Report on

THE UTILIZATION OF WASTE GASES IN SAUDI ARABIA

By a

SPECIAL PANEL

of the

Advisory Committee on International Technologic Assistance

Under

Contract SCC-21718
Task Order No. 1
Foreign Operations Administration

Division of Engineering and Industrial Research
NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL
Washington, D. C.

July 14, 1954

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1. Letter of Transmittal

2. Final Recommendations
   of Special Panel

3. Staff Report

Division of Engineering and Industrial Research
National Academy of Sciences-National Research Council
Washington, D.C.
July 14, 1954

NATIONAL ACADEMY OF SCIENCES
NATIONAL RESEARCH COUNCIL

ADVISORY COMMITTEE ON INTERNATIONAL TECHNOLOGIC ASSISTANCE
OF THE
DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH

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July 10, 1954

Mr. Harold V. Bozell, Chairman
Advisory Committee on International Technologic Assistance
37 Lincoln Street
Larchmont, New York

Dear Mr. Bozell:

I am sending you herewith the report on the Utilization of Waste Gases in Saudi Arabia by the staff and the special panel set up under the direction of your Committee. This is now ready for transmittal under Task Order No. 1 of Contract SCC-21718 between the National Academy of Sciences and the Foreign Operations Administration.

The report is in two sections: (1) The report of the special panel set up as later outlined in this letter and (2) the report of the staff comprising six months survey and analysis of the technologic and economic questions inherent in the problem of the utilization of flared gas.

A special advisory panel was appointed on the recommendation of your Committee and under their direction a project director and associate were employed. The names of the Committee, the panel and the staff are appended herewith. Three meetings of the special panel have been held and the staff has had the counsel and advice of the individual members of the panel throughout the survey and analysis of the several technical proposals which were recommended for study by the staff at the first and second meetings of the panel.

The recommendations were given final review and discussion and unanimously approved at the third panel meeting held June 23, 1954. At the final meeting there were in attendance also the members of the Advisory Committee on International Technologic Assistance and the Chairman of the Division of Engineering and Industrial Research under which the Advisory Committee is set up in the National Research Council. The Panel at its final meeting agreed to continue in an advisory capacity until September 30, to be available if requested for supplementary advice on the original request.

The Chairman and members of the panel and staff wish to express their appreciation to the many specialized agencies and experts who cooperated in securing information. A list of these sources is appended to the staff report.

Yours very truly,

Frederick M. Feiker

Frederick M. Feiker
Technical Director

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Project Director Mr. James A. Barr Mining Engineer and Fertilizer Specialist

Associate Project Director Dr. Samuel H. Manian Chemical Engineer

Members of scientific and technical advisory boards, committees and panels of the Division do not serve as representatives of the organizations or agencies by which they are employed but as individual scientists, technologists and research workers, contributing their personal scientific knowledge to the Academy-Research Council.

Final Recommendations of Special Panel

on

The Utilization of Waste Gases in Saudi Arabia

The National Academy of Sciences-National Research Council under Task Order No. 1 of Contract SCC-21718 between the Academy and the Foreign Operations Administration was requested to "conduct studies and surveys in the United States based on available information on the technical and engineering feasibility of the utilization of flare gases from oil producing operations in Saudi Arabia (if it is necessary to accomplish the purposes of this Task Order for experts to be sent to Saudi Arabia, prior approval therefor will be obtained from FOA); to give particular attention to the possibility of producing fertilizers or components thereof from these gases; to include consideration of other uses and products obtainable from these sources; to consider also the utilization of other natural resources of Saudi Arabia and the surrounding area in connection with these flare gases; and to advise and recommend to the FOA in the interim and final reports the processes, products, and uses which appear to bear promise of useful exploitation, and the steps which might be taken to put these recommendations into effect."

The special panel appointed by the Advisory Committee on International Technologic Assistance submits the following 8 recommendations as its conclusions from the survey and analysis made by the special staff under its direction. The principal facts relating to the various projects outlined below are analysed in the attached Table I.

1. Cement The study indicates that a cement plant (capacity 1,250 barrels per day) is a very promising proposal. The raw materials necessary - limestone, gypsum, and clay - are available in Saudi Arabia. A moderate amount of gas would be used to fire the kilns. Our information indicates that there is a sufficient domestic demand in Saudi Arabia to take the entire plant output. The price of imported cement leaves a very satisfactory margin of profit over the estimated production costs.

The plant is relatively simple to build and requires a relatively small staff of trained technicians. It presents a large opportunity for the training of local operators and supervisors.

The fact that the entire output of this plant would be useful in Saudi Arabia puts this proposal in a separate class from all the others from the standpoint of direct benefit to that country.

It is recommended that this project be studied on location by qualified experts to determine optimum capacity and engineering details necessary for design.

2. Sulphur Recovery Recovery of sulphur from the gas is a necessary preliminary step for most of the gas uses covered in this study. The figures in the Table refer to the treatment of 100 million cubic feet a day, based on an average of 5 per cent H_2S in the gas. There is a large margin of profit over the estimated costs for a shipment of elemental sulphur. This seems to be a favorable project economically regardless of the disposition of any other project discussed herein.

3. Fertilizer. The successful operation of a fertilizer plant in Saudi Arabia depends primarily upon the export market. Estimates have been made that under present conditions the maximum local use of fertilizer in Saudi Arabia might be 5,000 - 10,000 tons per year.

Since nitrogen fertilizer production to be economical must be a fairly large project, and since the estimates obtained in this study indicate a rather modest margin of market value over cost of production, it would appear that further intensive study should be made before any decisions are made to establish fertilizer plants in Saudi Arabia. This should include a study of the competitive situation, present and prospective, in other countries of the Middle and Far East.

The report of the Staff includes a discussion of the relative desirability of the production of various types of fertilizer, which discussion would be of value in the further study of this matter.

Briefly summarized, it appears probable that in entering into fertilizer production in Saudi Arabia, the best first step would be the production of ammonium sulphate and urea. An economical size ammonia plant with a capacity of say 52,000 NT per year is required as a preliminary to the production of nitrogen fertilizers. The production of ammonium sulphate at the rate of 160,000 NT per year would be a suitable first step. Farmers in the Middle and Far East have been accustomed through long experience to use of ammonium sulphate. Agronomists approve of it as an almost universal nitrogen fertilizer for rice and most other crops, and as being particularly suitable to alkaline soils. There will be a minimum of sales resistance. There are no special problems of storage, handling, or use. Urea also finds good acceptance for rice culture. It has a higher percentage nitrogen than ammonium sulphate and will bear shipping for greater distances.

A desirable second step might be the production of ammonium phosphate and possibly concentrated superphosphate.

The desirability of proceeding with these additional steps might depend upon the phosphorus needs for the area which would be served by these plants.

Ammonium phosphate is a fertilizer of high analysis, can be made of good mechanical condition and with no serious problems of storage or use. Its production and the production of concentrated

superphosphate would require the establishment of a sulphuric acid plant and a phosphoric acid plant.

In addition to the use of urea and certain phosphates in fertilizers there is a real opportunity to use those components in feed supplements in animal husbandry.

4. Carbon Black - Channel A channel black plant of modest size to produce 10,000 tons per year would consume about 25 million CFD of natural gas and appears to have a fair prospect of profitable operation for export. The current U.S.A. export of channel black amounts to approximately 100,000 NT per year. Channel black is preferred for use in the compounding of natural rubber. The future world use of natural rubber is estimated to increase from the present amount of 1.8 million long tons to 2.5 million long tons by 1975. U.S.A. production of channel black is decreasing because of the value of natural gas for other purposes and because of the improved quality of oil furnace blacks. There appears to be an excellent prospect of a continuing export demand for the production of a channel black plant in Saudi Arabia.

Due to the decrease of production of channel black in the United States, there is a prospect of obtaining a second hand plant and thus reducing capital requirements in Saudi Arabia. This is reflected in the investment figure of 5 million dollars given in the Table. The

rate of return on investment indicated in the preliminary study is not high. On the other hand it would make use of the gas which is here assummed at 3¢ per MCF, and a further study of profitability would seem to be justified.

5. Synthetic Rubber The proposal for the establishment of a synthetic rubber plant in Saudi Arabia has considerable long-time appeal because of the estimated large increase in future years of the world need for synthetic rubber. It is estimated that by 1975 world requirements will be 2.5 million tons of synthetic rubber a year compared with the present annual production capacity of slightly more than 1 million tons.

The data developed by the Staff indicate that the principal raw materials - butane, isobutane, and propane - can be obtained from the natural gas in Saudi Arabia. For the amounts shown in the table a minimum of 92 million CFD of natural gas would be treated. The figures in the table indicate the amounts of butane and propane cuts deducted in the process of treatment. It would be necessary in addition to obtain benzene and isoprene in relatively small quantities by importation.

The amount of GR-S rubber produced by an economical plant - 46,000 long tons per year - should be absorbed easily by European and African markets. On the other hand, the amount of Butyl rubber produced by an economical plant is nearly 50% of the present world

production of that type.

The figures produced by these estimates do not indicate an adequate margin of market value over production costs to justify the capital investments required. The project is one of great importance, however, and it would appear that if the project seems desirable from the standpoint of general considerations, further study would amply be justified by specialists in this field. This study should include the possibility of transporting to Europe the butane and propane cuts of the gas for use there in the manufacture of rubber as discussed in the Staff report.

