC's LPG and raffinate streams can be fed directly to the process, whereas light naphtha feed requires hydrotreating first to remove sulfur. The sulfur in the light naphtha stream is not harmful for the Z-Former reaction, but sulfur in the coke deposited on the catalyst which converts to SO_x might cause corrosion of the regeneration circuit.

Operating conditions are similar to that of catalytic reforming except that the temperature is slightly higher and the pressure is slightly lower. The inlet temperature for each reactor is 500-600°C, the reaction pressure 3-7 kg/cm²G, and the LHSV 0.5-2.0/h. As severity increases (e.g. lower reaction pressure, greater heat supply, or lower LHSV), the yield of aromatics is found to increase although the operating costs increase at the same time.

The products of the process are hydrogen-rich fuel gas, BTX and C₉+aromatics. Fuel gas includes hydrogen and C₁ to C₅ hydrocarbons that are formed in the reaction. The fuel gas is suitable for power generation. High purity hydrogen can be obtained by using a PSA unit if needed.

Part of the off gas is recycled to the reactor section as a heat carrier. This lowers the hydrogen partial pressure of the reaction system and accelerates the dehydrogenation reaction. The remaining off-gas is discharged from the system as fuel gas. The liquid fraction is sent to the



Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc

stabilizer, and bottoms from this tower is BTX which can then be fractionated. The stabilizer overhead is recycled to the reactor section together with the recycle off-gas.

The catalyst regeneration method is similar to that of a conventional catalytic reformer. By introducing air into a circulating nitrogen flow, the coke on the catalyst is burned off. The time required for regeneration is short, and is usually completed while the catalyst in the reaction phases maintains activity.

Between 80 and 90 percent of the aromatic product is BTX, as shown in Table 5.E.1. The other 10-20 percent is C9+ aromatics. The BTX component is mostly toluene (i.e., 44 to 48 percent), which is also the one of least value. The yield based on C3-C5 fresh feed ranges from 50 to 60 percent. The higher yields correspond to the higher carbon number feedstocks. The BTX yield of the LPG is the lowest at 52 percent, while light naphtha's yield is the highest at 62 percent. (Yields are based on the High Aromatics Yield case presented by Chiyoda).

Using LPG and light naphtha feeds, the BTX can be separated via distillation alone, without solvent extraction. However, Mitsubishi's tests indicate that the raffinate separated from the catalytic reformat has a wide variety of paraffins, and the purity of BTX obtained only by distillation would tend to be lower due to shape selectivity of the Z-FORMER catalyst, solvent extraction may be required ahead of distillation.

Table 5.E.1
Z-FORMER Process Material Balance
(Metric tons per year)

Feed Case	LPG	Light Naphtha	Raffinate	LPG + Light Naphtha + Raffinate
Feedstock:	89,000	375,000	220,000	684,000
Products:				
Benzene	14,600	90,000	41,800	146,400
Toluene	20,800	93,700	55,000	169,500
Xylenes	11,000	48,800	26,400	86,200
C9+ aromatics	6,600	22,500	24,200	53,300
H2 rich fuel gas	36,000	120,000	72,600	228,600

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

The three feedstocks could be combined in any combination to maximize the aromatics production. To maximize economies of scale for the Z-FORMER unit, all three streams could be combined, along with a hydrotreater for the light naphtha stream. To eliminate the additional cost of a hydrotreater, the LPG and raffinate streams could be combined. However, using the raffinate stream may result in the additional capital and operating costs associated with solvent extraction.

2. Strengths and Weaknesses

The Z-FORMER process is generally suitable, from an economical view point, for a plant with relatively small or medium size capacity of 15,000 BPSD or less, since it adopts a switching reactor system. Therefore, ATC's available feedstocks are well suited to this process.

For the light naphtha feed, the additional capital cost for a hydrotreater is necessary to ensure sulfur removal, in order to meet the BTX product specifications and to prevent corrosion of the catalyst regeneration circuit.

In order to use the raffinate stream, solvent extraction may be required, resulting in additional capital and operating costs.

An advantage of the Z-FORMER process is its ability to accept all of ATC's available feedstocks of LPG, light naphtha, and raffinate without having to fractionate the naphtha and raffinate streams first.

Since aromatics yields increase at lower reaction pressures and greater heat supply to the reaction (or lower LHSV), the plant can be designed to suit the manufacturer's requirements.

⇒ Low Investment Cost case, resulting in lower aromatics yields, (about 10 percent less) with correspondingly lower investment and operating costs.

⇒ High Aromatics Yield case, with the plant designed to maximize aromatics yields, with higher construction and operating costs (about 15 percent higher).

Either a switching or cyclic reactor system can be applied to the Z-FORMER process. While a switching reactor maximizes aromatics production, a cyclic system offers lower capital investment. Mitsubishi/Chiyoda recommend a switching reactor system for ATC to maximize aromatics production.

3. Capital Investment

The estimated capital investment cost is \$158.8 million (2000, Thailand). Details are shown in Table 5.E.2. When light naphtha is used as a feedstock, the estimated cost of a naphtha hydrotreater is included in the total equipment cost. A solvent extraction unit is not included in the equipment cost for these cases including this feed stream.

Table 5.E.2

Z-FORMER Process Estimated Capital Investment Cost (\$MM)

Feed	LPG + Lt. Naphtha + Raffinate
Total equipment cost	74.1
Engineering and design ¹	
Royalties ¹	
Catalyst ²	8.1
Total inside battery limits	82.2
Modifications to existing units	21.5
Outside battery limits	40.6
Total plant capital	144.3
Owner's cost	14.4
Total capital investment	158.8

¹ Included in Total Equipment Cost

² Estimated catalyst life is one year

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd, 1996-1997, Chem Systems Inc.

4. Operating Costs

Estimated utility consumption are shown in Table 5.E.3.

Table 5.E.3

Z-FORMER Process Estimated Utilities Consumption (per ton of BTX produced)

Feed Case		LPG + Lt. Naphtha + Raffinate
Utilities	Units	Per Ton BTX
Power	kWh	116.9840
Fuel gas	metric tons	0.1351
HP Steam	metric tons	1.1738
LP Steam	metric tons	0.1773
Cooling water	metric tons	146.3282
Boiler feed water	metric tons	0.4727
Inert gas	Nm ³	2.7966
H ₂		0.0014

Source: A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co.,Ltd., 1996-1997, Chem Systems Inc.

The estimated cash cost of production for the Z-FORMER process, shown in Table 5.E.4, is \$379 per metric ton, the second lowest of all the options under study.

5. Feedstock Requirements

LPG, light naphtha, and raffinate are all suitable feedstocks for the Z-FORMER process, although resulting product yields and utility consumptions vary due to differences in feedstock characteristics.

ATC.'s light naphtha feedstock is the most suitable of the three for the Z-FORMER process. However, a hydrotreater is required to remove sulfur, to meet BTX product specifications and to prevent corrosion of the catalyst regeneration circuit.

No pretreating of the LPG is necessary, provided the LPG contains no sulfur, making ATC's LPG stream suitable for Z-FORMER. However, the aromatics yields from LPG are the lowest of the three feedstocks available.

ATC's available raffinate is rich in paraffins, making it suitable feedstock for the Z-FORMER process.

TABLE 5.E.4
TOTAL CASH COST OF PRODUCTION ESTIMATE FOR : BTX
PROCESS : Z-FORMER

Plant start-up	2001	CAPITAL COST	MILLION US \$
Analysis date	1998	ISBL	82.2
Location	THAILAND	OSBL	40.6
Capacity	402.1 Thousand MT/yr	Total Plant Capital	122.8
		Other Project Costs	12.3
		Total Capital Investment	135.1
Throughput	361.9 Thousand MT/yr		

PRODUCTION COST SUMMARY		UNITS	PRICE	US \$	ANNUAL	US \$
		Per MT	US \$ /	Per MT	COST MM	Per Lb
		Product	Unit		US \$	
RAW MATERIALS	LPG, MT	0.2213	266.0000	58.88	21.31	
	Light Naphtha, MT	0.9326	268.0000	249.94	90.45	
	Raffinate (Bz extraction), MT	0.5471	268.0000	146.63	53.06	
	Catalyst & Chemicals		20.1442	20.14	7.29	
	TOTAL RAW MATERIALS			475.59	172.11	0.216
	C9+aromatics, MT	0.1326	278.0000	(36.85)	(13.34)	
	Hydrogen/Fuel gas, MT	0.5685	260.0000	(147.81)	(53.49)	
	TOTAL BY-PRODUCT CREDITS			(184.66)	(66.83)	(0.084)
	NET RAW MATERIALS			290.92	105.28	0.132
UTILITIES	Power, kWh	116.9838	0.0626	7.32	2.65	
	Cooling Water, MT	146.3282	0.0349	5.11	1.85	
	Steam, LP, MT	0.1733	13.4700	2.33	0.84	
	Boiler Feed water, MT	0.4727	14.8700	17.45	6.32	
	Fuel, MT	0.1351	0.4968	0.23	0.08	
	Inert Gas, Nm3	2.7966	260.0000	35.13	12.71	
	Hydrogen-reformer, MT	0.0014	0.0472	0.13	0.05	
	TOTAL UTILITIES		260.0000	0.36	0.13	
	NET RAWMATERIALS & UTILITIES			68.08	24.64	0.031
	VARIABLE COST			359.00	129.92	0.163
DIRECT FIXED COSTS	Labor, 24 Men	16.15 Thousand	US \$	1.07	0.39	
	Foremen, 12 Men	32.38 Thousand	US \$	1.07	0.39	
	Super., 2 Men	72.80 Thousand	US \$	0.40	0.15	
	Maint., Material & Labour	3.00 % of ISBL		6.81	2.047	
	Direct Overhead	45 % Labour & Supervision		1.15	0.41	
	TOTAL DIRECT FIXED COSTS			10.51	3.80	0.005
ALLOCATED FIXED COSTS	General Plant Overhead			6.08	2.20	
	Insurance, Property Tax			3.39	1.23	
	TOTAL ALLOCATED FIXED COSTS			9.48	3.43	0.004
	TOTAL CASH COST			378.99	137.15	0.172

