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PROJECT PROFILE FOR THE ESTABLISHMENT OF POLYAMIDE PRODUCTION PLANTS IN THE ARAB WORLD*

Prepared by

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* The views expressed in this paper are those of the author and do not necessarily reflect the views of the Secretariat of UNIDO. Mention of firm names and commercial products does not imply the endorsement of UNIDO. This document has not been edited.

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POLYAMIDES

INTRODUCTION

The U.S. Federal Trade Commission defined nylon fibers as "a manufactured fiber in which the fiber-forming substance is a long-chain synthetic polyamide in which less than 85% of the amide $(-\underset{O}{\mathrm{C}}-\mathrm{NH}-)$ linkages are attached directly to two aromatic rings".

It is clear that this definition specifies the type of bond between monomers and not the nature of the monomers used. As such, this definition does obviously relate to a wide-ranging class of polymers, all called Nylon.

Polyamide is considered one of the most important polymers in the production of synthetic fibers because it is the basic ingredient utilized in the manufacturing processes of nylon. Other products such as aramides are also produced from polyamides but on a limited production scale and therefore, only nylon production will be considered in this report.

As stated above, there are several different types (classes) of nylon which are basically characterized by their molecular structure, particularly by the number of carbon atoms existing in the molecule of the polyamide. The two most widely consumed nylon types are the polycapromide (polyamide 6 or nylon 6) and the polyhexamethylene adipamide (polyamide 6,6 or nylon 66). Both of these types account for about 98% of the total nylon consumption.

Nylon is consumed in producing end products in different areas of applications which include but are not limited to the following:

1. Apparel: clothing, sheer hosiery, underwear and nightwear for women, garments, ropes, swimwear...etc.
2. Home furnishing: carpets and rugs, curtains, upholstery and slipovers...etc.
3. Industrial: tire cords, hoses, ropes, sewing thread, fishing lines and nets...etc.

The rate of growth of the above mentioned applications in the Arab World has been continuously increasing during the past three decades, during which almost all of the needed nylon materials have been imported from other countries. Even though all the raw materials needed to produce the nylon are basically available in some of the Arab countries, yet at present only Egypt is reported to be producing 4,000 tons/year of nylon 6. The consumption forecast of nylon in the Arab states in the year 2010 has been estimated* to range between 40,000 and 78,000 tons of both nylon 6 and 66 per year. Unless a production plant is established, this quantity will always have to be imported from other countries.

Having realized the need to establish such production facilities, one should decide the type of nylon which must be produced during the initial phase. This decision may be based on the following*:

* AIDO, Petrochemical Industry in the Arab World. p. 2 - 49. 1988.

1. The international production capacity of nylon 6 was 34% higher than that of nylon 66 in 1985. This ratio is expected to increase in the future.

2. Both fibers can be equally used in similar applications with the exceptions possibly where the threads are produced or used under high temperatures.

3. A plant design capacity of nylon 66 is normally 25% higher than that of nylon 6.

4. Production of nylon 6 requires one basic raw material (caprolactam) while two basic raw materials (hexamethylenediamine and adipic acid) are needed for nylon 66.

5. Nylon 6 is easier to control through production and fabrication in the developing countries, especially those with hot atmospheric conditions.

6. The continuous production process of nylon 6 and its suitability to various capacities is easy to operate when compared with the nylon 66 batch process.

7. Only multinational companies produce nylon 66 while nylon 6 is produced by many different companies all around the world including some in the developing countries.

8. Nylon 6 exhibits higher humidity absorbing capacity and has superior dyeing properties.

9. Nylon 6 is normally preferred for plastics because of its lower melting point, its resistance to heat, and generally its lower price.

Based upon the above, at this stage, priority should be given to producing nylon 6 instead of nylon 66.

The purpose of this report will be to prepare a project profile for the production of nylon 6 with at least the necessary capacity to meet the Arab World consumption requirements.