6. Transportation of Gas to European Markets The only project which the Panel and the Staff have developed which would make a large use of the flare gases presently wasted is the transportation of the gas to European markets.

The Panel believes that a gas pipe line, based upon the Bechtel survey, is economically feasible and that European markets could easily absorb the 1 billion CFD of natural gas available in the Middle East. The project would cross many national boundaries. It is recommended for detailed study if and when it is not ruled out by political or other general considerations.

The alternative method indicated in the Table for transportation of liquefied gas deserves, we believe, the most careful study. This involves liquefaction of the gas in Saudi Arabia and transportation

at atmospheric pressure in specially insulated tankers to the markets.

This proposal is somewhat revolutionary in character and the cost estimates are necessarily preliminary for lack of any experience in this method of transportation. Based on these estimates, the project would be quite profitable. If successful, the project would be of great benefit both to Saudi Arabia and other countries of the Middle East and to Europe. The Panel recommends that this matter be given very careful study by qualified experts as representing possibly the most hopeful opportunity of making use of these gases. It is further suggested that the results of the Chicago project for transporting gas in this way be awaited before firm conclusions are made (see Staff Report pp. 138 and 142).

The figures on the Table are based on 3 hundred million cubic feet a day of gas from Saudi Arabia, representing the present flare gas available. The figures are proportionate allocations to Saudi Arabia of larger projects to take care of waste gases for the entire Middle East area.

It is understood that if a profitable use of gases can be made, there is every prospect that by exploration additional amounts of natural gas could be found in Saudi Arabia.

7. Electric Power There is no prospect of economically transmitting electric power from Saudi Arabia to the large markets of Europe.

The power developed would therefore be limited to that required locally for any of the above projects and for the use of the local population. The plant indicated on the Table - 40,000 kilowatts - probably would be adequate for any of these purposes at the present time.

It is recommended that the power project be reviewed particularly as to costs when the requirements have been determined more definitely.

8. Other Projects The Panel has given consideration to a number of other proposals and at the request of the Panel some of these have been studied by the Staff. These include production of aluminum, caustic soda, and chlorine. None of these appears to be sufficiently promising from an economic standpoint at the present time to justify a recommendation that they be considered further.

Respectfully submitted,

Harold S. Osborne, Chairman

Robert L. Bateman
Harry A. Curtis
Henry Gardiner Symonds
Joe J. King (Alternate)
Mayor F. Fogler
Max A. McCall
Joseph Pope
R. B. Wittenberg
E. L. DeGolyer

Table I Analysis of Principal Projects for Utilization of Waste Gases in Saudi Arabia

Item No.	Type of Product	Plant Capacity per yr.	Amount Gas Required millions CFD	Capital Investment million $	Product Cost million $ annual before return on investment	Market Value million $ annual	Remarks
1	Cement	400,000 bbls.	4	8	1.2	3.0	
2	Sulfur Recovery (per 100 million CFD)	65,000 NT	5	4	1.0	3.3	Product Cost @ $15.50 NT; Market Price @ $50 NT in Europe; Freight from Saudi allowed @ $20 NT
3 (a)	Fertilizer (First Step) Ammonium Sulphate	160,000 NT	5	20	7.7 6.7	9.3 8.0	52,000 NT annual capacity NH_3, uses 38,400 NT NH_3 Market value $50 NT
	Urea	10,000 NT			1.0	1.3	Market value USA $125 NT; Uses 5400 NT NH_3 leaving 9000 NT NH_3 capacity.
3 (b)	Fertilizer (Second Step) Ammonium Phosphate (Wet Method)	18,000 NT		0.8	2.0	2.0	USA market value $107.60 NT. Saudi cost $108.69 NT. In addition, need capital investment ($1.8 million) for H_3PO_4 and H_2SO_4 plants.
	Concentrated Superphosphate (Wet Method 46/48% P_2O_5)	30,000 NT		3.3	2.4	2.4	
4	Carbon Black - Channel	10,000 NT	25	5.0	1.1	1.5	Market value @ 7.5¢ lb. f.o.b. USA works, 10¢ lb. FAS NYC export. Saudi cost 5.5¢ lb.

Table I Analysis of Principal Projects for Utilization of Waste Gases in Saudi Arabia (continued)

Item No.	Type of Product	Plant Capacity per yr.	Amount Gas Required millions CFD	Capital Investment million $	Product Cost million $ annual before return on investment	Market Value million $ annual	Remarks
5	Synthetic Rubber						
	GR-S	46,000 LT	2.5*	82	20	23	Saudi cost @ 20¢ lb. Market value 23¢ lb.
	Butyl	46,000 LT	3 *	59	19	22	Saudi cost @ 19¢ lb. Market value 22¢ lb.
6 (a)	Transportation of Gas						
	Gas Pipe Line	1800 miles 34"-36" pipe 700 miles 24"-26" pipe	500	500	60	95	Cost @ 38¢ MCF delivered Europe, 1949 costs times 1.2; market value @ 60¢ MCF wholesale. This is Step 1 of 2 equal stages.
6 (b)	Liquefied Gas	20 tankers 15000 NT each Liquefying plant for 500 million CFD	500	350	55	77	Cost 43¢ MCF f.o.b. London; market value 60¢ MCF for wholesale distribution yield of 400 MMCFD to markets.
7	Electric Power	40,000 KW	11	13	1.5		Saudi cost at 6 mills per KWH

* Butane and propane cuts actually required - approximately 275 million CFD required to produce these cuts if all natural gas is taken from Abqaiq up to the full pressures of 500 psig. A minimum of 92 million CFD need be processed by resorting to the gases at Abqaiq and Ain Dar at pressures only up to 50 psig.

THE UTILIZATION OF WASTE GASES

IN

SAUDI ARABIA

Staff Report to The Special Panel

of

The Advisory Committee on International Technologic Assistance

Division of Engineering and Industrial Research

Mr. James A. Barr, Project Director

Dr. Samuel H. Manian, Associate Project Director

National Academy of Sciences-National Research Council

2101 Constitution Avenue

Washington, D.C.

June 23, 1954

Contract SCC-21718 Task Order No.1
Foreign Operations Administration

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Division of Engineering and Industrial Research

MR. JAMES A. BARR, Project Director

DR. SAMUEL H. MANIAN. Associate Project Director

National Academy of Sciences—National Research Council

2101 Constitution Avenue • Washington, D. C.

June 23, 1954

Contract SCC-21718 Task Order No. 1
Foreign Operations Administration

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FOREWORD

FOREWORD

FOREWORD

On November 1, 1953, the Foreign Operations Administration made the following request to the National Academy of Sciences-National Research Council. It asked the Academy-Council

"to conduct studies and surveys in the United States based on available information on the technical and engineering feasibility of the utilization of flare gases from oil producing operations in Saudi Arabia (if it is necessary to accomplish the purposes of this Task Order for experts to be sent to Saudi Arabia, prior approval therefor will be obtained from FOA); to give particular attention to the possibility of producing fertilizers or components thereof from these gases; to include consideration of other uses and products obtainable from these sources; to consider also the utilization of other natural resources of Saudi Arabia and the surrounding area in connection with these flare gases; and to advise and recommend to the FOA in the interim and final reports the processes, products, and uses which appear to bear promise of useful exploitation, and the steps which might be taken to put these recommendations into effect."

To carry out this request, a special Panel was assembled and under its direction a number of possible projects for the utilization of the now wasted gases were selected for investigation by the Staff.

A volume of pertinent material has been accumulated in the Staff office from many sources, government and private. Cooperation at the sources of information has been fully extended, without reservation. Personal conferences have been held at Wilson Dam, Alabama, New York City, Boston, Akron, Beltsville, Chicago and Washington, D.C. Technicians, research engineers and officials of companies not only have given information requested but in many instances have shown continuing interest in the projects. In some cases, information was obtained from European sources (England, Belgium, France, Italy). The appreciation of the Staff is recorded for the cooperation of the many agencies listed in the appendix.

The determination by the Staff of the feasibility of the projects was based on technologic and economic criteria and for this purpose estimates of capital requirements and operating and production costs were obtained. These were then analyzed and evaluated. In the procedure, subsidiary criteria were considered such as the agronomy and water supply of Saudi Arabia, transportation, natural resources, requirements for technical skills and managerial capabilities and responsibilities.

The Staff found in general that adequate evaluations could not be made without considering the industrial status and needs, present and potential, in neighboring countries in the area. Many factors have been found to have a regional aspect and it has not been possible to give complete evaluations without investigating the present trends in the region and their relationships to world markets.

General Technical and Economic Factors

It was necessary to consider a number of factors which are common to any industrial venture in Saudi Arabia. Details should be checked in the country before final decisions are made. The Staff has verified the following comments as far as possible.

Gas Availability

The question of a realistic and long-range dependable figure for availability of gas is closely related to the operations of the Aramco Oil Company. The difficulty of forecasting its rate of operation in the future and the current planning for use of gas of undetermined quantities for its own account in future years, make it difficult for Aramco to determine figures which could be interpreted for long range firm gas availability.

There is available at current rates of operation (900,000 B/D of crude oil), a total of 600 million cubic feet per day of gas as shown in Table I on page 11. This table also shows that possible gas uses by Aramco for its own operations would account for about 300 million cubic feet per day at the present time, leaving a balance of 300 million cubic feet per day going to flare. The geographic distribution of this flare gas at the various oil centers is also given in Table I.