Source : Source : A final Report: By-Product Upgrading Technologies, prepared for The Aromatics (Thailand) Public Co., Ltd., 1996-1997, Chem Systems Inc.

6. Experience List

The demonstration plant (200 BPD) at Mitsubishi Oil's Kawasaki refinery began operating in November 1990 and was shut down in December 1991 at the end of the planned demonstration run. Both LPG and light naphtha feedstocks were run during the demonstration period. A 10,000 BPD commercial facility is expected to produce about 140,000 metric tons per year of BTX.

7. Integration with Existing Facilities

The integration of the Z-FORMER process with the existing facilities is even more difficult than the ALPHA process discussed earlier in this report. This is not unexpected, considering that the Z-FORMER process produces more aromatics than any of the other technologies studied herein. In the ISBL areas a new sulfolane unit and benzene column will be required (additional capacities are at 68 and 50 percent of the existing capacity, respectively). The toluene column and Tatoray unit will have their capacities increased by 28 and 26 percent, respectively. It is expected that these latter units can be debottlenecked to meet these new capacity requirements.

The Z-FORMER Unit requires up to 33 rai of land. Therefore, the space requirement will be equal to or greater than any of the other technologies studied herein. CHIYODA has estimated that the Z-FORMER Unit can fit into one of the two plots of land available and the hydrotreater and stabilizer can fit into the other plot.

From Table 5F, it can be seen that the utility are will need additional investment in the electricity distribution (including a new transformer), high-pressure and low-pressure steam distribution from the central utilities, cooling water system, and the boiler feed water system.

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Table 5 F The comparison of estimated utilities requirement of five technologies

	Utility rate of The Aromatics				CYCLAR	ALPHA	RZ-100	AROMAX	Z-FORMER
	Existing	Design	Consumption	Availability					
Electricity (kWhr/yr)	204,000,000	170,000,000	153,000,000	51,000,000	3,799,614	52,374,068	35,493,228	42,995,652	57,039,266
HP steam (MT/yr)	578,160	481,800	433,620	144,540	40,554	9,895	7,259	244,431	471,984
MP steam (MT/yr)	546,624	455,520	409,968	136,656	-	41,185	187,143	123,576	
LP steam (MT/yr)	241,776	201,480	181,332	60,444	2,062	-	-	-	71,292
Boiler feed water (MT/yr)	473,040	394,200	354,780	118,260	45,351	2,874	185,826	2,866	190,072
Cooling water (MT/yr)	26,280,000	21,900,000	19,710,000	6,570,000	3,964,731	47,743,410	8,154,105	28,907,873	58,838,569
Fuel gas (Nm3)	8,409,600	7,008,000	6,307,200	2,102,400	10,728	51,777	35,526	63,033	54,323
Hydrogen (Nm3)	315,360,000	262,800,000	236,520,000	78,840,000	-	545	542	550	562
Plant air (Nm3)	52,560,000	43,800,000	39,420,000	13,140,000	-	11,650,640	-	-	-
Inert gas (Nm3)	10,512,000	8,760,000	7,884,000	2,628,000	-	262,790	-	-	1,124,512

Source : Engineering Division , The Aromatics (Thailand) Public Co.,Ltd

CHAPTER 6

TECHNICAL ANALYSIS

This chapter technically analyzes the five available technologies for the upgrading of ATC's by-products. In this Chapter, the analysis result will point out the reasons why ATC should select such technologies to convert its by-products into main products.

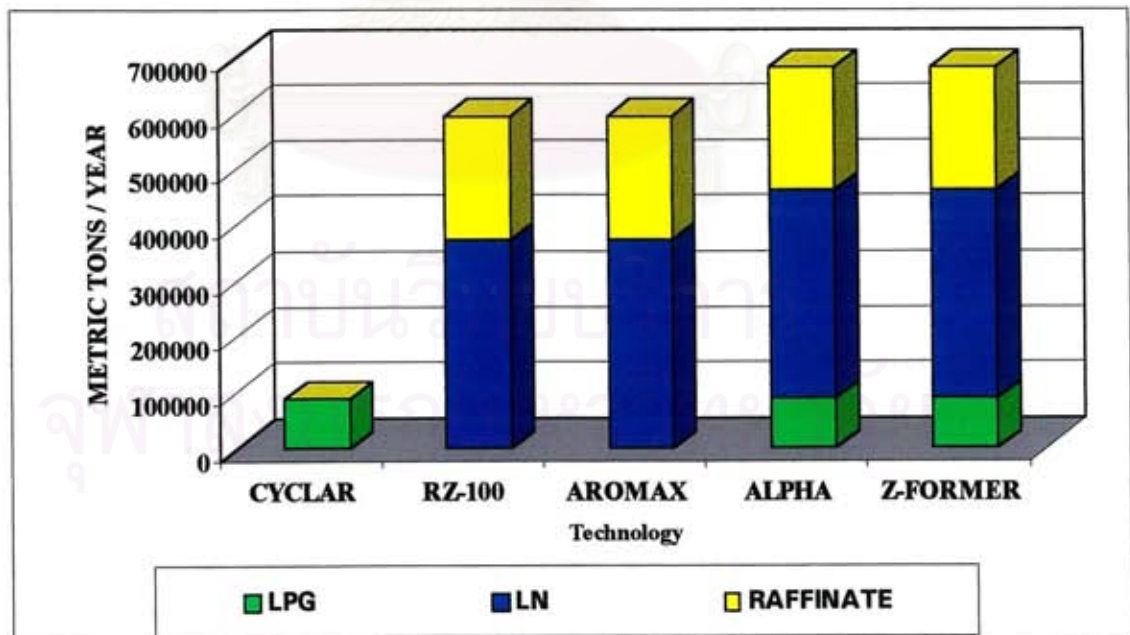
From chapter 5, the data of five technologies can be summarized as follows:

6.1 Feedstock Suitability

The ATC feedstocks which are suitable for each process and quantities are shown in Figure 6.1

FIGURE 6.1

FEEDSTOCK CAPACITY BY PROCESS

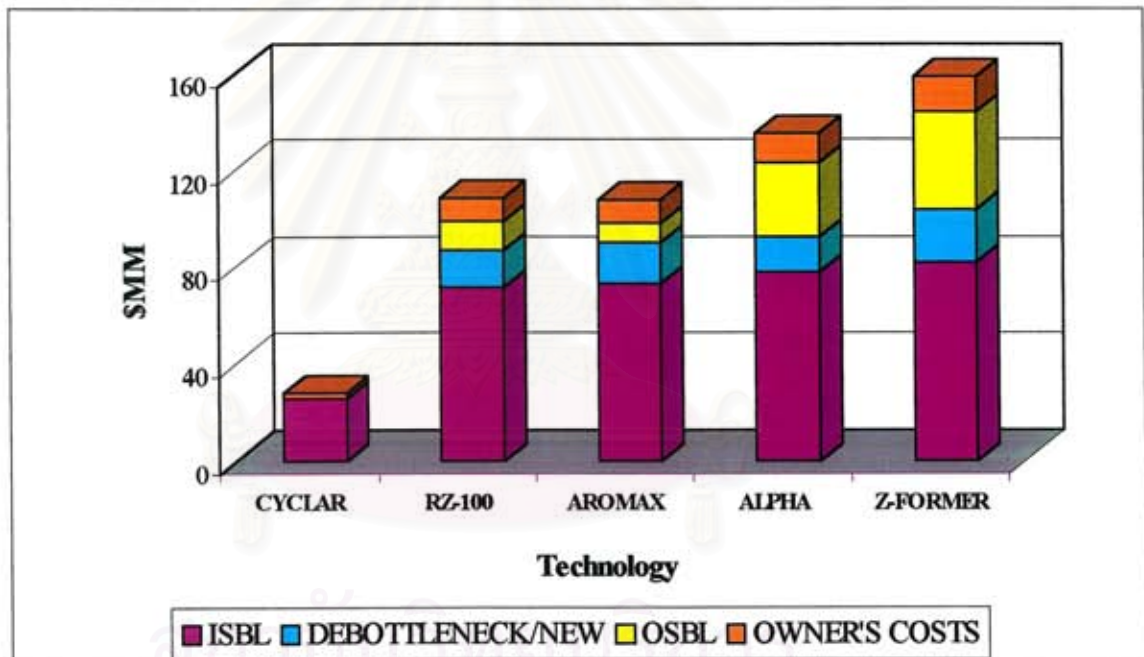


Only the ALPHA and Z-FORMER processes are suitable to handle all three of ATC's feeds. The CYCLAR process could be used in conjunction with either the RZ-100 or AROMAX processes to handle a majority of the feeds, but this will require parallel units.