SUPPLY/DEMAND FOR NYLON FIBERS

The international demand on nylon fibers has been continuously growing. It increased from 400 thousand tons in 1960 to over 3,000 thousand tons in 1986 while the actual international production reached 3,500 thousand tons in the same year (1986). The overall growth rate is expected to continue increasing about 2 - 2.6 percent through the year 2000. The international actual production and production capacities for polyamide fibers are listed in Table 1:

Table 1: World Actual Production & Production Capacity For Polyamide Fibers* (000'MT)

Region	Actual Production			Production Capacity	
	1979	1984	1986	1986	1988
West Europe	719	629	667	831	853
U.S.A.	1234	1094	1140	1292	1386
Other Americas	228	231	250	392	404
Japan	313	307	279	356	359
East Europe	445	605	646	747	764
Others	335	458	518	690	778
World Total	3274	3324	3500	4308	4544

*UNIDO, The Development of Integrated Petrochemical Industry in the Arab Region, Paper presented to the Asian-Arab Preparatory Meeting for the Regional Consultation on the Petrochemical Industry in the Arab Countries, 1989.
Saudi Consulting House/AIDO, Petrochemical Study in the Arab World, vol. 4 p. 641, 1983

Despite the strong competition of other synthetic fibers to nylon, in general the growth rate of nylon consumption in the developing countries including the Arab World has been increasing much faster than in the industrial countries where this sector is considered to be approaching maturity. The various uses of nylon make it necessary to consider the possibility of establishing plants for the production of the nylon chips/fibers in the Arab World. Some of the pertinent applications include:

- Production of fishing nets and ropes
- Production of carpets
- Production of tire cords
- Production of textile materials

The consumption rate of growth of nylon (mainly nylon 6 and nylon 66) has been increasing in the Arab World as indicated in Table 2:

Table 2: Consumption of Polyamide in the Arab World* (000'MT)

Region**	1977	1979	1981	1983	1985
Eastern Arab Countries	6615	7876	11334	14552	14299
Central Arab Countries	2654	3219	3097	3920	5274
Western Arab Countries	8550	10650	12907	14004	16260
Other Arab Countries	1000	1500	2000	2200	2900
Total	18819	23245	29338	34676	38733

* GOIC/AIDO, Production of Aromatics in the Arab Countries, Vol.II, p. 111 - 115, 1988

** The regions specified in Table 2 (as well as later in this report) include the following countries:
Eastern Arab Countries: Saudi Arabia, Iraq, Kuwait, Bahrain, and United Arab Emirates (UAE)
Central Arab Countries: Egypt, Jordan, Syria
Western Arab Countries: Algeria, Libya, Morocco, Tunisia
Other Arab Countries: Djibouti, Lebanon, Mauritania, Oman, Palestine, Qatar, Sudan and Yemen (North and South)

The Gulf Organization for Industrial Consulting presented the Arab countries polymide consumption forecast through the year 2010 using high, medium and low scenarios. The results for the high and low scenarios are indicated in Table 3:

Table 3: Consumption Forecast for Polyamide in the Arab World 1990-2010* (000'MT)

Region	1990		1995		2000		2005		2010	
	High	Low	High	Low	High	Low	High	Low	High	Low
East Arab Co.	18456	14485	21832	14370	24736	14370	26284	14398	29555	14470
Cen. Arab Co.	6464	4816	7634	4855	8670	4942	9601	5041	10446	5126
West Arab Co.	19660	15799	23550	15925	26700	16212	29580	16536	32240	16817
Other Arab	3700	2739	4300	2739	4700	2742	5100	2745	5400	2748
Total	48580	37840	57316	37889	64806	38266	70565	38720	77641	39162

*GOIC/AIDO, Production of Aromatics in the Arab Countries, Vol.II, p. 152 - 166, 1988

At present, only one Arab plant with a production capacity of 4000 metric tons of polycapromide from caprolactam is reported to exist in Egypt.* Other publications** mention no production figures for Egypt. In any case, it appears that in the Arab world there are no present plans to establish new plants. As such, one can rightfully assume that the present and future consumption balance will be satisfied only through imports from other countries unless some Arab plants are initiated in the near future.