Table II on page 13 gives the chemical analyses of the gases at the five different important collection centers and at three or four spots at each center where the pressures range from high to low.

If an economic outlet for gas is developed in the future, a search for additional supplies could be undertaken, with reasonable promise of success.

Plant Location

The controlling factor in the selection of plant sites has been proximity to the waste gas supply. The map on page 15 shows the location of the four fields where gas is being wasted - Qatif, Dammam, Abqusiq, and Ghawar. All of these with the exception of Ghawar are within a radius of 50 miles; Ghawar is approximately 75 miles from the port of Dammam.

Some of the raw materials required are within this radius and others are within reasonable transportation distances and close enough to the Government railroad for rail connection and haulage. A detailed inspection and testing of these raw materials is recommended before final locations are decided upon.

The water supply in the general area is adequate. There is an aquifer under the Dammam area at about 400 feet which affords a limited supply by pumping from drilled wells. The water is on the alkaline side, about 2,000 p.p.m. solids which one can drink and live, but limitation for other essential uses is advisable. U.S. government experts and Arabian American Oil geologists should be consulted before final selection of sites. Adjacent sea water may be used for cooling purposes in unlimited quantities as a matter of economics. The inshore Persian Gulf water is quite shallow and it is necessary to go out several miles to gain sufficient depth for relatively cool water since surface water becomes very warm in the hot summer. In any system of water utilization in arid areas cooling towers should be used to conserve fresh water, but there are limits since, if solids are allowed to build up by evaporation, incrusting on all surfaces becomes a serious problem, so that in addition to loss by water by

evaporation, water must be bled from the system and temperatures controlled within limits; i.e. temperature rise, which is a problem for experts in final design. Evaporation in steam type evaporators and vapor compression distillation can always be used in areas of cheap fuel such as at Dammam.

The harbor at Dammam is another important factor in site selection. The length of the pier to the shallow harbor is 8.5 km. and to the deep harbor 2.7 km. more. The depth of the water in the former is at least 12 feet and in the latter at least 26 feet. In the deep harbor pieces up to 50 tons can be handled. Larger ones have to be transferred to the shallow harbor by a floating crane owned by the Arabian American Oil Co. This crane is able to handle pieces up to 100 tons, which can be hauled on the railroad by special arrangements. The capacity of the harbor is now 50,000 tons maximum a month and would have to be made larger for projects listed in this report.

There are some through roads in the area but the roads tributary to and in the plant sites would have to be built. There are ample local materials for such purpose.

The terrain in the Dammam area shows no serious obstacles to general construction and for use for building sites.

There is no available source of power for new projects in the Dammam area but with the availability of cheap gas, power can be produced at relatively low rates in sufficient quantity for the projects selected. Power is discussed later in the report.

Labor Supply

Labor supply is always an important consideration and from reports available, there is an ample supply from the towns in the area, Dammam and Dhahran. Due to the operations of U.S.A. contractors and the Arabian American Oil Co. there is an expanding pool of native labor trained in mechanical and operating skills but it will be necessary to train a major portion of operators under the direction of imported technicians and trained operators having in mind an increase in the number of native operators as they are trained.

The labor costs used in estimating construction and production costs are based on information obtained from existing operating and contracting companies now in Saudi Arabia. The cost of importing technicians and executives into Saudi Arabia is an important expense item and in addition pay is increased to make the jobs attractive both from a living and financial standpoint.

Fringe Benefits

Because of extensive operations of Arabian American Oil Co. in its excellent public relations program, a number of facilities have been provided in the 50 mile radius which will indirectly benefit new industries. Any new industry will have to provide the so-called fringe benefits of employee housing, village utilities, roads, certain amusement projects, health facilities. These have been included in estimating costs.

Conversion of Costs

The Staff wishes to note its recognition of limitations in the cost analyses as they are presented herein. It understands the problems which

confront a company in estimating costs and particularly costs in Saudi Arabia, where numerous extraordinary assumptions are necessary due to lack of experience. Conversion factors for plant equipment, its transportation, and construction in Saudi Arabia as supplied by eight U.S.A. companies ranged from 1.3 to 3 times U.S.A. costs depending on the amount and nature of fringe requirements of housing, roads, health and recreation facilities, and importation of technical personnel and special construction and trade labor. The Staff selected an average conversion factor of 2 and applied it uniformly for the conversion of U.S.A. capital requirements to Saudi capital requirements covering these items.

Cost of Gas

Cost of flare gas for use in the various projects is taken at 3¢ per MCF at the well head. This, however, is subject to negotiation plus final estimate of costs of gathering and transporting to the location of the project when finally selected.

The following is an example of these costs:

Pipe line transportation cost for 50 miles	1¢ MCF
Cost of gas compression to 250 PSIG if required	2¢ MCF

TABLE I

Gas Production and Usage* - 1954

	Dammam	Qatif	Abqaiq	Ain Dar	'Uthmaniyah	Shedgum	Total
Crude Production Rate - MBPD	60	37	320	300	110	76	903
	Million Cubic Feet Per Day						
Gas Production							
High	15	15.4	178	98	33	25	364.4
Intermediate	2.4	5.6	37				45.0
Low	1.8		45	56	18	14	134.8
Spheroid	1.8	1.6	16	19	7	5	50.4
Stabilizer in Area	2.7		12				14.7
Total	23.7	22.6	288	173	58	44	609.3
Gas Uses							
Boiler	11.5		37.5				49.0
Ind. Uses	.2		.5				.7
Infection			159.5				159.5
Comb. Gas	6.0						6.0
Turbines							
Vapor Recovery Plant	3.0						3.0
Total	20.7		197.5				218.2
To Power Turbines to Flare				60	13.0	17	90.0
To Flare Directly	3.0	22.6	90.5	113	45.0	27	301.1
Total	23.7	22.6	288.0	173	58.0	44	609.3

*Excludes Ras Tanura Refinery where stabilization and refinery gases used in operation.