6.2 Investment Cost

Figure 6.2 summarizes investment cost for the five processes under consideration.

FIGURE 6.2
ESTIMATED CAPITAL COST

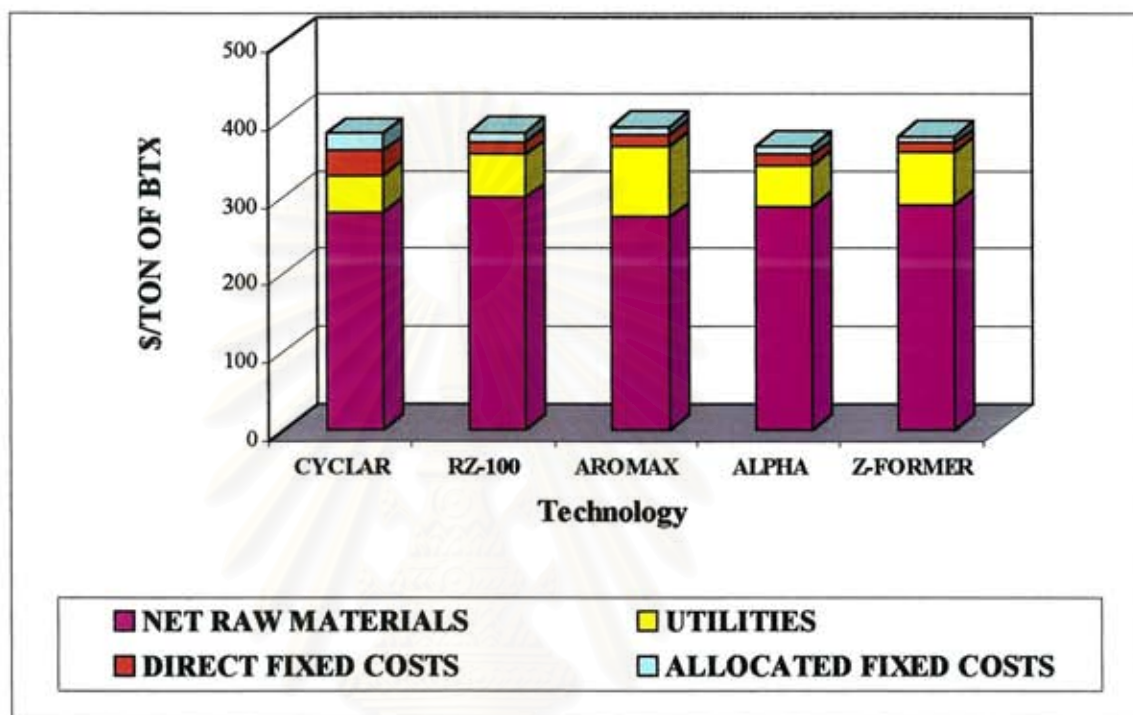


CYCLAR has the lowest estimated capital cost at \$27.8 Million, while the Z-FORMER process has the highest, at \$158.7 Million.

6.3 Cost of Production

FIGURE 6.3

TOTAL CASH COST OF PRODUCTION COMPARISON



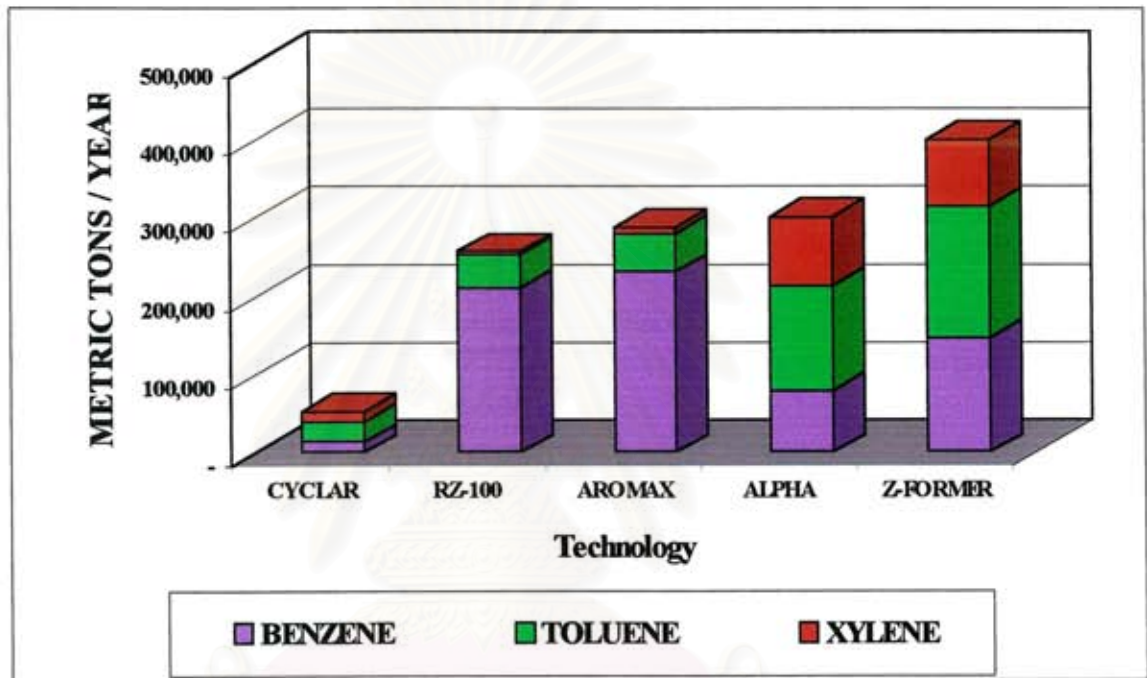
As shown in Figure 6.3, the ALPHA process has the lowest estimated cash cost of production per ton of BTX produced, at \$367 per metric ton of BTX.

The Z-FORMER, CYCLAR, RZ-100 and AROMAX estimated costs of production are within \$13 per ton of BTX, ranging from \$379 per ton of BTX to \$392. Within the margin of error, these all five processes should be considered relatively equal on a cash cost basis.

6.4 BTX Production

FIGURE 6.4

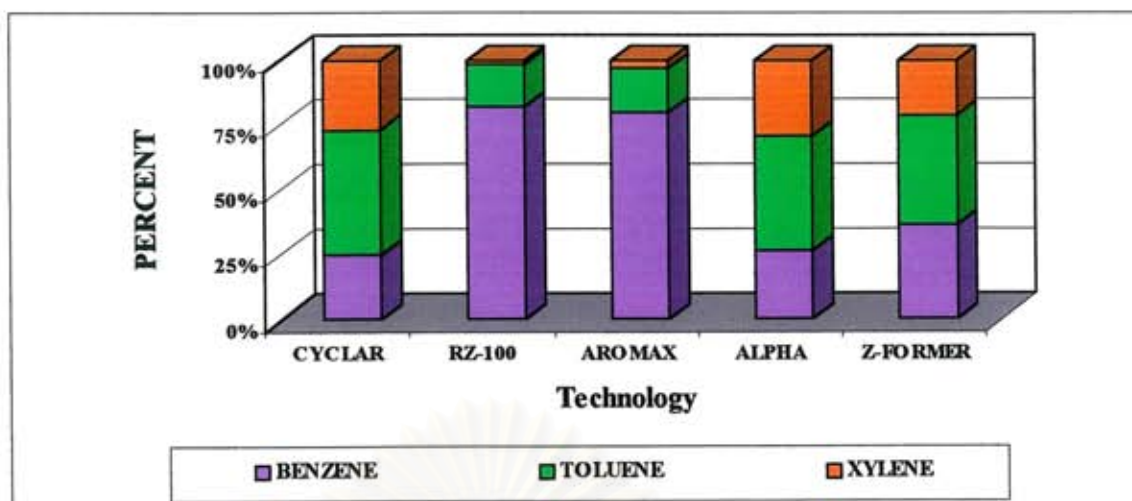
ESTIMATED PRODUCTION OF AROMATICS



The estimated production of benzene, toluene and xylenes using ATC's available feedstocks, are shown in Figure 6.4. The Z-FORMER yields has the highest production of aromatics, using all three of ATC's available feedstocks, while the CYCLAR yields the lowest amount. This is also shown on a percentage basis in Figure 6.5.