Assuming that realistic future consumption figures are the average of the high and low scenaries (See Table 3), one concludes that

* AIDO, Petrochemicals in the Arab Countries, Vol.2, sec.5, p.5 - 53, 1988

** GOIC/AIDO, Aromatic Compounds in the Arab Countries, Vol.II, P.185, 1988 there will be a need to establish production plants with a total capacity of about 50,000 - 60,000 MT/year. Almost all of this tonnage should consist of nylon 6 and nylon 66. Furthermore, if the regional consumption is taken into consideration, one would recommend the establishment of two separate plants - one to be located in the Eastern Arab Countries and the other in the Western Arab region.

As indicated previously, nylon 6 should be given priority in planning the future nylon production. Therefore, assuming nylon 6 to account for 50 percent of the nylon consumption, the two plants suggested above should be planned each to produce 12,500 tons of nylon 6 per year. Most international producers of nylon 6 operate with capacities ranging between 4,000 to 6,000 tons per year. This indicates that a proposed capacity of 12,500 MT/year should be economically adequate.

Taking into consideration the economics of the proposed plants and the future continuity of their operations, it is recommended that later plans should also include the establishment of at least one plant to produce caprolactam, the main raw material needed for the production of nylon 6.

POSSIBLE PLANT LOCATIONS

In general, the following factors must be considered in selecting a plant location:

1. Availability of raw materials and their prices delivered to the plant.
2. Products' local consumption and cost of export distribution.

3. Availability of infastructure including services, roads, ports...etc.
4. Availability of experienced manpower and its cost.
5. Nature of site and its effect on cost of civil works.
6. Atmospheric and weather conditions which may affect the operation of the project.
7. Other related factors.

Because of the nature of this report, these factors are mentioned, but have not been studied in the detail necessary to decide on a definite plant location. But a quick review, knowing the petrochemical production activities in the Arab countries, leads us to believe that Jubail in Saudi Arabia, Beiji in Iraq, and Skikda in Algeria offer themselves as potential candidates for plant locations. This appears so because:*

Jubail produces benzene and ammonia which constitute the basis for the production of nylon 6 and nylon 66.

Beiji also produces benzene and ammonia.

Skikda produces benzene while ammonia could be delivered from other local locations.

In general, the production plants of caprolactam and polyamide resins are capital intensive and require advanced technology for their operation. Therefore they can be good candidates for joint venture projects with a foreign partner. This will insure provision of technology, operating expertise, and marketing strength as well as financing for these projects.

For the purpose of estimating the profitability of this project,

*GOIC/AIDO, Production of Aromatics in the Arab Countries, Vol. II, p.186, 1986 only the Arab Eastern region plant will be considered. In order to achieve conservative results, the following assumptions will be made:

1. Cost of manpower will be assumed similar to that in Saudi Arabia as it is basically the highest in the region.
2. Costs of utilities will be assumed similar to those in Iraq as they are higher than in Saudi Arabia.

This will ensure that whichever location is finally selected, the profitability figures will be higher than those estimated in this report. Nonetheless, for this profile, the site will be in Iraq.

TECHNICAL STUDY

In this section, the following will be presented and discussed:

I. Manufacturing Process.

II. Raw Materials Requirements and Costs.

III. Process Utilities Requirements and Costs.

IV. Manpower Requirements and Costs.

I. Manufacturing Process

Polyamide (nylon 6) is produced from caprolactam as indicated by the following chemical reaction:

$$\underset{\text{caprolactam}}{C\text{-}CH_2CH_2CH_2CH_2\text{-}N} + H_2O \; \text{-->} \; \underset{\text{nylon 6}}{\text{--}C\text{-}CH_2CH_2CH_2CH_2\text{--}n} + H_2O$$

The caprolactam is generally produced from cyclohexane, toluene or phenol.