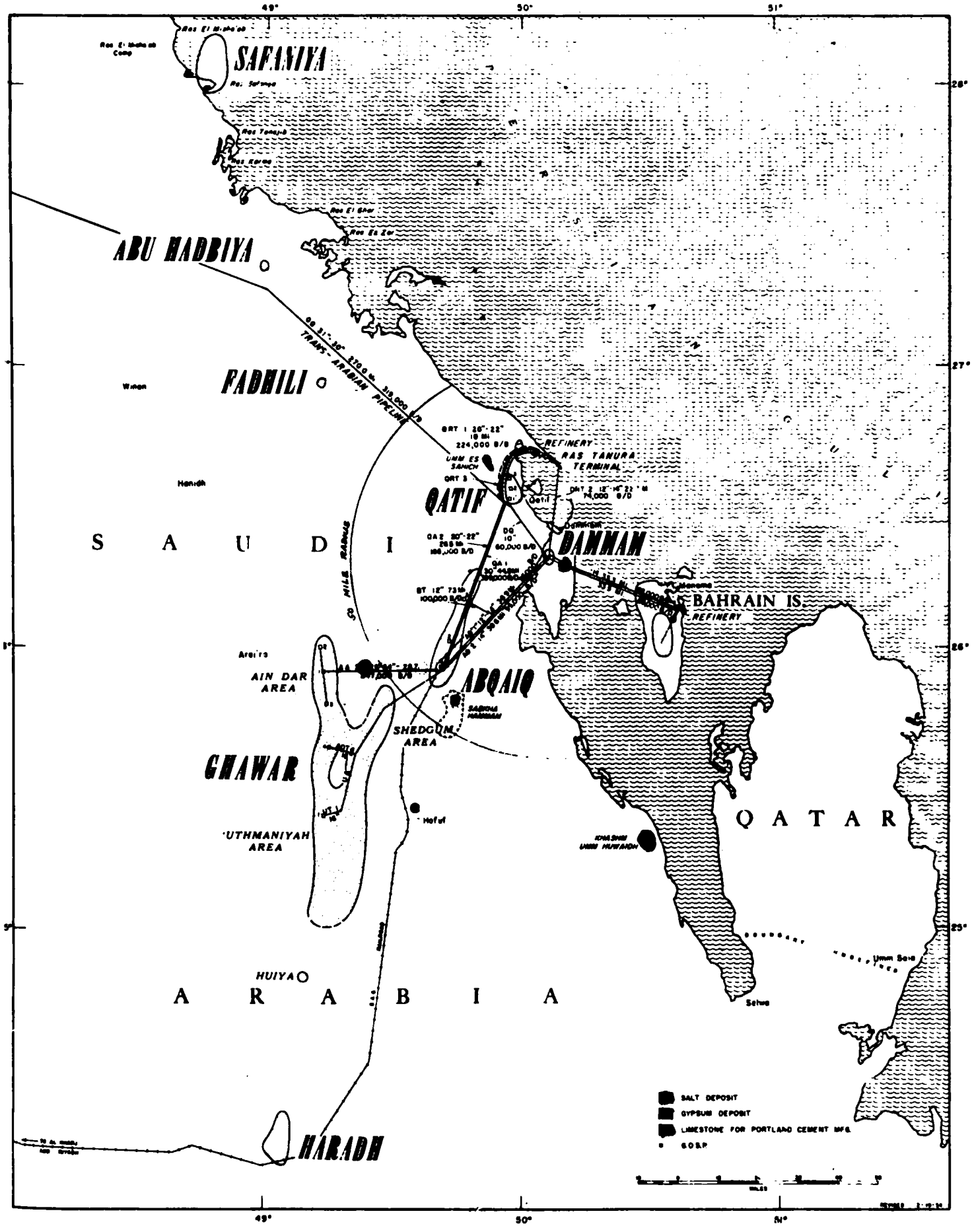
TABLE II

Gas Analyses

Component	Abqaiq 1st	Abqaiq 2nd	Abqaiq 3rd	Abqaiq 4th	Ghawar 1st	Ghawar 2nd	Ghawar 3rd	Dammam 1st	Dammam 2nd	Dammam 3rd	Dammam 4th	Qatif	Qatif	Qatif	Abqaiq Stab. Ovhd.
Pressure PSIG	500	250	50	5	400	50	5	300	150	60	1.5	315	50	1.5	
Carbon Dioxide	9.25	9.95	7.69	3.88	12.99	13.16	7.79	8.0	9.3	14.7		11.45	20.60	8.7	1.5
Hydrogen Sulfide	2.64	3.78	6.99	7.00	3.20	5.82	1.51	1.5	1.2	2.4		7.85	14.65	18.6	9.4
Methane	64.06	51.05	19.03	2.84	59.80	37.69	8.45	81.0	74.7	52.6		57.48	18.34	3.4	0.39
Ethane	14.47	20.18	26.18	17.55	14.59	20.09	23.25	4.6	7.8	14.0		13.27	16.78	16.3	16.14
Propane	6.00	9.60	22.77	31.10	6.07	14.01	31.24	2.2	3.1	7.3		5.91	17.79	28.4	50.78
Butane	2.18	3.34	10.92	22.40	1.95	5.85	17.34	1.5	2.0	4.8		1.82	6.70	17.0	13.97
Pentanes Plus	1.40	2.10	6.42	15.23	1.03	3.03	10.22	1.2	1.9	4.2		1.41	2.95	7.6	7.72
Non-Condensibles					0.37	0.35	0.02					0.81	2.92		

The components are expressed as volume per cent at atmospheric pressure.

SAUDI ARABIAN OIL FIELDS AND PIPELINES



FERTILIZERS

FERTILIZERS

In considering the manufacture of fertilizers in Saudi Arabia, it is anticipated that the major part of the fertilizer production will be exported. This conclusion is based on the following conditions.

Agronomy According to W. J. Edens, Chief, Agriculture Division, U.S.A. Operations Mission to Saudi Arabia, out of a total area of approximately 865,000 square miles of Saudi Arabian territory, approximately 500,000 acres of land is arable. About one-half of the arable land lies fallow at all times, leaving 250,000 acres for use. About 50 per cent of the arable land or 125,000 acres is a possible market for fertilizer.

If we estimate the average rate of application of fertilizers as 200 lbs. per acres, we get a theoretical need of 12,500 tons per year, of which we might expect farmers to use about 6,000 tons after an extended educational program. However, we have been informed by the Foreign Operations Administration Mission in Saudi Arabia that real statistics are unavailable and that the estimate of imported fertilizers is less than 50 tons annually.

Agriculture missions both from the U.S. government and the United Nations are continuing to work in Saudi Arabia. Soil analyses are being made and field tests are planned. However, it is thought that any considerable change in the amount of fertilizer used in Saudi Arabia is not to be expected for some time.

Water Supply Scarcity of water is a major problem. U.S. Government and United Nations missions are making extensive and intensive investigations.

In general, rainfall is so scant that only small areas of irrigation can be developed from this source. Records and data are lacking over a sufficient period of time for comprehensive planning. It is desirable to have hydrologic records for a period of 25 to 50 years before making extensive investments in engineering structures.

There is a 12 to 20 inch annual precipitation in a limited southwest area which could be further conserved for irrigation.

Ground water is not likely to be found in any appreciable quantity that would have any real impact on the overall economy of Saudi Arabia.

The demineralization of sea water by evaporation or by other means offers little hope for a supply of water low enough in cost for irrigation.

Fertilizers Considered for the Utilization of Waste Gases

Recent reports from agriculture missions working in Saudi Arabia show the land to be on the alkaline side but the knowledge is limited and the Staff does not feel qualified to make an accurate statement as to the fertilizer or fertilizers best suited for use in Saudi Arabia. A letter from W. J. Edens, Chief, Agriculture Division, U.S. Operations Mission to Saudi Arabia states -

> "Our soil scientist and agronomist feel that the greatest response by plants would be to nitrogen. The current preferential need is for nitrogen; however, it is our opinion that responses would be good to phosphorus."

This concurs with the thinking of the Staff to the effect that in all probability different fertilizers will be required in different localities and for different crops in Saudi Arabia.

The Staff presents the following rather general discussion of various types of fertilizers indicating facts pertinent to the use of fertilizers in Asia and at the same time keeping in mind the problems of exporting.

Ammonia For the production of nitrogen fertilizers, it is necessary to include a synthetic anhydrous ammonia plant and from this the various nitrogen products are produced.

Ammonium Sulphate The most commonly used synthetic fertilizer of the nitrogen type in Asia is ammonium sulphate. Farmers are accustomed to this fertilizer, throwing it on their small plots of land by hand. The physical condition is excellent and stands dampness. The main objection to the inclusion of this fertilizer in the Saudi Arabia projects is economic, since it is relatively low grade (20%N) which is a draw-back for long freight hauls in high cost transportation areas.

Urea Urea is of higher grade (45%N). As to physical conditions, it is more hygroscopic than ammonium sulphate but not as hygroscopic as ammonium nitrate. In dry countries, this does not give any trouble but for humid areas special bags are necessary. Urea is suitable agronomically for most types of soil and climates according to Dr. Frank Parker of the U.S. Department of Agriculture. The problems of the manufacture of urea are known and have been controlled, as evidenced by plants operating in Europe, Japan, and the United States. New plants are being constructed in India and in the United States.

Ammonium Nitrate This is recognized as a fertilizer suitable for many soils and climates. It has a nitrogen content of 34% which is between that in ammonium sulphate and in urea. The explosive properties of ammonium nitrate have been studied and it is now felt that there is little danger provided certain well known precautions are observed in its manufacture, transportation, and storage and in the treatment of fires in which it may be involved. The product should be prepared in granular form, coated with an inert anti-caking agent and packaged in waterproof bags. The process of the manufacture of ammonium nitrate has been well developed so that the only problems are those relative to hygroscopicity and economics.

Ammonium Phosphate This is a high grade two element fertilizer composed of nitrogen and phosphate compounds usually produced as 11-48-0 or 16.5-20-0 (per cent nitrogen -N_2, per cent phosphate - P_2O_5, zero per cent potash -K_2O). The product is a mixture of mono- and di-ammonium phosphates, a practically non hygroscopic fertilizer of excellent mechanical condition that stores, ships and handles well in the field. It presents no mechanical, explosion or fire problems in use such as occurs with some other nitrogen bearing fertilizers. The product is well accepted here and abroad and is generally recommended by agronomists where need for nitrogen and phosphate is indicated.

Phosphorus While it is recognized that the main demand for fertilizers in the East is for nitrogen types, it is also an accepted fact that the continued use of nitrogen types alone will ultimately create a phosphorus shortage in the soil (depending on the original content) which should be

supplied by a fertilizer component. Close examination may reveal soil deficiencies not only in such mineral elements as phosphorus and potash but the micro-nutrients such as copper, boron, zinc, and others which are equally important. Normal superphosphate is cheapest for local use and may be ammoniated. This fertilizer also supplies sulfur which is important in some areas but probably not of great significance in Saudi Arabia. Its production is relatively simple and cheap if combined with basic facilities, especially sulfuric acid. Concentrated superphosphate because of its high phosphorus content (usually 45/48% P_2O_5) should find an increasing use in the broad area and it can be combined with nitrogen compounds to produce high analysis mixtures containing as much as 22% N and 22% P_2O_5. As used in this text the term concentrated superphosphate is synonymous with the commonly accepted trade term of triple superphosphate. Production of ammonium phosphate is a logical sequence since phosphoric acid must be produced as the first step in the manufacture of concentrated superphosphate. The phosphoric acid is ammoniated by well-known processes, such as those used at Trail, B.C., to form a nitrogen phosphate type fertilizer of excellent physical condition, and handling and storage properties.

Potash It is recognized that potash deficiencies often exist or develop and the agronomist must carefully study this phase but since it would not be a product of Saudi Arabia (at least at this stage), potash is not included in this report. It would seem unlikely that the soils of Saudi Arabia will require substantial quantities of potash in the near future.

Nitric Phosphate This type of fertilizer has been little used in the U.S.A. but one company has recently begun large scale production. There has been no wide distribution and its acceptance and results have not been established. The Tennessee Valley Authority began a research program during World War II, during the sulfur shortage, with the idea of substituting nitric acid in part for sulfuric acid and it was successful in proving up several methods. All the products are not water soluble but are "available" by A.O.A.C. methods. While field tests have shown good results in certain areas, it is felt that the products are not suitable in areas of low rainfall and soil conditions such as exist in Saudi Arabia.

Fused Phosphate This product is described as a water insoluble phosphate though "available" to a certain per cent according to A.O.A.C. analytical methods.