FIGURE 6.5

COMPARISON OF BTX YIELDS



Of the five processes under consideration, the Alpha process shows the most potential production for xylene, the most desirable aromatics product, while the RZ-100 process shows the least.

AROMAX has the highest estimated potential benzene yield, at 231,246 tons per year and Z-FORMER has the highest estimated potential Toluene yield at 169,500 tons per year.

With all the data mentioned, we will analyze each technology in various aspects to ensure that the screened technologies can really be used. The analysis will be carried out as follows.

6.5 Technical Analysis

1. ATC FEEDSTOCK AVAILABILITY AND QUALITY – Strategic Fit with ATC objective : Feed Utilization

The ability to handle all three of the ATC feeds (LPG, Light Naphtha and Raffinate) gives the ALPHA process the highest score. Z-FORMER also obtains the highest score due to its ability to handle all three feeds.

AROMAX and RZ-100 handle the same feeds, which is a majority of the light naphtha and raffinate feeds. So, both of them are in the middle score.

The CYCLAR process handles only the LPG feed, the smallest of the three feedstocks, therefore, CYCLAR gains the lowest score.

2. INVESTMENT REQUIREMENTS

Total investment including modifications to existing facilities and OSBL.

The ranking of the investment (ISBL, OSBL, Owner's Cost and modifications to the existing plant) is also straightforward. The CYCLAR process is the lowest investment and, therefore, is given the highest score.

AROMAX and RZ-100 processes are given a lower score than CYCLAR process due to higher, but similar investment.

ALPHA scores a lower than the above process with its investment of \$135 MM.

The Z-FORMER is given the lowest score due to its highest investment.

3. COST OF PRODUCTION (COP)

The ranking of the cost of production is straightforward. The ALPHA process was given the highest score (assumed = 5) due to its lowest cost.

Z-FORMER with its slightly higher COP, is given a slightly lower score (assumed = 4).

CYCLAR and RZ-100 processes have been given a score of assumed equal to 3 based on similar COP.

AROMAX with the highest COP, is given the lowest score (assumed = 1).

4. ATC MAIN PRODUCT – Strategic Fit with ATC objective : Product Mix

In terms of production of aromatics product, the Z-FORMER process produces the most BTX followed by ALPHA process.

The AROMAX and RZ-100 processes produce nearly the same amount of product, mostly benzene.

CYCLAR produces a well rounded mix of BTX, but due to its size, very little in terms of capacity.

Thus, the highest score is given to Z-FORMER and the lowest to CYCLAR.

The high production of BTX from the ALPHA and Z-FORMER processes are ranked next to later and last, respectively, because of the large affect on the existing facilities (including utilities).

5. TECHNOLOGY RISK – Current proven technology

From experience list records of five technologies, it can be concluded that all technologies are already have been proven. For example, BP at Scotland and Saudi Basic Industries Corporation (SABIC) at Yanbu are currently using the CYCLAR process in an aromatics unit. The first unit of RZ-100 was started up in late 1997. Sanyo's ALPHA process has been commercial since 1993 and plant operations have been stable to date. Chevron's project in its Pascagoula refinery included the additional AROMAX unit and Z-Former in plant at Mitsubishi Oil's Kawasaki refinery began operating in November 1990.

6.6 Summary

From the analysis, we can sum up that technologies RZ-100, Z-FORMER and ALPHA present no problem on the utilization side. For example, on the production side, all three technologies can yield a satisfactory volume of BTX. On the production cost side, the figures are not much different. On the compatibility with the existing conditions, there are no apparent problems.

Meanwhile, considering the remaining two technologies: CYCLAR and AROMAX, we find some obstacles if they are to be selected, for the following main reasons:

CYCLAR

For CYCLAR process, it can be seen that generally the performance of this process does not present any problem both in compatibility and existing condition regarding operation, facility, utility, as well as the problem of coordination with the technology itself. At present, the technology has been commercially licensed, which makes the risk of the process rather low, because this technology has been licensed to many plants such as that in Saudi Arabia. But the main defect of this technology is that if we consider from points 1 and 2 on feed utilization, ATC can use

only LPG in the CYCLAR process, while there remain Light Naphtha and Raffinate which cannot be used at all and have to be sold away at the same low prices. Also, if we look at the main products that can be obtained by this technology, we can see that the benzene, toluene and xylenes obtained are in a very small quantity.

Therefore, it can be concluded that it is not suitable to choose the CYCLAR technology as a process to convert the by-products into main products, because with the CYCLAR technology, ATC can use only one of its by-products – LPG – and merely at 89,000 metric tons. Meanwhile, ATC still have 370,000 metric tons of Light Naphtha and 230,000 metric tons of Raffinate that remain useless to the company. Therefore, it is logical that in decision making for selecting an appropriate by-product upgrading technology, the CYCLAR technology should be discarded and not taken into further consideration in the next step.

AROMAX

For AROMAX process, this technology by itself generally does not seem to present any problem, although it cannot utilize the three by-products of ATC, as the feed that is not utilized is 89,000 metric tons of LPG, compared to the other two feeds that are Light Naphtha and Raffinate that can be utilized. The volume of the newly obtained main product is not too small compared to other technologies. As for the integration with various existing facilities, although it is not the best, it is at a satisfactory level and not too difficult to use. Nevertheless, an important problem arises if we really want to choose this technology to reprocess the by-products into main products, as we will find that the company who is the licensor is CHEVRON who no longer licenses this technology. It is available only as part of a joint-venture agreement.

Therefore, AROMAX should be cut off from consideration. If AROMAX is selected as a suitable technology, the problem will arise, and our study will be useless as we cannot realize the operation because we cannot obtain the licenses of this technology for the reprocessing. Meanwhile, ATC has no policy of joint venture. Therefore, it is concluded that AROMAX should not be considered as a suitable technology.

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CHAPTER 7

ECONOMIC ANALYSIS

For the economic decision making for selecting an appropriate by-product upgrading technology, we will consider whether ATC will benefit from using the appropriate technology to convert by-products into main products, and how much will the technology worth the investment.

The result of the technical analysis in Chapter 6 will be applied in the economic decision making. This means that, when all the technologies studied have initially been screened to check the possibility and feasibility in really using each technology, we can then be sure that ATC can use such technologies as soon as such technologies have passed through the economic analysis in this Chapter.

Before going on to the economic analysis, we must first explain the analysis tools.

7.1 ANALYSIS OF THE REVENUES

We use the expense list of each project to make an estimation of the investment project in order to decide which project to chose, by comparing the benefit gained from the modification or change to the system with the cost of capital. Two principles are adopted for investment decision in this report:

- 1) The calculation of Net Present Value (NPV)
- 2) The calculation of Interest Rate of Return (IRR)

For both calculation methods, the following related information is required:

1. Investment cost
2. Net cash flow
3. Project life
4. Discount rate

- 1) Calculation of Net Present Value (NPV)

Each technology requires an initial investment of three years, while the investor will have to bear expenses without income. The expenses will involve construction and machinery installation. Only when the construction of each technology project is completed, and the production process begins, then the revenue will come gradually. In this study, we will calculate by yearly periods. To make a comparison of the revenues and expenses, the revenues received periodically as well as the expenses made periodically must first be calculated to obtain the present value, by giving the production-starting year as the present year. The result of the comparison is called net present value. This is the difference of the present value of cash expected to receive at each period throughout the project life and the present value of the expenses made periodically for the technology being considered, at a depreciation rate held as rate of investment value.

The basis of decision making is to consider from the calculated NPV. If the NPV is higher than 0, it is worth the investment. If the NPV is under 0, it is not worth the investment.

2) Calculation Method of Interest Rate of Return (IRR)

This method is to find the rate of return on investment with compound interests. This will bring all the investments with compound interests to the present value of net cash return from the investment, at the same interest rate as the one used for depreciation, with the following calculation formula.

The basis of decision making is to consider from the required rate of return within the calculated IRR, by comparing it with the cost of capital value or depreciation. If the IRR is higher than the required rate of return, then the investment should be made. If the IRR is less than the required rate of return, the investment should not be made.

7.2 SELECTION OF INVESTMENT ALTERNATIVE

In normal investment selection, various aspects of study should be carried out including engineering or economics. After study, sometimes it is found that there is more than one option of projects worth the investment. For example, all the studied technologies yield more IRR than the cost of capital, which means that the investment is good for all these technologies. Meanwhile, we must pick up only the mutually exclusive technology. This means that we must chose only one project proposal. However, these technologies require different cost of capital with

different rate of return. Therefore, we will select the one that gives the highest return.

7.3 ECONOMIC ANALYSIS

For this economic analysis, we will choose the method of the incremental revenue analysis to help in the decision making for the selection of an appropriate technology to upgrade by-products.