Internationally, nylon 6 is manufactured by either of the following two processes:

a) Batch Polymerization - Autoclave Process

This process, as presented in the flow sheet in Figure 1, involves the following steps:

1. Pumping of high purity molten caprolactam at about 80°C into the autoclave.
2. Addition of water which acts as a catalyst with amounts ranging from 3 to 5 percent.
3. Addition of chemical additives such as titanium dioxide, optical brightners, chain stopping agents (such as amines), stabilizers...etc.
4. Purging the vessel with nitrogen and raising the temperature to between 220 -240° C.

Polymerization will start taking place with the increase in pressure up to 18 bar (250 psig). This increase in pressure is caused by the rise in temperature of the solution. The additives will help in controlling the molecular weight (ranges from 14,000 - 20,000) and consequently the viscosity of the resin.

After the reaction is stabilized, the water is removed by a vacuum pump. This step is essential so as to minimize the depolymerization process which normally occurs with reversible chemical reactions.

The temperature is then raised further to about 270° C and kept constant for several hours until the equilibrium phase has been achieved.

This manufacturing process is finalized as the molten resin is quenched by extruding it under water into small diameter rods which

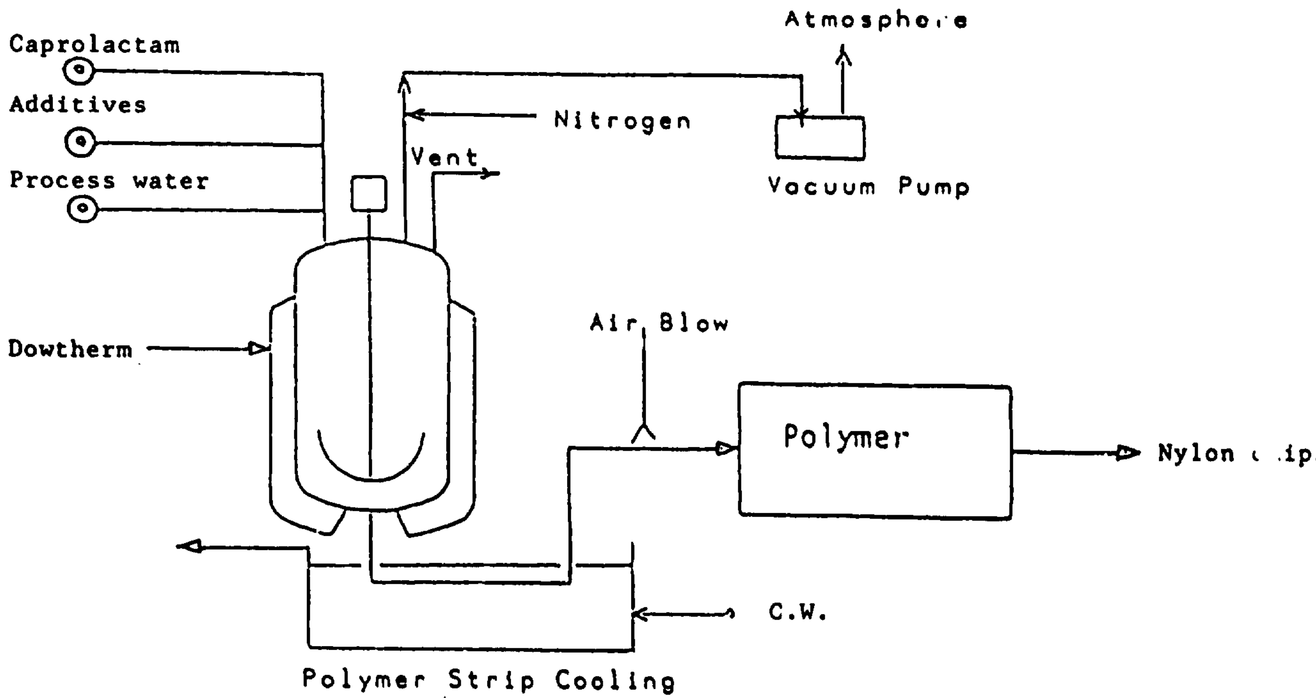

Figure 1. Autoclave Process Flow Diagram

(Source: Chem Systems, How to Start Manufacturing Industries, File G 50, UNIDO, Vienna) are jet-blown and then cut into the desired chips. These chips are blended and packaged for further processing to produce the end products.

As stated above, the polymerization reaction is reversible and will reach the equilibrium phase. This means, of course, that a certain amount of the nylon 6 resin will remain as caprolactam monomer which must be removed. This is accomplished by washing the chips with hot water at a temperature of 90 - 100° C.

The autoclave process is presently being used by only a few companies, in particular by those interested in producing different types of polyamide 6.

b) Continuous Polymerization - V.K. Tube Process

This process is basically the same as the Batch process except that it operates continuously. It consists of the following steps:

1. High-purity molten caprolactam is pumped from storage into the mixing tank.
2. Controlled amounts of water which acts as the catalyst is also added to the mixing tank.
3. Recovered caprolactam monomer and oligomers, acetic acid (chain terminator) and other additives (e.g. antistatic agents) are also added to the mixing tank.
4. The entire solution in this tank is mixed thoroughly.