Breakdown Used in Reporting Costs

In reporting on product costs, we have used the following breakdown as closely as possible. However, in many cases the reporting by companies or organizations did not contain this information and it was necessary to use the data available. The breakdown followed was

Product Costs

Raw materials

Labor and supplies

Plant overhead

Local taxes 1% of investment

Insurance 1% of investment

Depreciation - varies according to process, deterioration and obsolescence factors - usually 6-8%

Local office or plant overhead - 50% of labor

Company overhead - general administrative and sales (G.A.S.)

This must be applied with due consideration to prevent double charges. For instance, in a three step process where the first step process is not intended for sale, the G.A.S. is applied to the final product.

The company overhead varies according to the type of product and the individual organization. Some companies have elaborate and expensive structures. Some commodities are sold only to a very few customers that can be handled by a sales manager and a clerical staff while with other commodities a large staff is necessary.

In general, the G.A.S. is taken on an average ranging from 2-6% of the product sales price. A correction factor is applied to Saudi Arabia

G.A.S. to meet local requirements.

Except for costs of transportation of gas by pipe line or LPG by tanker, calculations of product costs do not include return on investment.

Cost of raw materials imported were based on market quotations at points of origin plus freight and handling to Saudi Arabia. Local materials such as gypsum, clay, and limestone were based on information supplied by Aramco plus freights to plant site.

The price of natural gas was taken nominally at 3¢ per MCF and obviously is subject to actual negotiation.

Labor charges in Saudi Arabia were obtained by adding 50% to the corresponding U.S.A. labor expenses. This reflects suggestions of Aramco and Fluor Corporation.

The following costs were based on a percentage of costs, determined according to the procedure described, and this automatically provides conversion factors to compensate for increased Saudi Arabian capital and operating costs.

Maintenance	3% of investment
Local taxes	1% of investment
Insurance	1% of investment

Depreciation, a percentage of investment according to type of plant and process, usually 6-8%

Local office or plant overhead - 50% of operating labor

General administrative and sales, as described.

These allocated percentages are the result of discussions with TVA.

Processes, Manufacturing Conditions, Costs

Ammonia Anhydrous ammonia is the basic material for the manufacture of nitrogen fertilizers in Saudi Arabia. It would use all local materials. The process is usually described in three stages - first, production of hydrogen by reforming of natural gas; second, purification of the reformed gas; and third, synthesis of ammonia from the hydrogen and from nitrogen derived from air.

Hydrocarbon gases such as coke oven gas, natural gas and some petroleum refinery gases can be reformed to produce hydrogen and carbon monoxide. The latter is converted to carbon dioxide. We will confine this report to the use of natural gas which is piped into a heater, then to sulfur removal equipment, then to a mixed gas reheater where steam is added, and then passed to a primary reformer.

The catalyst in the reformer tubes promotes the reaction between the hydrocarbons in the gas and steam to form a mixture of hydrogen, carbon monoxide and carbon dioxide. Small quantities of residual methane remain in the reformed gas.

A second reformer follows where an air and gas inlet provides the nitrogen required in the final mixture and also raises the mixed gas temperture to promote conversion of residual methane. A waste heat boiler follows which supplies process steam and cools mixed gases to the point required for the oxidation of carbon monoxide to dioxide and hydrogen by adding steam and passing over a catalyst. The gas stream now goes to heat exchangers for cooling and condensation of steam which is trapped off as water. The

residual gases go to a gas holder as a surge storage before the final steps.

The gas is then compressed in the first stage and the carbon dioxide scrubbed out by water under pressure. The scrubbed gas is then further compressed in the second stage of the process and scrubbed with an ammoniacal cuprous solution to remove residual carbon monoxide and then again scrubbed by a caustic soda solution to remove last traces of carbon dioxide. The gas leaving the caustic scrubber passes through a trap to the last stage of compression followed by cooling and drawing off of condensed ammonia to storage. The gas from the ammonia cooler condenser system is recycled through a high pressure converter with catalyst bed and heat exchanger, and thence to the cooling, condensing as noted above in a closed recycle.

The Tennessee Valley Authority gives the following table.

Process Requirements per Ton of Ammonia

Natural Gas	
Process gas MCF	21.3
Fuel gas MCF	9.9
Steam lb.	6,100
Power KWH	1,050
Water gal. in circulation*	175,000
Operating labor man hours	1.83
Maintenance labor man hours	0.71

*Only 3-5% of this water is needed for make-up.

Ammonia - Costs

Capital Investment

Capacity of plant - 150 MT per day

U.S.A.	Saudi Arabia
$6,000,000	$12,000,000

Capital costs do not include an item of $1,100,000 basis U.S.A. for a sour gas purification plant. They do include plant and equipment delivered and erected in Saudi Arabia and also include fringe facilities.

The subject of the gas purification is common to several other projects and has not been charged to any particular one. It is assumed that the sweetening plant would be self sustaining from the sale of recovered sulfur as such, or in the manufacture of sulfuric acid.

Product Cost per NT 100% Anhydrous Ammonia

	U.S.A.	Saudi Arabia
Raw materials	$20.68	$ 2.07
Labor, supplies, utilities, etc.	13.25	27.84
Plant overhead	9.79	16.16
Company overhead G.A.S.	2.50	3.50
	$46.22	$49.57

Market Price

U.S.A. February, 1954

Basis tank cars, works

Fertilizer grade 100% anhydrous ammonia per NT $85.88

Ammonium Sulphate The raw materials required for this process are anhydrous ammonia, carbon dioxide gas and finely ground gypsum or anhydrite, relatively pure and reactive with ammonia carbonate solutions.

The anhydrous ammonia is piped from an adjacent snythetic ammonia plant which will also supply carbon dioxide. This could also be available from stack gases.

Ammonia and carbon dioxide are reacted in water solution in carbonating towers. Heat of reaction is removed by heat exchangers using water as a cooling medium. Finely ground gypsum or anhydrite is reacted with ammonium carbonate solution in the presence of excess carbon dioxide in a series of reaction vessels in which, by double decomposition, ammonium sulphate and calcium carbonate are formed. Calcium carbonate is removed by filtration and may serve as a raw material for portland cement manufacture. The filtrate is then passed to stripping towers where unreacted ammonia and carbon dioxide are removed by passing counter current to a flow of steam. These gases are absorbed in water and recycled to the carbonation section. The effluent liquor is evaporated and the ammonium sulphate crystallized out, dried, cooled and readied for storage and shipment.

Ammonium Sulphate - Costs

Capital Investment

Capacity of plant - 500 NT per day

U.S.A.	Saudi Arabia
$2,543,000	$5,086,000

These figures are based on using natural gas for snythesis and gypsum for the sulfur radical. The U.S.A. figure is delivered and erected. The Saudi Arabia figures follow these same conditions and include auxiliary facilities and fringe requirements.

Product Cost per NT

	U.S.A.	Saudi Arabia
Raw materials Ammonia $50 NT Gypsum $ 8 NT		$23.17
Labor, supplies, etc.		9.74
Plant overhead		5.67
Company overhead G.A.S.		3.00
		$41.58

There is no comparable process now in use in the U.S.A.

Market Price

U.S.A. April 4, 1954	$45.50
Freight to Saudi Arabia (Conference Rate)	23.50
	$69.00

Lower prices were quoted for European sources c.i.f. Mediterranean ports -

approximately $47.50. This price was supplied by Dr. Mayor Fogler of the Allied Chemical and Dye Corporation.

Urea This study has been confined to the so-called "once-through" process for the manufacture of urea from ammonia and carbon dioxide, since the unconverted ammonia-CO_2 gas, instead of being recycled is sent to an adjacent fertilizer unit for the manufacture of ammonium sulphate. This reduces investment costs in the urea plant approximately 20 per cent.

Ammonia and carbon dioxide are piped from an adjacent synthetic ammonia plant (carbon dioxide is also available from the cement and boiler plants) into an autoclave at a ratio of $2NH_3$ to 1 of CO_2, in stoichiometric proportions, operating at 160° to 200° C and 120 to 200 atmospheres pressure. The ammonia and carbon dioxide react rapidly to form ammonium carbamate, an exothermic reaction. In the next stage the carbamate dehydrates to form urea; this latter reaction does not go to completion but only to equilibrium. The maximum conversion of the once-through process is 40 to 50 per cent.

Since the first reaction is highly exothermic and the second slightly endothermic, heat transfer surfaces are used in the autoclave. The aqueous solution leaving the decomposer step is concentrated by evaporation and crystallization or prilling, then dried, cooled and bagged in multiwall bags with a waterproof liner.

There are five other processes for the manufacture of urea which employ recycling -

1. Hot gas recycle process such as was used by I. G. Farben
2. Solution recycle process as used by duPont
3. Oil slurry recycle process known as the Pechiney process developed by the Chemical Electro-Metallurgical Products Co., St. Auban, France
4. Gas separation recycle process known as the Inventa Process, developed by the Hovag Company in Switzerland
5. Chemico Process, a CO_2 absorption gas separation system for recycling the unconverted carbamate - Chemical Construction Company

Urea - Costs

Capital Investment

Capacity of plant - 30 NT per day (45%N)

	U.S.A.	Saudi Arabia
	$1,400,000	$2,800,000

Product Cost per NT

	U.S.A.	Saudi Arabia
Raw materials Ammonia at cost, CO_2 and other chemicals	$30.75	$33.25
Labor, supplies, etc.	19.94	28.07
Plant overhead	14.72	29.00
Company overhead G.A.S.	3.00	5.00
Cost per NT	$68.41	$95.32
Cost per lb.	3.42¢	4.77¢

Market Price

U.S.A. Spring 1954	per NT	$125
Conference freight rate		$ 25
c.i.f. Saudi Arabia		$150

Nitric Acid This section is presented separately since the product is derived from ammonia and used in both the manufacture of nitric phosphates and ammonium nitrate.