Incremental revenue

In making decision on the investment, we must select a mutually exclusive project which means a project that gives the highest return, i.e. yielding NPV is higher than zero, or IRR is higher than cost of capital. However, as each project requires different capital, the comparison should be made by analyzing the IRR on the higher cost of capital to help in decision making.

The steps in decision making are to consider the IRR of each project to find out whether such a project is worth the investment. In this study the comparison will be made between the IRR obtained and the cost of capital (12%). The project that yields a return lower than 12% is not interesting.

Then the interesting projects are compared with each other, by calculating the incremental IRR on the higher cost of capital. If the IRR is over 12%, it means that the project requiring higher cost of capital is more interesting for investment. Then this project is compared to other selected projects until the best project is chosen.

Table 7.1 describes data used in making this economic analysis, and to find incremental IRR and incremental NPV. The figures shown in the table consist of:

1. Initial investment, K

From the data in Chapter 5, the value of initial investment is the figures of Total Capital Investment (\$ million), which is the whole construction period, starting from early 1998 to 2000, 3 years altogether.

2. Total fixed cost

From the data in Chapter 5, the figures of Total Fixed Cost are in the Table of TOTAL CASH COST OF PRODUCTION ESTIMATE FOR:

BTX, where the total fixed cost is composed of direct fixed costs such as labour, direct overhead, and allocated fixed costs such as general plant overhead, insurance, property tax.

3. Total variable cost

Just like fixed cost, the data from Chapter 5, the figures of Total Variable Cost are also in the Table of TOTAL CASH COST OF PRODUCTION ESTIMATE FOR : BTX. The total variable cost includes items such as raw materials, utilities.

4. Total cash cost, Y

This is the total value of Total fixed cost and Total variable cost. The total cash cost of the first year of operation is variable, because the capacity of running the plant in the first year is variable. In this study we fix the capacity of the first year at 75%, the second at 80%, and from the third year at 90%. For this we must separate the cash cost into fixed cost and variable cost and then calculate the fixed cost and variable cost to find the cash outflow which will be the expense of the plant. The cash outflow from Table 7.2 to 7.4 can be calculated as follows:

$$\text{Cash Outflow} = \{(\text{fixed cost}) + (\text{variable cost} * \text{capacity})\} * \text{Total BTX}$$

Remarks:

- 1) The fixed cost value is the constant expense. No matter at what capacity the plant runs, these figures remain constant, while the variable cost is inconstant capital that varies with the production capacity of each year. Therefore the calculation of variable cost must be calculated along with the capacity.
- 2) The available figures of Total fixed cost and Total variable cost are in \$/MT unit. Therefore, to find the Cash Outflow in \$, it is necessary to calculate with the Total BTX yield in MT/Yr unit, in order to find the Total fixed cost and the Total variable cost which are in \$ unit.

5. Total Receive, X

This is the total revenue calculated from

$$\text{Total Receive} = (\text{Benzene yield} * \text{unit price Benzene}) + (\text{Toluene yield} * \text{unit price Toluene}) + (\text{Xylene yield} * \text{unit price Xylene})$$

This Total Receive is then calculated to find Cash Inflow which is the revenue of the plant. The Cash Inflow from Table 7.2 to 7.4 can be calculated as follows :

$$\text{Cash Inflow} = \text{Total Receive} * \text{Capacity}$$

With the data of Table 7.1, we can further take all the figures for calculation to finally find the incremental IRR. The incremental IRR is shown in Tables 7.2 to 7.4. The Tables 7.2 to 7.4 have the following basic assumptions:

7.4 BASIC ASSUMPTIONS

- ★ Project startup : Quarter 1, 2001
- ★ Construction period : 3 years
- ★ For analysis purpose, project life extends from startup through 22 years of operation (end of year 2022)
- ★ Approximate capital expenditures during construction: 50 percent in 1998, 30 percent in 1999, and 20 percent in 2000
- ★ Salvage value : 0
- ★ All available technologies have already been become proven technologies.
- ★ Operating rates : 75 percent in year 2001, 80 percent in year 2002, 90 percent in 2003
- ★ No duty is charged on imported material and equipment
- ★ Financial Criteria :
 - ½ debt/equity ratio
 - 6 percent interest on debt
 - Cost of capital, i which is used for consideration for the study comprising of 1/3 of foreign loan, the cost of debt = 6% and equity = 2/3, the cost of equity = 15%

$$\text{Therefore } i = (1/3) \times 6\% + (2/3) \times 15\% = 2+10 = 12\%$$

★ This study considers 3 cases:

- Best case : very good economic situation
- Normal case : normal economic situation, calculating all condition at 80% of the best case
- Worst case : bad economic situation, calculating all condition at 55% of the best case

7.5 ECONOMIC DECISION MAKING

This study will compare 3 technologies: Z-FORMER, RZ-100 and ALPHA, to find the most appropriate technology. At first, we will find IRR of each technology and then compare it with the value i at 12%. From Table 7.2 to 7.4. we will obtain IRR of the three technologies which all have higher value than 12%. Therefore, all the three technologies are interesting for investment.

Then we take the cash flow value of the three technologies to find incremental IRR by first comparing ALPHA with RZ-100. The ALPHA would be more acceptable as superior if the additional investment can yield an IRR at least equal to the cost of capital (12%). From Table 7.2-best case, we will obtain the incremental IRR of ALPHA, compared to RZ-100, at the value of 52.08%, from Table 7.3-normal case we obtain 38.29%, and Table 7.4-worst case we obtain 23.61%. These results show that ALPHA can be accepted as more appropriate than RZ-100 .

Then we compare Z-FORMER to ALPHA. From Tables 7.2, 7.3 and 7.4, the results show the incremental IRR of Z-FORMER at 26.88% in the best situation, 20.18% in the normal situation and 12.06% in the worst situation. This shows that Z-FORMER is more appropriate than ALPHA. We can thus conclude that in all economic situations, either good, normal or bad, Z-FORMER is the most appropriate technology to convert by-products into main products.

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TABLE 7.1

Technology >>	RZ-100	Alpha	Z-Former
Initial investment, K(3yrs) \$Millio	108.7	135.2	158.8
Total fixed cost, \$/MT	28.21	25.25	19.99
Total variable cost, \$/MT	355.3	341.58	359
Total cash cost, Y (\$)	99,077,124	111,007,894	152,391,879
Output Yield, MT/Yr			
Benzene	211,923	80,104	146,400
Toluene	41,555	134,495	169,500
Xylene	4,865	88,015	86,200
Total BTX yield (MT/Yr)	258,343	302,614	402,100
Total Receive, X (\$)	156,501,435	197,130,235	253,968,700

Price, \$/MT	
Benzene	620
Toluene	497
Xylene	916

Source : Planning & Commercial Department, The Aromatics (Thailand) Public Co.,Ltd

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TABLE 7.2 ECONOMIC ANALYSIS : BEST CASE

capacity				75%	80%	90%	90%	90%	90%	90%	90%
End year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Year	-2	-1	0	1	2	3	4	5	6	7	8
RZ-100											
Cash Outflow	54,350,000	32,610,000	21,740,000	76,129,807	80,719,270	89,898,197	89,898,197	89,898,197	89,898,197	89,898,197	89,898,197
Cash Inflow	0	0	0	117,376,076	125,201,148	140,851,292	140,851,292	140,851,292	140,851,292	140,851,292	140,851,292
Net cash flow	(54,350,000)	(32,610,000)	(21,740,000)	(100,366,352)	44,481,878	50,953,094	50,953,094	50,953,094	50,953,094	50,953,094	50,953,094
Alpha											
Cash Outflow	67,600,000	40,560,000	27,040,000	85,166,171	90,334,516	100,671,205	100,671,205	100,671,205	100,671,205	100,671,205	100,671,205
Cash Inflow	0	0	0	147,847,676	157,704,188	177,417,212	177,417,212	177,417,212	177,417,212	177,417,212	177,417,212
Net cash flow	(67,600,000)	(40,560,000)	(27,040,000)	(113,454,892)	67,369,672	76,746,007	76,746,007	76,746,007	76,746,007	76,746,007	76,746,007
Z-Former											
Cash Outflow	79,400,000	47,640,000	31,760,000	116,303,404	123,521,099	137,956,489	137,956,489	137,956,489	137,956,489	137,956,489	137,956,489
Cash Inflow	0	0	0	190,476,525	203,174,960	228,571,830	228,571,830	228,571,830	228,571,830	228,571,830	228,571,830
Net cash flow	(79,400,000)	(47,640,000)	(31,760,000)	(132,708,978)	79,653,861	90,615,341	90,615,341	90,615,341	90,615,341	90,615,341	90,615,341
Incremental IRR											
Alpha - RZ-100	(18,615,296)	(9,972,480)	(5,936,000)	(47,612,316)	22,887,795	25,792,913	25,792,913	25,792,913	25,792,913	25,792,913	25,792,913
Z-Former - Alpha	(16,578,150)	(8,881,152)	(5,286,400)	(49,999,789)	12,284,189	13,869,334	13,869,334	13,869,334	13,869,334	13,869,334	13,869,334