5. The mixed solution is filtered and automatically metered into the vertical cylindrical reaction vessel where the polymerization takes place.

The vertical cylindrical reaction vessel is normally eight to ten meters high. It is equipped with several independent heating jackets to control the temperature of the reactants passing through from the top to the bottom of the vessel. In general, the polymerization process is achieved (under the same temperature and pressure described for the batch process) as the reactants pass slowly through the vessel with the temperature increasing to approximately 260° C. When the resin reaches the equilibrium phase, it is then quenched by extruding it under water to produce thin diameter rods which are jet-blown and then cut into the desired chips.

Most of nylon 6 is produced world-wide by this continuous process and not by the batch process for the following reasons:

1. The Polyamide produced by the continuous process has fixed and consistent properties which will result in producing fibers and textiles with predetermined homogenous quality.
2. Manpower requirement is minimized by the continuous process.
3. There is a minimization of waste, thus enhancing the economic viability of the project.
4. The polyamide produced is free of contaminations caused by hydrolysis.

Unless the aim is to produce only textile fibers, it is preferable to produce chips which give more opportunities of utilization for various purposes by different clients in different locations. This is particularly important when the project is regional and will serve several countries. Production of fibers could be achieved by feeding molten polyamide before the extrusion into rods and as such these amounts become "captive" to this particular plant. The decision as to what the final product should be depends on the consumption and the ability to market these final products.

Considering the above factors, it seems clear that the Continuous Process should be used for this project.

II. Raw Materials Requirements and Costs

Based on a plant capacity of 12,500 MT/Year, the required raw materials and their costs are tabulated in Table 4:

Table 4: Raw Materials and Their Costs*

Product	Conversion (per ton Nylon 6)	Quantity (MT/Y)	Price ($/MT)	Annual Cost (000'$)
Caprolactam	.906 tons	11,325	1,605	18,177
TiO_2	.003 tons	37.5	2,200	83
Waste Nylon	0.1 tons	1250	1,300	1,625
Chemicals & Additives	$33.9 per ton produced			424
			Total	20,269

*Source: Survey of technical literature.

It should be pointed out that some producers are feeding more nylon waste with the feedstocks so as to minimize the amount of caprolactam and thus to improve the economics of the plant. Chemical Marketing Reporter (Nov. 1989) quoted a producer who stated that up to 50% waste nylon may be used in their plants.