Anhydrous ammonia is oxidized to the oxides of nitrogen by passing through a platinum catalyst. The oxides of nitrogen are hydrated and absorbed in water in a bubble tower of similar apparatus, preferably under pressure, to form the nitric acid of commerce, in this case about 60% of strength but it can be made of higher strength.

Nitric Acid - Costs

Note: U.S.A. costs are estimated by Tennessee Valley Authority

Capital Investment

Capacity of plant - 3 units of 60 NT each per day

	U.S.A.	Saudi Arabia
	$1,900,000	$3,800,000

Product Cost per NT

	U.S.A.	Saudi Arabia
Raw materials Ammonia and catalyst	$13.53	$14.58
Labor and supplies, etc.	4.54	6.63
Plant overhead	3.33	7.26
Company overhead (Integrated in another product)		
Total cost per NT	$21.40	$28.47

Ammonium Nitrate In one method, ammonia is reacted with nitric acid in solution, and the solution is evaporated and crystallized in vacuum crystallizers, salted out and centrifuged. The crystals are sent to a drum where they are coated with an inert substance such as bentonitic clay to reduce caking and to form pellets for proper physical condition in handling and use and to reduce absorption of moisture from the air.

The pellets are dried, screen-sized to eliminate fines which are recycled. The product is bagged in a multiwall paper bag with one layer of waterproof paper. The bags should not be stored from one season to the next and should be kept in a dry place.

In an alternate method, the ammonium nitrate solution is evaporated until a molten ammonium nitrate containing a little water is obtained. This molten mixture is pumped to the top of a tall shot tower and sprayed into it much as molten lead is sprayed into a tower. This process is known as prilling and gives a pelletized material of good physical condition.

The trend to ammonium nitrate was accelerated by the shutdown of nitric acid plants for munitions after World War II. These plants were leased and converted to peace time manufacture of ammonium nitrate; hence in any ammonium nitrate production a potential munitions plant is setup.

Commercial Solvents Corporation has developed the so-called Stengel process where preheated anhydrous ammonia is reacted with nitric acid at 400°F, molten ammonium nitrate is formed which is cooled to the solid state, then crushed, sized, coated and bagged for shipment. This process eliminates evaporation and prilling.

Ammonium Nitrate - Costs

Note: U.S.A. costs are estimated by the Tennessee Valley Authority

Capital Investment

Capacity of plant - 230 NT per day prilled - estimated analysis 34%N

	U.S.A.	Saudi Arabia
	$900,000	$1,800,000

Product Cost per NT

	U.S.A.	Saudi Arabia
Raw materials Nitric acid, clay, ammonia	$28.60	$34.78
Labor, supplies, etc.	9.68	14.52
Plant overhead	1.85	3.27
Company overhead G.A.S.	4.00	6.00
Total cost per NT	$44.13	$58.57
Cost per unit nitrogen (Basis 34%N)	$ 1.30	$ 1.73

Market Prices

U.S.A. bagged f.o.b. works	$68 - $70 NT
Freight to Saudi Arabia - Conference	$34
Total cost	$102 - $104
Cost per unit of nitrogen	$3.00 - $3.06

Elemental Phosphorus - Electric Furnace Method There are two commercial processes of making phosphorus from phosphate rock

1. Phosphate rock with a silica flux for making a suitable slag is charged into a blast furnace with coke for fuel. Reduction of the rock to elemental phosphorus takes place. There are no current operations by this process.
2. Phosphate rock, flux and coke are charged into an electric furnace where heat is supplied by electric current through carbon or graphite electrodes.

Calcium silicate is slagged off, iron in the charge combines with phosphorus to form ferro-phosphorus (about 23% P_4) which is also tapped off. The balance of phosphorus is volatilized as elemental P_4, cleaned of dust preferably in a Cottrell precipitator; the gas and vapor stream goes to a water sprayed condenser, phosphorus is drawn off in molten form into water covered storage, and the non-condensable exit gases containing principally carbon monoxide are used as fuel, usually for calcining and nodulizing the raw phosphate rock.

Note that this is the basis for phosphoric acid and phosphate fertilizers. The basic product is elemental phosphorus produced in an electric furnace as described above. The second step is the production of phosphoric acid which is then used in the third step to acidulate phosphate rock to make concentrated superphosphate or in a separate step to react with ammonia to produce ammonium phosphate.

Elemental Phosphorus - Costs

Note: U.S.A. costs are estimated by the Tennessee Valley Authority

Capital Investment

Capacity of plant - 19.4 NT per day from one electric furnace of 10,000 KW input.

U.S.A.	Saudi Arabia
$2,800,000	$5,600,000

It is not known without tests of the phosphate rock whether a nodulizing plant would be required to prepare the furnace feed. If a nodulizing plant is required, the investment cost is estimated at $1,208,000 in addition to the furnace plant cost.

Raw materials are phosphate rock from Egypt or, if obtainable, from Jordan; coke from Mediterranean area; silica, locally; power generated from flare gas; electrodes, imported. The manufacture of elemental phosphorus in Saudi Arabia is not a low cost picture.

Product Cost per NT

	U.S.A.	Saudi Arabia
Raw materials	$126.71	$243.12
Labor and supplies, etc.	40.32	64.00
Plant overhead	41.48	76.04
Company overhead G.A.S.	7.50	9.00
Total cost per NT	$216.01	$392.16
Cost per lb.	10.8¢	19.7¢

Phosphoric Acid A very small proportion of the elemental phosphorus is sold direct to consumers. By far the larger proportion of the phosphorus is converted to 75%/80% phosphoric acid (H_3PO_4). The elemental phosphorus is burned with a correct proportion of air in a chamber, then hydrated and collected as phosphoric acid. The condensate ($H_3PO_4 + H_2O$) is drawn off at the bottom of the chamber, cooled and piped to process or shipment.

Phosphoric Acid - Costs

Note: U.S.A. costs are estimated by the Tennessee Valley Authority

Capital Investment

Capacity of plant - 59.9 NT per day 100% phosphoric acid (H_3PO_4)

U.S.A.	Saudi Arabia
$300,000	$600,000

This includes oxidizing (burning tower), hydrating tower, scrubber, pumps and piping, cooling, intermediate storage tank.

Product Cost per NT 100% Phosphoric Acid

	U.S.A.	Saudi Arabia
Raw materials Phosphorus	$70.88	$127.96
Labor, supplies, etc.	2.39	3.57
Plant overhead	2.10	3.10
Company overhead G.A.S. (Integrated with another product)		
Total cost NT 100%	$75.37	$134.63
80%	60.30	107.70

Ammonium Phosphate There are several methods of making this fertilizer but we will describe a relatively simple process which bubbles anhydrous ammonia into a solution of phosphoric acid to form a crystalline mixture of mono- and di-ammonium phosphate which is centrifuged and then dried under carefully controlled temperature conditions in a direct heat rotary dryer, followed by cooling. The product is then ready for storage, or shipping in bulk or in paper or cloth bags. No particular precautions need to be taken in storing in bulk or packaging except to protect from the weather.

Ammonium Phosphate - Costs

Note: U.S.A. costs are estimated by the Tennessee Valley Authority

This is made from electric furnace phosphoric acid. The production of ammonium phosphate assumes a source of ammonia and phosphoric acid as feed to the ammonium phosphate unit.

Capital Investment

Capacity of plant - 54¼ NT bagged per day

U.S.A.	Saudi Arabia
$370,000	$740,000

Ammonium Phosphate - Costs
(continued)

Product Cost per NT

	U.S.A.	Saudi Arabia
Raw materials Phosphoric acid and ammonia	$69.06	$118.77
Labor and supplies, etc.	7.61	10.51
Plant overhead	3.81	5.81
Company overhead G.A.S.	4.00	5.00
Total cost NT	$84.48	$140.09

Market Price

U.S.A. March 1954 bagged Los Angeles $107.60

Basis 11-48%, Canadian origin

Concentrated Superphosphate - Furnace Method This is made from phosphoric acid produced from electric furnace elemental phosphorus. Phosphoric acid at 75% to 80% strength is mixed with ground phosphate rock in a simple T.V.A. designed cone type mixer to form a slurry. The slurry is discharged onto a slowly moving conveyer where it rapidly sets up and is discharged onto a second means of conveying such as a motor driven dump car and is then discharged onto a pile in a storage shed.

The phosphoric acid reacts with the phosphate rock to form concentrated superphosphate, a fertilizer which may run about 48% (A.O.A.C.) available P_2O_5 which has a high percentage of water soluble P_2O_5.

The product is left in the pile to cure, complete the reactions and

dry out for a period of 30 to 60 days, then is excavated and conveyed to a pulverizer and crushed to pass a 6 to 8 mesh screen and bagged for shipment.