capacity	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
End year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Year	9	10	11	12	13	14	15	16	17	18	19
RZ-100											
Cash Outflow	89,898,197	89,898,197	89,898,197	89,898,197	89,898,197	89,898,197	89,898,197	89,898,197	89,898,197	89,898,197	89,898,197
Cash Inflow	140,851,292	140,851,292	140,851,292	140,851,292	140,851,292	140,851,292	140,851,292	140,851,292	140,851,292	140,851,292	140,851,292
Net cash flow	50,953,094	50,953,094	50,953,094	50,953,094	50,953,094	50,953,094	50,953,094	50,953,094	50,953,094	50,953,094	50,953,094
Alpha											
Cash Outflow	100,671,205	100,671,205	100,671,205	100,671,205	100,671,205	100,671,205	100,671,205	100,671,205	100,671,205	100,671,205	100,671,205
Cash Inflow	177,417,212	177,417,212	177,417,212	177,417,212	177,417,212	177,417,212	177,417,212	177,417,212	177,417,212	177,417,212	177,417,212
Net cash flow	76,746,007	76,746,007	76,746,007	76,746,007	76,746,007	76,746,007	76,746,007	76,746,007	76,746,007	76,746,007	76,746,007
Z-Former											
Cash Outflow	137,956,489	137,956,489	137,956,489	137,956,489	137,956,489	137,956,489	137,956,489	137,956,489	137,956,489	137,956,489	137,956,489
Cash Inflow	228,571,830	228,571,830	228,571,830	228,571,830	228,571,830	228,571,830	228,571,830	228,571,830	228,571,830	228,571,830	228,571,830
Net cash flow	90,615,341	90,615,341	90,615,341	90,615,341	90,615,341	90,615,341	90,615,341	90,615,341	90,615,341	90,615,341	90,615,341
Incremental IRR											
Alpha - RZ-100	25,792,913	25,792,913	25,792,913	25,792,913	25,792,913	25,792,913	25,792,913	25,792,913	25,792,913	25,792,913	25,792,913
Z-Former - Alpha	13,869,334	13,869,334	13,869,334	13,869,334	13,869,334	13,869,334	13,869,334	13,869,334	13,869,334	13,869,334	13,869,334

capacity	90%	90%	90%	IRR	NPV	i
End year	2020	2021	2022			
Year	20	21	22			
RZ-100						
Cash Outflow	89,898,197	89,898,197	89,898,197			
Cash Inflow	140,851,292	140,851,292	140,851,292			
Net cash flow	50,953,094	50,953,094	50,953,094	48.64%	\$249,252,893.63	12%
Alpha						
Cash Outflow	100,671,205	100,671,205	100,671,205			
Cash Inflow	177,417,212	177,417,212	177,417,212			
Net cash flow	76,746,007	76,746,007	76,746,007	64.40%	\$409,399,047.86	12%
Z-Former						
Cash Outflow	137,956,489	137,956,489	137,956,489			
Cash Inflow	228,571,830	228,571,830	228,571,830			
Net cash flow	90,615,341	90,615,341	90,615,341	65.02%	\$484,587,042.82	12%
<u>Incremental IRR</u>						
Alpha - RZ-100	25,792,913	25,792,913	25,792,913	52.08%	\$129,321,354.23	12%
Z-Former - Alpha	13,869,334	13,869,334	13,869,334	26.88%	\$47,736,474.96	12%

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TABLE 7.3 ECONOMIC ANALYSIS : NORMAL CASE

capacity				60%	64%	72%	72%	72%	72%	72%	72%
End year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Year	-2	-1	0	1	2	3	4	5	6	7	8
RZ-100											
Cash Outflow	54,350,000	32,610,000	21,740,000	62,361,417	66,032,987	73,376,129	73,376,129	73,376,129	73,376,129	73,376,129	73,376,129
Cash Inflow	0	0	0	93,900,861	100,160,918	112,681,033	112,681,033	112,681,033	112,681,033	112,681,033	112,681,033
Net cash flow	(54,350,000)	(32,610,000)	(21,740,000)	(110,073,177)	34,127,931	39,304,904	39,304,904	39,304,904	39,304,904	39,304,904	39,304,904
Alpha											
Cash Outflow	67,600,000	40,560,000	27,040,000	69,661,138	73,795,813	82,065,164	82,065,164	82,065,164	82,065,164	82,065,164	82,065,164
Cash Inflow	0	0	0	118,278,141	126,163,350	141,933,769	141,933,769	141,933,769	141,933,769	141,933,769	141,933,769
Net cash flow	(67,600,000)	(40,560,000)	(27,040,000)	(127,519,393)	52,367,537	59,868,605	59,868,605	59,868,605	59,868,605	59,868,605	59,868,605
Z-Former											
Cash Outflow	79,400,000	47,640,000	31,760,000	94,650,319	100,424,475	111,972,787	111,972,787	111,972,787	111,972,787	111,972,787	111,972,787
Cash Inflow	0	0	0	152,381,220	162,539,968	182,857,464	182,857,464	182,857,464	182,857,464	182,857,464	182,857,464
Net cash flow	(79,400,000)	(47,640,000)	(31,760,000)	(149,151,198)	62,115,493	70,884,677	70,884,677	70,884,677	70,884,677	70,884,677	70,884,677
Incremental IRR											
Alpha - RZ-100	(18,615,296)	(9,972,480)	(5,936,000)	(51,969,993)	18,239,606	20,563,701	20,563,701	20,563,701	20,563,701	20,563,701	20,563,701
Z-Former - Alpha	(16,578,150)	(8,881,152)	(5,286,400)	(52,377,507)	9,747,956	11,016,072	11,016,072	11,016,072	11,016,072	11,016,072	11,016,072

capacity	72%	72%	72%	72%	72%	72%	72%	72%	72%	72%	72%
End year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Year	9	10	11	12	13	14	15	16	17	18	19
RZ-100											
Cash Outflow	73,376,129	73,376,129	73,376,129	73,376,129	73,376,129	73,376,129	73,376,129	73,376,129	73,376,129	73,376,129	73,376,129
Cash Inflow	112,681,033	112,681,033	112,681,033	112,681,033	112,681,033	112,681,033	112,681,033	112,681,033	112,681,033	112,681,033	112,681,033
Net cash flow	39,304,904	39,304,904	39,304,904	39,304,904	39,304,904	39,304,904	39,304,904	39,304,904	39,304,904	39,304,904	39,304,904
Alpha											
Cash Outflow	82,065,164	82,065,164	82,065,164	82,065,164	82,065,164	82,065,164	82,065,164	82,065,164	82,065,164	82,065,164	82,065,164
Cash Inflow	141,933,769	141,933,769	141,933,769	141,933,769	141,933,769	141,933,769	141,933,769	141,933,769	141,933,769	141,933,769	141,933,769
Net cash flow	59,868,605	59,868,605	59,868,605	59,868,605	59,868,605	59,868,605	59,868,605	59,868,605	59,868,605	59,868,605	59,868,605
Z-Former											
Cash Outflow	111,972,787	111,972,787	111,972,787	111,972,787	111,972,787	111,972,787	111,972,787	111,972,787	111,972,787	111,972,787	111,972,787
Cash Inflow	182,857,464	182,857,464	182,857,464	182,857,464	182,857,464	182,857,464	182,857,464	182,857,464	182,857,464	182,857,464	182,857,464
Net cash flow	70,884,677	70,884,677	70,884,677	70,884,677	70,884,677	70,884,677	70,884,677	70,884,677	70,884,677	70,884,677	70,884,677
<u>Incremental IRR</u>											
Alpha - RZ-100	20,563,701	20,563,701	20,563,701	20,563,701	20,563,701	20,563,701	20,563,701	20,563,701	20,563,701	20,563,701	20,563,701
Z-Former - Alpha	11,016,072	11,016,072	11,016,072	11,016,072	11,016,072	11,016,072	11,016,072	11,016,072	11,016,072	11,016,072	11,016,072

capacity	72%	72%	72%			
End year	2020	2021	2022			
Year	20	21	22	IRR	NPV	I
RZ-100						
Cash Outflow	73,376,129	73,376,129	73,376,129			
Cash Inflow	112,681,033	112,681,033	112,681,033			
Net cash flow	39,304,904	39,304,904	39,304,904	34.43%	\$182,570,046.54	12%
Alpha						
Cash Outflow	82,065,164	82,065,164	82,065,164			
Cash Inflow	141,933,769	141,933,769	141,933,769			
Net cash flow	59,868,605	59,868,605	59,868,605	45.10%	\$314,564,040.78	12%
Z-Former						
Cash Outflow	111,972,787	111,972,787	111,972,787			
Cash Inflow	182,857,464	182,857,464	182,857,464			
Net cash flow	70,884,677	70,884,677	70,884,677	45.66%	\$374,186,839.09	12%
<u>Incremental IRR</u>						
Alpha - RZ-100	20,563,701	20,563,701	20,563,701	38.29%	\$90,587,225.92	12%
Z-Former - Alpha	11,016,072	11,016,072	11,016,072	20.18%	\$26,601,624.55	12%