III. Process Utilities Requirements and Costs

The process utilities requirements and their estimated costs are tabulated in Table 5.

Table 5: Process Utilities and their Costs

Utility	Consumption per MT Nylon	Total Annual Consumption	Price per unit	Total Annual Cost (000'$)
Electricity	200 KWH	2.5 MM KWH	.035 $	125
Cooling Water	140 M^3	1.75 MM M^3	.03 $	53
Steam	4.2 Tons	52,500 Tons	11 $	578
Natural Gas	6,000 SCF	75 MM SCF	1$/1000SCF	75
Inert Gas	7.5 NM^3	93,750 NM^3	.05 $	5
			Total	836

IV. Manpower Requirements and Costs

The total estimated manpower requirements and their costs are presented in Table 6.

Table 6: Manpower Requirements and Costs

Category	Number Needed	Wages/Month (US$)	Annual Cost (US$)
Plant Manager	1	3,800	45,600
Production Manager	1	3,200	38,400
Technical Staff	5	3,000	180,000
Skilled Labor	15	1,600	288,000
Semi-skilled Labor	9	650	70,200
Supporting Staff	6	1,000	72,000
Total	37		694,200

ECONOMIC EVALUATION

This section provides the estimates of the investment requirements and operating costs for a plant producing 12,500 MT nylon 6 chips per year. Even though, the location is assumed to be Iraq, the estimated costs of manpower are taken for Saudi Arabia. The utilities costs are taken for Iraq as reported by GOIC/AIDO study on "Production of Aromatic Compounds in the Arab Countries, June 1988".

It is believed that using the higher manpower prices in Saudi Arabia will yield conservative results for a location site in Iraq. It is further assumed that no customs duties or taxes would be levied on imported equipment or raw materials.

The following items will be calculated and/or estimated:

A. Fixed Capital

B. Annual Operating Costs

C. Working Capital

D. Total Investment

E. Finance

F. Depreciation

G. Total Annual Production Cost

H. Project Fixed and Variable Costs

I. Estimation of Sales Revenue

J. Calculation of Annual Net Profit

K. Calculation of Rate of Return

L. Calculation of Pay-back Period

M. Determination of Break-even Point

N. Summary of Project Economics.

A. Fixed Capital

The costs of the Plant Battery Limits and Off-sites for an annual production capacity of 12,500 MT nylon 6 chips were based on estimates of Chem Systems* for a similar capacity plant situated in Benelux. The values are adjusted for inflation and time. In addition, to estimate the Arab cost, a location factor** of 1.3 was used.

* How to Start Manufacturing Industries, File G51, ISIC 3513, UNIDO.

** GOIC/AIDO, Aromatic Compounds Study, Vol. II, p.408, 1988

A 15% contingency was included in the final figures. The final estimates are listed below:

Estimated Costs (000'$)

	Chem Systems* Estimates	Corrected Estimates-1990	Arab Location Estimates	Final Estimate 15% Contingency
Battery Limits	7,500	9,020	11,730	13,500
Off-sites	3,010	3,610	4,690	5,390
			Total Fixed Capital	18,890

* How to Start Manufacturing Industries, UNIDO.

The land area required for the plant is around 2500 m². It is assumed that it will be rented from the host government at nominal rates.

B. Annual Operating Costs

	Cost (000'$)
1. Raw Materials	20,269
2. Utilities	836
3. Salaries and Wages	694
4. Maintenance: 3% of erected plant cost for materials and labor	567
5. Insurance (0.5% of erected plant cost)	95
6. General Expenses (telephones, faxes ... etc.)	200
7. Packaging and handling	1,000
Total	23,661

C. Working Capital

		Value (000'$)
Imported Raw Materials	(3 months)	5,067
Utilities	(3 months)	209
Wages and Salaries	(3 months)	174
	Total	5,450

D. Total Investment

	Value (000'$)
Fixed Capital	18,890
Working Capital	5,450
Total Investment	24,340

E. Finance

It is assumed that it is 100% of equity financing.