Some companies make a so-called granular type. The crushed product is moistened and rolled in a cylinder to form pellets; the next step is drying, followed by screening out oversize which is recrushed, combined with fines and recycled through the pelletizing cylinder. The resulting product is a closely sized granular product with practically no dust. Granular type fertilizers are gaining in favor and may possess certain advantages in handling and in plant response.

Concentrated Superphosphate - Costs
Furnace Method

Note: U.S.A. costs are estimated by the Tennessee Valley Authority

Capital Investment

Capacity of plant - 32.3 NT per day of bagged product
48% available P_2O_5

U.S.A.	Saudi Arabia
$170,000	$340,000

This includes storage shed for curing and shipping superphosphates but no provision for seasonal storage of product.

Concentrated Superphosphate - Costs
Furnace Method
(continued)

Product Cost per NT

	U.S.A.	Saudi Arabia
Raw materials Phosphate rock and phosphoric acid	$40.89	$69.30
Labor, supplies, etc.	6.10	8.09
Plant overhead	2.37	3.69
Company overhead G.A.S.	2.70	4.20
Total cost per NT	$52.06	$85.28
Cost per unit basis 48% P_2O_5	$ 1.10	$ 1.78

Market Price

U.S.A. Spring 1954 f.o.b. Tampa

46% P_2O_5 $45.08

Concentrated Superphosphate - Wet Method (Using sulfuric acid)

In normal areas such as the U.S.A., where power rates are less than 1¢ for large users, and sulfuric acid prices low because of Gulf sulfur, it is generally the case that phosphoric acid and concentrated superphosphate (45/48% available P_2O_5) are produced cheaper by the wet method than from elemental phosphorus produced in the electric furnace and the plant investment per unit of P_2O_5 produced is lower.

The wet process is conducted in two steps -

Step No. 1 - Phosphoric Acid Phosphate rock is acidulated with diluted sulfuric acid to produce dilute phosphoric acid. The mix is filtered on standard rotary filters and water washed to produce a dilute phosphoric acid and leave a gypsum cake. The phosphoric acid will contain soluble impurities such as iron and alumina phosphates, arsenic, and other elements in the phosphate rock which are soluble in sulfuric acid. This does not constitute any particular detriment in fertilizers, but would in the manufacture of chemicals, especially "food grade".

The crude phosphoric acid requires relatively expensive purification so that electric furnace phosphoric acid is generally preferred and used for chemical manufacture. The crude phosphoric acid produced in the first step may be used to dilute sulfuric acid, which is then used to acidulate phosphate rock and produce a boosted grade, i.e. 26/28% P_2O_5 available normal superphosphate. This in turn may be ammoniated to 5/7% nitrogen content. This practice is growing in the U.S.A.

Step No. 2 - Concentrated Superphosphate The dilute phosphoric acid from the first step is evaporated down to about 58/60 Be' beyond which point the impurities make it difficult to handle because of solids salting out which are high in P_2O_5. This depends on impurities in the phosphate rock used in Step No. 1.

The concentrated phosphoric acid is in turn used to acidulate ground phosphate rock. The resulting slurry sets up on a slow moving conveyor or a "den" and in a short time can be conveyed into storage piles for curing

and completion of reactions. After curing for about 30 to 60 days, the product is usually dried, pulverized and granulated before bagging and shipping.

There are a number of variations practiced in the manufacture of phosphoric acid and concentrated superphosphate by the "wet" method which we will not attempt to include in this report.

Concentrated Superphosphate - Cost
Wet Method

Capital Investment

Capacity of plant - 30,000 NT per year 46/48% available P_2O_5

	U.S.A.	Saudi Arabia
Rock grinding unit	$ 125,000	
Phosphoric acid unit	$1,523,000	
Total cost	$1,648,000	$3,296,000

This is an integrated unit for the manufacture of phosphoric acid (first step) and the manufacture of concentrated superphosphate (second step). Sulfuric acid will be needed (100/120 NT per day - basis 100% H_2SO_4). The cost of this is reported in detail in the section of the recovery of sulfur. The investment costs are

	U.S.A.	Saudi Arabia
Sulfuric acid unit	$720,000	$1,440,000

Product Cost per NT

First Step - Phosphoric Acid 100%

	U.S.A.	Saudi Arabia
Raw materials Delivered in Saudi Arabia - phosphate rock from Morocco, sulphuric acid from sour gas		$76.12
Labor, supplies, etc. and Plant overhead		20.68
Company overhead G.A.S. (Integrated with other products)		
Total cost NT		$96.80

Second Step - Acidulation of ground phosphate rock to produce 46/48% available P_2O_5

	U.S.A.	Saudi Arabia
Raw materials Phosphoric acid from first step, phosphate rock from Morocco		$51.75
Labor, supplies, etc. and Plant overhead and Company overhead, G.A.S.		27.10
Total cost per NT		$78.85
Per unit available 47% available P_2O_5		$ 1.68

Comparative Costs of Concentrated Superphosphate

	Per NT product	Per Unit P_2O_5
Manufactured in Saudi Arabia		
Electric Furnace Method 48% P_2O_5	$85.28	$1.78
Sulfuric Acid Wet Method 46/48% available P_2O_5	78.85	1.68
Imported from Tampa, Florida Bulk 46% P_2O_5 @ 98¢/unit c.i.f.	70.08	1.52

Comments: While the cost of bulk concentrated superphosphate from Tampa, c.i.f. Saudi Arabia is lower than local production cost, the local consumption is so low that it makes bulk imports impractical. Imports would have to be in bags which would call for higher freight rates which we estimate would bring cost c.i.f. Saudi Arabia to approximately $78 NT, or $1.70 per unit. In any case the concentrated superphosphate would have to be bagged so that we will not add bagging costs for purposes of these comparisons.

Fused Phosphate Rock The following data is from the T.V.A. The experimental production of fused phosphate rock has been carried on for several years by the T.V.A., following up previous research by the U.S. Department of Agriculture and others, where it was found that if all or nearly all the fluorine in the phosphate is driven off by heat and water vapor, the resulting product is substantially "citrate" available.

The product acts very much like normal superphosphate made by the acid method, especially on non-alkaline soils. It has shown very good results on pasture lands.

There has been very limited production and use of the fused phosphate rock so that commercial experience and acceptance has been very limited and it may be said to be still in the experimental stage. The T.V.A. feels that its phase of the work has proceeded far enough and is ready for commercial exploitation on the merits of the process and product as demonstrated by pilot plant operations and field tests.

The process embraces the charging of bricquetted and sized lump phosphate into a shaft type furnace fired near the bottom by gas in a special design semi Dutch oven type Tuyere. The charge is melted and fluorine eliminated by action of heat in the presence of water vapor from the combustion of gas. The melt is tapped off and granulated in water. The next step is drying and grinding to at least 80 mesh. This fine grinding is essential since the coarse material will not show sufficient availability by the A.O.A.C. method and would not give satisfactory results in the field.

Fused Phosphate Rock - Costs

Note: U.S.A. costs are estimated by the Tennessee Valley Authority

Capital Investment

Capacity of plant - 189,000 NT per year
28% P_2O_5

	U.S.A.	Saudi Arabia
	$2,495,000	$4,990,000

Product Cost per NT

	U.S.A.	Saudi Arabia
Raw materials Phosphate rock, clay, natural gas	$13.29	$14.70
Labor, supplies, etc.	5.46	7.89
Plant overhead	2.06	8.19
Company overhead G.A.S.	3.00	4.00
Total cost per NT	$23.81	$34.78
Cost per ton P_2O_5	85.00	124.00
Cost per unit P_2O_5	$ 0.85	$ 1.24

Comments: While the production costs compare very favorably per unit of P_2O_5 with concentrated superphosphate by the wet method, it is the opinion of fertilizer experts consulted (Mr. K. D. Jacobs and others, U.S. Department of Agriculture, Beltsville, Maryland) that fused phosphate is not water soluble and would not be acceptable in the general Saudi Arabian area.

Nitric Phosphates Essentially the processes used or under development consist of acidulating phosphate rock with nitric acid and other acids, such as sulfuric and phosphoric, followed by ammoniation and in most forms with the addition of potash, either the chloride or sulphate, the latter where the sulphate radical is needed.

The Tennessee Valley Authority has done considerable research on four types of nitric fertilizers as follows -

No. 1. Acidulation of phosphate with nitric phosphoric acid mixtures, ammoniation, adding potash salt, drying.

No. 2. Acidulation of phosphate rock with nitric sulphuric acid, ammoniation, adding potash salt, drying.

No. 3. Same as No. 2 except sulphate radical is obtained from sulphate of potash.

No. 4. Acidulation with nitric acid, ammoniation to dicalcium stage, filtration. Filtrate treated with ammonia and CO_2. Calcium carbonate separated by filtration. Extract ammonium nitrate by crystallization. Results - products containing dicalcium phosphate and ammonium nitrate.

Nitric Phosphates - Costs

Capital Investment

Capacity of plant - 100,000 tons per year

	U.S.A.
	$1,300,000

Product Costs

We have no accurate data on operating costs. It is understood that a 12-12-12 nitric phosphate is being sold in Ohio at $70/72 per ton in direct competition with regular 12-12-12 goods which have been quoted at $74 per ton.

SULFUR RECOVERY

SULFUR RECOVERY

Sulfur Dioxide and Sulfur Removal from Sour Natural Gas It is necessary to remove the sulfur content (H_2S) from natural gas before it can be used in other processes which require a purified gas and it is advisable that gas be sulfur free when transported in pipelines in order to prevent corrosion and eliminate the possibility of toxic reactions. There are several processes for doing this but only one will be described in this report, the Girdler process.