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TABLE 7.4 ECONOMIC ANALYSIS : WORST CASE

capacity				41%	44%	50%	50%	50%	50%	50%	50%
End year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Year	-2	-1	0	1	2	3	4	5	6	7	8
RZ-100											
Cash Outflow	54,350,000	32,610,000	21,740,000	45,150,929	47,675,134	52,723,544	52,723,544	52,723,544	52,723,544	52,723,544	52,723,544
Cash Inflow	0	0	0	64,556,842	68,860,631	77,468,210	77,468,210	77,468,210	77,468,210	77,468,210	77,468,210
Net cash flow	(54,350,000)	(32,610,000)	(21,740,000)	(122,206,708)	21,185,497	24,744,667	24,744,667	24,744,667	24,744,667	24,744,667	24,744,667
Alpha											
Cash Outflow	67,600,000	40,560,000	27,040,000	50,279,846	53,122,435	58,807,614	58,807,614	58,807,614	58,807,614	58,807,614	58,807,614
Cash Inflow	0	0	0	81,316,222	86,737,303	97,579,466	97,579,466	97,579,466	97,579,466	97,579,466	97,579,466
Net cash flow	(67,600,000)	(40,560,000)	(27,040,000)	(145,100,021)	33,614,868	38,771,852	38,771,852	38,771,852	38,771,852	38,771,852	38,771,852
Z-Former											
Cash Outflow	79,400,000	47,640,000	31,760,000	67,583,963	71,553,695	79,493,160	79,493,160	79,493,160	79,493,160	79,493,160	79,493,160
Cash Inflow	0	0	0	104,762,089	111,746,228	125,714,507	125,714,507	125,714,507	125,714,507	125,714,507	125,714,507
Net cash flow	(79,400,000)	(47,640,000)	(31,760,000)	(169,703,973)	40,192,533	46,221,347	46,221,347	46,221,347	46,221,347	46,221,347	46,221,347
Incremental IRR											
Alpha - RZ-100	(18,615,296)	(9,972,480)	(5,936,000)	(57,417,089)	12,429,371	14,027,186	14,027,186	14,027,186	14,027,186	14,027,186	14,027,186
Z-Former - Alpha	(16,578,150)	(8,881,152)	(5,286,400)	(55,349,655)	6,577,665	7,449,495	7,449,495	7,449,495	7,449,495	7,449,495	7,449,495

capacity	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
End year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Year	9	10	11	12	13	14	15	16	17	18	19
RZ-100											
Cash Outflow	52,723,544	52,723,544	52,723,544	52,723,544	52,723,544	52,723,544	52,723,544	52,723,544	52,723,544	52,723,544	52,723,544
Cash Inflow	77,468,210	77,468,210	77,468,210	77,468,210	77,468,210	77,468,210	77,468,210	77,468,210	77,468,210	77,468,210	77,468,210
Net cash flow	24,744,667	24,744,667	24,744,667	24,744,667	24,744,667	24,744,667	24,744,667	24,744,667	24,744,667	24,744,667	24,744,667
Alpha											
Cash Outflow	58,807,614	58,807,614	58,807,614	58,807,614	58,807,614	58,807,614	58,807,614	58,807,614	58,807,614	58,807,614	58,807,614
Cash Inflow	97,579,466	97,579,466	97,579,466	97,579,466	97,579,466	97,579,466	97,579,466	97,579,466	97,579,466	97,579,466	97,579,466
Net cash flow	38,771,852	38,771,852	38,771,852	38,771,852	38,771,852	38,771,852	38,771,852	38,771,852	38,771,852	38,771,852	38,771,852
Z-Former											
Cash Outflow	79,493,160	79,493,160	79,493,160	79,493,160	79,493,160	79,493,160	79,493,160	79,493,160	79,493,160	79,493,160	79,493,160
Cash Inflow	125,714,507	125,714,507	125,714,507	125,714,507	125,714,507	125,714,507	125,714,507	125,714,507	125,714,507	125,714,507	125,714,507
Net cash flow	46,221,347	46,221,347	46,221,347	46,221,347	46,221,347	46,221,347	46,221,347	46,221,347	46,221,347	46,221,347	46,221,347
Incremental IRR											
Alpha - RZ-100	14,027,186	14,027,186	14,027,186	14,027,186	14,027,186	14,027,186	14,027,186	14,027,186	14,027,186	14,027,186	14,027,186
Z-Former - Alpha	7,449,495	7,449,495	7,449,495	7,449,495	7,449,495	7,449,495	7,449,495	7,449,495	7,449,495	7,449,495	7,449,495

capacity	50%	50%	50%			
End year	2020	2021	2022			
Year	20	21	22	IRR	NPV	I
RZ-100						
Cash Outflow	52,723,544	52,723,544	52,723,544			
Cash Inflow	77,468,210	77,468,210	77,468,210			
Net cash flow	24,744,667	24,744,667	24,744,667	19.28%	\$67,028,611.06	12%
Alpha						
Cash Outflow	58,807,614	58,807,614	58,807,614			
Cash Inflow	97,579,466	97,579,466	97,579,466			
Net cash flow	38,771,852	38,771,852	38,771,852	25.78%	\$147,152,687.58	12%
Z-Former						
Cash Outflow	79,493,160	79,493,160	79,493,160			
Cash Inflow	125,714,507	125,714,507	125,714,507			
Net cash flow	46,221,347	46,221,347	46,221,347	26.29%	\$178,473,236.70	12%
Incremental IRR						
Alpha - RZ-100	14,027,186	14,027,186	14,027,186	23.61%	\$42,169,565.54	12%
Z-Former - Alpha	7,449,495	7,449,495	7,449,495	12.06%	\$183,061.55	12%

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TABLE 7.5 SUMMARY OF ECONOMIC RESULTS

Best case

	NPV	IRR
RZ-100	\$249,252,893.63	48.64%
ALPHA	\$409,399,047.86	64.40%
Z-FORMER	\$484,587,042.82	65.02%

	incremental NPV	incremental IRR
ALPHA - RZ-100	\$ 129,321,354.23	52.08%
Z-FORMER - ALPHA	\$ 47,736,474.96	26.88%

Normal case

	NPV	IRR
RZ-100	\$182,570,046.54	34.43%
ALPHA	\$314,564,040.78	45.10%
Z-FORMER	\$374,186,839.09	45.66%

	incremental NPV	incremental IRR
ALPHA - RZ-100	\$ 90,587,225.92	38.29%
Z-FORMER - ALPHA	\$ 26,601,624.55	20.18%

Worst case

	NPV	IRR
RZ-100	\$67,028,611.06	19.28%
ALPHA	\$147,152,687.58	25.78%
Z-FORMER	\$178,473,236.70	26.29%

	incremental NPV	incremental IRR
ALPHA - RZ-100	\$ 42,169,565.54	23.61%
Z-FORMER - ALPHA	\$ 183,061.55	12.06%

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CHAPTER 8

CONCLUSION AND RECOMMENDATION

8.1 CONCLUSION

This Thesis has as objective to study the means of selecting an appropriate technology to convert ATC's by-products into main products, by selecting from five technologies available at present. These technologies are ALPHA, AROMAX, RZ-100, CYCLAR and Z-FORMER. The selection is made on both the technical and economic sides to pick up only one most appropriate technology. This report proposes the case study in the ATC's plant.

The desire to convert ATC's by-products into main products arises from the fact that ATC's production process produces a large quantity of by-products. ATC has to sell these by-products at low prices or uselessly burn them. Hence comes the idea for these value added by-products.

The result of the study and data analysis indicates that aromatics are still in demand. This assures that once the by-products are treated by an appropriate technology and converted into main products, there is ready market for these products.

The initial technical screening indicates that three technologies are capable to convert the by-products into main products. The two technologies eliminated are CYCLAR and AROMAX. The reason to cut out AROMAX is that CHEVRON, the licensor, has no longer the policy to license its technology except in the form of joint-venture. As for CYCLAR, this process uses only LPG and in small quantity. Thus the ATC's by-products cannot be utilized at the fullest benefit. Therefore, there remain three possible technologies: ALPHA, RZ-100 and Z-FORMER for further study.

The technologies considered appropriate have been analyzed on the economic side. The result of economic analysis shows that the most appropriate technology is Z-FORMER.

8.2 RECOMMENDATIONS

From the economic analysis, it is found that some factors are variable such as interest rates and sales prices. In this study, we make the supposition according to the actual economic situation. But if the factors

vary, those who want to apply this study must check how the supposition has changed as this can greatly affect the application. Moreover, this study is carried out with the actually available technologies. If new technologies are found, they must be further studied. The same goes for economic changes where we must further study the changes in revenues and expenses, which occur from the changes of the prices of raw materials or goods. Furthermore, on the financial side, there may be change in the financial structure or the rate of return as well as interest rate. Therefore, whoever wants to make use of this study must pay attention to the above changes.