F. Depreciation

	Depreciation Value (000'$)
Assume a useful life time of 12 years for the entire plant	1,574

G. Total Annual Production Costs

	Value (000'$)
Operating Costs	23,661
Depreciations	1,574
Total	25,235

H. Project Fixed and Variable Costs

a) Fixed Costs

	(000'$/year)
Annual Depreciation	1,574
Maintenance	567
Insurance	95
Salaries*	347
Total	2,583

b) Variable Costs

	(000'$/year)
Raw Materials	20,269
Utilities	836
General Expenses	200
Labor Cost*	347
Packaging and handling	1,000
Total	22,652

I. Estimation of Sales Revenue

Selling Price is assumed to be US$ 2,280 per metric ton. Although the current quoted selling price is higher and because of the strong competition of other fibers, it was decided to use a conservative estimate.

Total Sales Value = 2280 x 12,500 =		$ 28,500,000
Loss during Packaging and Handling	3 % or	855,000
Total Net Sales Value		$ 27,645,000

*Assume 50% of the wages/salaries are fixed costs and 50% are variable costs.

J. Calculation of Annual Profit

Total Net Sales Value	$ 27,645,000
Total Production Costs	25,235,000
Total Annual Profit (Assume no taxes)	$ 2,410,000

K. Calculation of Annual Rate of Return

$$\text{Rate of Return}^* = \frac{\text{Annual Profit}}{\text{Total Investment}} = \frac{2,410,000}{24,340,000}$$

$$= 9.9\%$$

L. Calculation of Pay-back Period*

$$\text{Pay-back Period} = \frac{\text{Total Investment}}{\text{Annual Profit + Depreciation}}$$

$$= \frac{24,340,000}{2,410,000 + 1,574,000}$$

$$= 6.1 \text{ years}$$

M. Determination of Break-even Point (BEP)

The break-even point is defined as the point at which the income of the project is equal to the total expenses and thus the project does not produce profits or losses. The BEP was determined graphically as shown if Figure 2 and calculated as indicated below:

$$\text{BEP} = \frac{\text{Average Fixed Costs}}{\text{Net Sales Value - Average Variable Costs}}$$

$$= \frac{2,583,000}{27,645,000 - 22,652,000} = 52\ \%$$

*Assuming plant operates at full production starting the first year of operation.

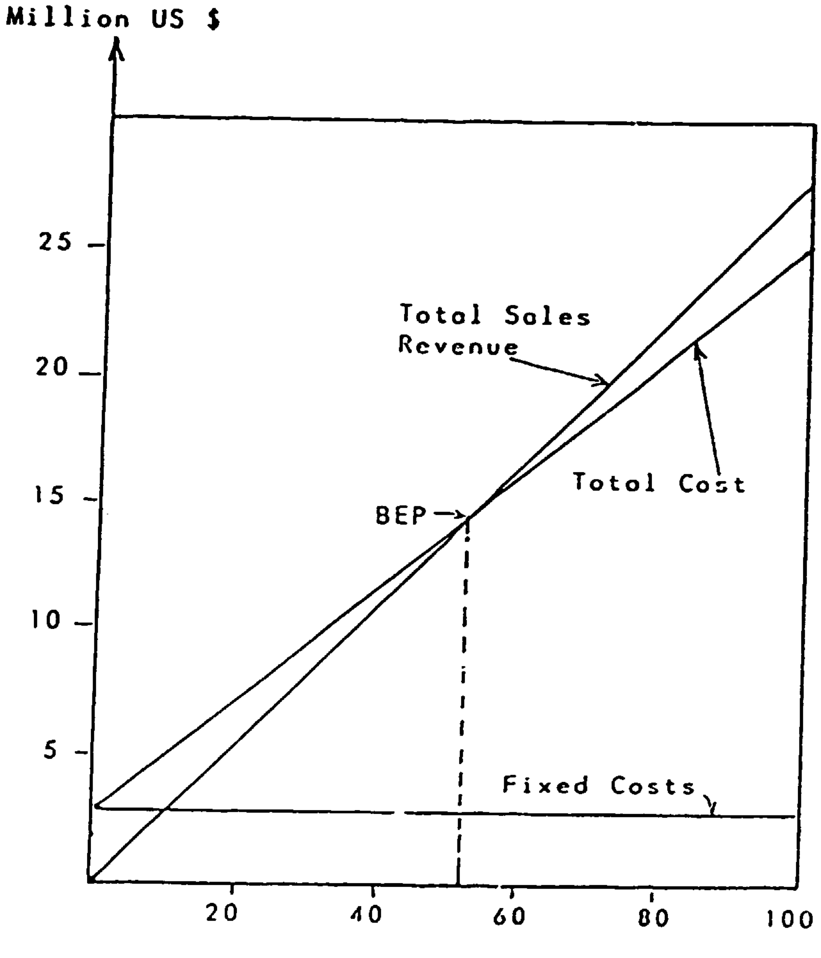

Figure 2. Determination of Break-even Point

N. Summary of Project Economics

Production Capacity	12,500 MT/Year
Total Investment	US$ 24,340,000
Working Capital	5,450,000
Production Cost	25,235,000
Raw Materials Cost	20,269,000
Cost of Utilities	836,000
Salaries and Wages	694,000
Depreciation	1,574,000
Fixed Costs	2,583,000
Variable Costs	22,652,000
Gross Sales Revenue	28,500,000
Net Sales Revenue	27,645,000
Annual Profit	2,410,000
Rate of Return	9.9%
Pay-back period	6.1 years
Break-even Point	52%
Total Manpower required	37
Land Area required	2,500 m^2

POSSIBLE RISKS

Based on the above results, even though the economical results of this project profile are rather encouraging, one should consider certain risks which may be encountered in case of establishing such a nylon 6 production plant. The possible risks include:

1. The feedstocks have a very significant effect on the total production costs. This profile is prepared on the assumption that these feedstocks will be imported from other countries. Thus they are subject to the prevailing conditions at any future time, and the plant could be subjected to pressures related to the prices or even to acquiring such feedstocks. Naturally the economic viability of the entire operation could be affected. Since the raw materials needed to produce the required feedstocks are basically available in several of the Arab countries, it would be more logical to plan to produce them locally. This would avoid dependency on outside sources for the safe operation of the plant, and would, no doubt, also improve its profitability.

2. A nylon 6 plant is capital intensive and requires advanced technology. As such the operation requires highly skilled operators. Therefore, it is important to train the appropriate number of needed laborers or possibly utilize some expatriates in order to give the local labor the necessary training on the job for a specified period.

3. This is only a project profile. Therefore, it is important that the results be verified by a more detailed study before final decisions are taken regarding the establishment of such a plant.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions:

Based on the outcome of this study, it is concluded:

1. The consumption of nylon 6 in the Arab countries has been continuously increasing during the past two decades.
2. The demand for nylon 6 has been met by imports from other countries.
3. There is a need to establish a nylon 6 manufacturing plant to satisfy the Arab World consumption.
4. The products which constitute the basis for the production of nylon 6 are basically available in Saudi Arabia, Iraq and Algeria. As such, any of these countries may be suitable for the plant location.
5. The feedstocks costs have a definite and direct effect on the economic viability of the project as it accounts for better than 85% of the production cost.
6. A simple economic evaluation indicates this is a viable project.

Recommendations

Based on the above it is recommended that:

1. Detailed studies should be carried out to confirm the results of this report.
2. Serious plans should be made to implement the two suggested projects , one to be located in the Eastern Region and the other in the Western Region.
3. As part of the planning, serious consideration should be given to the possibility of manufacturing caprolactam, the main feed-stock for nylon 6.