Although the economic decision making study, using the presently available data to calculate by economic theory, has found the answer that Z-FORMER is the most appropriate technology, but in practice there might be some factors or reasons that ATC cannot use this technology, even if the economic return is theoretically the highest. In fact, the decision to select the technology depends exclusively on the management team of ATC, who might not consider just the result of the economic theory. In the world of reality, there exist factors beyond the theory that affect decision making.

Therefore, to present the highest benefit to the company, the following comments are added to these recommendations, that will evaluate the alternative implementation of the remaining four technologies: CYCLAR, AROMAX, ALPHA and, RZ-100 which have the right to be selected as each technology could be become the most appropriate technology in the following situation.

CYCLAR

From Chapter 6, Technical Analysis, it is concluded that CYCLAR is not appropriate for ATC to use as a technology to convert its by-products into main products. This is because CYCLAR has a limitation in feedstock utilization as explained in the above conclusion.

However, supposing that if we do not take feedstock utilization into consideration, we will find that CYCLAR is a technology that reserves the right to be considered as an appropriate technology for by-product upgrading. For instance, supposing that ATC has a by-product upgrading project, but has a limited financing. We know from the beginning that CYCLAR requires the lowest capital cost, just at \$27.8 million, while AROMAX is second in low investment. The remaining technologies required up to \$107.6 million, that is far higher than CYCLAR. Therefore, in case of limited capital, CYCLAR becomes an interesting choice. Moreover, CYCLAR is a highly flexible technology because, supposing

that ATC at present has little money, it can first invest in CYCLAR. When later ATC is better in finance, it can invest more in by-product upgrading technology, as CYCLAR unit could be combined with an RZ-100 unit or an AROMAX unit.

Moreover, the preparation of staff and training requires minor budget as CYCLAR technology belongs to UOP who is the licensor of the existing technology of ATC. Also, as CYCLAR is a small process that does not need complex training, the investment is not high compare to other technologies.

Finally, as CYCLAR uses LPG as the only feedstock, it may be considered as more appropriate than other technologies, in the case where the world market price of LPG falls heavily with little demand, whereas the demand and the world market price of Light Naphtha and Raffinate are high without having to be used as feedstock in by-product upgrading process.

AROMAX

As we known from the conclusion in Chapter 6, although ATC may consider AROMAX as the most appropriate by-product upgrading technology, but in reality it cannot be implemented because of the licensing problem from CHEVRON who is the licensor. Therefore, there is only one situation in which ATC would select AROMAX: the take-over of ATC by CHEVRON. If this happens, AROMAX will of course be used. Recently, rumour runs about the take-over of ATC by CHEVRON, but there is still no conclusion on the subject.

ALPHA

ALPHA uses all three by-products - LPG, Light Naphtha and Raffinate - as feedstock in its by-product upgrading process. Therefore, it should be the most appropriate technology in the case where the demand and world market price of the three products fall and the products are unmarketable, or where ATC modifies its existing process such as debottleneck or process revamp which would excessively bring forward the three products. In the situation where ATC has excessive unmarketable by-products, ALPHA should be the most appropriate technology.

Moreover, if the demand in Toluene and Xylenes has a high value resulting in the rise of market price of Toluene and Xylenes, ALPHA is

more interesting than other technologies as it produces more Toluene and Xylenes than other technologies.

RZ-100

RZ-100 is a technology using two by-products: Light Naphtha and Raffinate. It could be selected as appropriate for converting by-products in several situations. Firstly, supposing a situation that LPG, a by-product of ATC, has a very high demand and good market price, then the product can be sold without being used as feedstock in by-product upgrading process.

Moreover, RZ-100 is an interesting technology because of its flexibility. A small RZ-100 unit could be designed to process only the Raffinate stream, or a larger one designed to process the combined Raffinate and Light Naphtha stream. Therefore, if ATC has excessive Raffinate, it can use RZ-100, or if the volume of Raffinate decreases, then it can be combined with Light Naphtha to obtain the same output.

Finally, RZ-100 would be the most interesting technology in the situation where the demand for Benzene is high and its world market price is much higher than those of Toluene and Xylenes, because RZ-100 can produce more Benzene than other technologies can do.



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APPENDIX

WORLD CONSUMPTION OF PETROCHEMICAL PRODUCTS

Unit : Million Metric Ton	1995	1996	1997	2002E	2007E	Av. Increase 1992- 1997	Av. Increase 1997- 2002
Aromatics Percent	43.1 13.3	43.8 13.2	46.4 13.2	57.4 13.3	62.5 12.8	2.2	4.4
Olefins Percent	109.9 34.0	112.8 33.9	119.8 34.0	145.6 33.9	160.8 33.0	4.3	4.0
Plastics Percent	81.6 25.2	84.2 25.3	88.8 25.2	106.9 24.9	129.1 26.5	4.7	3.8
Elastomers Percent	7.3 2.3	7.2 2.2	7.4 2.1	8.5 2.0	9.7 2.0	-0.3	3.0
Fibres Percent	16.0 5.0	15.9 4.8	16.7 4.7	20.6 4.8	24.4 5.0	2.6	4.3
Formaldehyde Resin Percent	7.8 2.4	7.7 2.3	8.1 2.3	9.6 2.2	10.7 2.2	0.5	3.3
Key Intermediates Percent	57.5 17.8	60.8 18.3	65.0 18.5	81.5 18.9	90.8 18.6	4.2	4.6
World Total Percent	323.2 100.0	332.4 100.0	352.2 100.0	430.1 100.0	488.0 100.0	3.8	4.1

จุฬาลงกรณ์มหาวิทยาลัย

CONSUMPTION OF PETROCHEMICAL PRODUCTS IN ASIA

Unit: 1,000 Metric Ton

	1995	1996	1997	2002E	2007E	Av. Increase 1992- 1997	Av. Increase 1997- 2002
Aromatics Percent	12,537 14.8	13,684 15.5	14,534 15.5	19,642 16.7	21,624 15.8	7.7%	6.2%
Olefins Percent	24,585 28.9	25,735 29.1	27,488 29.3	36,121 30.8	40,385 29.6	5.7%	5.6%
Plastics Percent	25,062 29.5	25,661 29.0	26,931 28.7	31,305 26.7	39,365 28.8	3.7%	3.1%
Elastomers Percent	1,997 2.4	1,958 2.2	2,007 2.1	2,330 2.0	2,721 2.0	0.3%	3.0%
Fibres Percent	7,437 8.8	7,491 8.5	7,889 8.4	9,999 8.5	12,283 9.0	3.0%	4.9%
Formaldehyde resin Percent	1,845 2.2	1,835 2.1	1,911 2.0	2,117 1.8	2,334 1.7	1.8%	2.1%
Key Intermediates Percent	11,479 13.5	12,052 13.6	13,088 13.9	15,874 13.5	17,930 13.1	6.8%	3.9%
World Total Percent	84,942 100.0	88,416 100.0	93,848 100.0	117,388 100.0	136,642 100.0	5.1%	4.6%

**IMPORT OF PETROCHEMICAL PRODUCTS BY THAILAND
1993-1999**

Unit : Metric Ton/Year

	1996	1997	1998	1999	Jan.-Nov.		% Av. Increase	
					2000	2001	Jan. - Nov. 2000- 2001	1994-99
BENZENE	2.5	3.2	10.2	1.3	1.3	143.3	10923	-53.6
TOLUENE	69,563.8	81,946.9	84,786.6	69,936.9	63,774.7	64,006.1	0.4	1.7
ORTHOXYLENE	17,376.4	11,406.4	26,903.4	19,621.2	19,621.2	22,785.5	16.1	17.9
PARAXYLENE	0.0	0.3	0.0	86,840.1	70,546.6	206,809.3	193.2	901.9
MIXED XYLENES	14,124.8	20,421.1	26,484.3	17,440.4	13,556.1	22,816.3	68.3	1060.1
STYRENE	114,938.4	124,948.4	143,176.4	150,404.5	133,125.9	216,461.6	62.6	12.9
PTA	213,648.1	289,248.2	306,448.2	353,959.3	325,816.9	238,098.2	-26.9	21.6

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย



BIOGRAPHY

Supamas Isarabhakdi was born on the 3rd April 1973 in Bangkok, Thailand. She started her school years in 1976 at Thipphanee Kindergaten, Saint Francis Xavier Convent, and Sateevithaya Girls College, respectively. She entered Chulalongkorn University in 1991 academic year and obtained her Bachelor's Degree in Industrial Engineering in 1994 academic year.

She began to work at the Head Office of Thai Petrochemical Industry Public Company Limited in May 1995 for two months before joining The Aromatics (Thailand) Public Company Limited, working at the plants in Map Ta Phut Industrial Estate of Rayong.

While working at ATC, she continues her graduate study in Engineering Management at The Regional Centre for Manufacturing Systems Engineering at Chulalongkorn University, since January 1997.

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