The gas stream is passed through absorbing towers in contact with an amine solution which absorbs the H_2S. The pregnant amine solution is heated and stripped of H_2S in a second tower. The "acid" gas goes to a combustion furnace where one-third of the H_2S is burned to SO_2, and then recombined with the other two-thirds of the H_2S and passed to a reactor. The H_2S reacts with the SO_2 to form sulfur vapor which goes to a condenser where liquid sulfur is tapped off and sent to forms or solidifying pits. The exit gas from the condenser containing some unreacted H_2S is reheated with additional fuel gas and passed to a second reactor for final removal of remaining sulfur.

If sulfuric acid is to be made adjacent to the H_2S stripping unit, the second step in sulfur removal may be omitted and then all of the H_2S from the first step in burned to SO_2 in the combustion chamber of a sulfuric acid plant for the production of sulfuric acid as described later.

50 tons of this recovered sulfur will supply a 150 ton per day sulfuric acid plant. Solid or "lump" sulfur is the crude sulfur of commerce which can be shipped in packages or bulk and has a good position in the world markets at prices that have been increasing for some time.

Sulfur Recovery - Costs

The Chemical Construction Corporation estimated a U.S.A. plant cost of $2,000,000 for treating 26 million CFD gas containing 14.6% H_2S and 15.8% CO_2. This includes sulfur recovery.

The Foster-Wheeler Corporation estimated a U.S.A. plant cost of $1,100,000 for treating 75 million CFD gas containing 5% H_2S and lower CO_2. Includes sulfur recovery.

The Whitco Chemical Company estimated a U.S.A. Girbitol unit for sweetening 25 million CFD gas containing 3½% H_2S at $650,000. This does not include sulfur recovery.

Capital Investment

Capacity of plant - 65,000 NT per year

U.S.A.	Saudi Arabia
$2,000,000	$4,000,000

These figures are based on sweetening 100,000,000 CFD of gas containing an average of 5% H_2S.

Product Cost per NT Sulfur

	Saudi Arabia
Raw materials	
5,000,000 CFD gas @ 3¢ MCF	$ .75
Other materials	.07
Labor, supplies, etc.	5.79
Plant overhead	5.48
Company overhead G.A.S.	3.00
Total	$15.09

Market Price

Crude, bulk, export f.o.b. vessel	
U.S.A. Gulf ports NT	$28.50 - $30.00

Sulfuric Acid Sulfide ores, elemental sulfur and hydrogen sulfide gas are the basic raw materials which are roasted or burned to form SO_2 gas. The SO_2 gas is oxidized and hydrated in two basic types of plants to form sulfuric acid. One type is the so-called chamber plant where the SO_2 is oxidized by nitre gas (nitrogen oxide) and hydrated in chambers and towers to form sulfuric acid, usually 60 Be' (77.67% H_2SO_4). This type is now very little used in new projects. The second and most used is the "contact" process plant. The hot SO_2 gas from sources mentioned is passed through a waste heat boiler, then passed through a bed of vanadium catalyst and oxidized to SO_3, followed by cooling and hydration and is then collected as H_2SO_4 which may be made any required strength, liquid phase usually 66 Be' (93.19% H_2SO_4).

Sulfuric acid is an intermediate product for manufacture of fertilizers in Saudi Arabia but no doubt a limited quantity could be sold to Aramco for oil refining.

Sulfuric Acid - Costs

Capital Investment

Capacity of plant - 100 NT per day
100 % H_2SO_4

U.S.A.	Saudi Arabia
$720,000	$1,440,000

Product Cost per NT 66 Be' H_2SO_4

	U.S.A.	Saudi Arabia
Raw materials Sulfur at $40 NT		$13.30
Labor, supplies, etc. and Plant overhead and Company overhead G.A.S.		6.00
Total cost basis 66 Be'		$19.30
basis 100% H_2SO_4		$20.70

C E M E N T

CEMENT

Because of the shortage of water, the "dry" process has been selected instead of the "wet" process which utilizes slurries in the preparation and feed of the raw materials to the kilns.

Size of Plant

Aramco has stated that at its peak of construction it consumed approximately 750 B/D of portland cement in Saudi Arabia. Current and continuing needs are at the somewhat lower level of 600 B/D. Other domestic requirements are estimated to be as much again, making the total Saudi Arabian requirement, 1,200 B/D or more. The plant developed in this report is for 1,250 B/D, with provisions to double this capacity when needed. All production would be for use in Saudi Arabia and distribution is not predicated on external markets.

Raw Materials

The gas requirement for a plant of the capacity of 1,250 B/D per day is estimated at 4,000,000 CFD.

Limestone and clay in the approximate proportion of 3 to 1 are the principal raw materials for portland cement. Addition of small quantities of gypsum (3%) is necessary to control and reduce the extremely rapid rate of setting. Limestone, clay and gypsum are available in Saudi Arabia in sufficient quantities. The plant described includes the development of a gypsum quarry and grinding plant and a limestone quarry and crushing plant.

Process

Limestone rock received from the quarry is given a primary and secondary crushing in various types of crushers and hammer mills and the size reduced to 3/4 inch pieces. The clay is added by automatic proportioning equipment and the mixture fed to ball and tube mills for further reduction in size to small particles.

The burning operation is carried out in cement kilns (in this plant 8½' x 300') the raw materials flowing counter current to the heat source. The horizontal rotary kiln is inclined 3/4 inch for each foot of length and rotated at a rate of one complete turn each minute. Heat is to be supplied by combustion of natural gas, giving flames of 30 to 40 feet long creating temperatures of 2,700°F in the hottest zone where the raw material mixture is brought to point of near fusion.

The hot clinker emerging from the kiln at about 2,000°F passes through an air quenching cooler (3' X 50'), gypsum is added and the mixture is ground several times in finishing mills to extreme fineness, so that more than 90% passes through a 200-mesh screen. Cement is shipped in paper bags of 94 lbs. (1 cu. ft.) capacity and in barrels of 376 lbs. (4 bags) capacity and also in bulk.

Note: The government of Iraq has issued requests for bids (3 volumes of detailed specifications) open until June 15, 1954 for construction of two cement plants, each 350 T/D (2,100 B/D). All of the proposed cement production is for use in the construction of four dams and no external distribution to foreign markets is planned.

Cement - Costs

Capital Investment

Capacity of plant - 1,250 barrels per day

U.S.A.	Saudi Arabia
$3,923,000	$7,846,000

This plant is for a gas fired dry process, delivered and erected, with quarries, auxiliary facilities and power plant.

Production Costs per Barrel

U.S.A.	Saudi Arabia
$1.75-$2.00	$3.00

Present Prices per Barrel

Bagged, export, F.A.S., N.Y.	$4.08	
Delivered in Aramco warehouse ($1.90 per bag)		$7.60
Delivered to job site close to warehouse ($2.50 per bag)		$10.00

CARBON BLACK

CARBON BLACK

The production of carbon black would utilize a large amount of natural gas. Two broad types of blacks are recognized by the industry - contact (chiefly channel) and furnace. The yield is 2 to 3 lbs. of channel per 1,000 cubic feet of gas and 6 to 8 lbs. for the gas furnace blacks. In addition, there is a group of oil-furnace blacks manufactured from special aromatic tars, which are by-products from petroleum catalytic cracking operations.

The largest use of carbon black is in loading of rubber (25-35% in tires). The following table from the Bureau of Mines Yearbook, 1952 indicates the use pattern of carbon black in the United States during 1952.

Use	Thousands of Pounds	Per Cent
Rubber	1,074,545	93.1
Ink	44,116	3.84
Paint	10,628	0.92
Miscellaneous	24,985	2.16
Total	1,154,274	100.0

The Godfrey L. Cabot, Inc. of Boston, Massachusetts is one of the largest producers of carbon blacks in the U.S.A. and internationally. Their advice and recommendations were therefore requested and the following letter from Mr. Thomas Cabot is a comprehensive evaluation of the world situation in carbon blacks. This letter was sent as a follow-up after a conference in Boston.

April 16, 1954

Doctor S. H. Manian
National Research Council
2101 Constitution Avenue, N.W.
Washington D.C.

Dear Doctor Manian:

You have asked about the manufacture of channel black as a use for flare gas in Arabia. In our opinion this is not a wise use, for channel black is an obsolescent quality as Table A will demonstrate. The reason is that furnace blacks from oil, first produced about 1941, are capturing the markets because of better quality and despite a somewhat higher price. We expect this trend to accelerate for even better oil furnace blacks (ISAF and SAF) were introduced last year. The present prices and relative wear in tire treads are shown on Table B.

The fact that channel black has held up better in the export market when expressed as a ratio of total exports is not significant, for oil furnace black is now made in England and Canada whereas the free world still gets all its channel black from the United States. World decline of channel black use has been even more pronounced than figures for the United States shown in Table A would indicate.

The use of flare gas in Arabia for making furnace black is also not very promising. To be sure there are some qualities of furnace blacks made from gas, such as semi-reinforcing furnace (SRF) and high modulus furnace (HMF), which are used in substantial quantity. We believe, however, that the production and sale of these qualities will decline slowly from here on because of competition of newer oil furnace blacks such as free extrusion furnace (FEF) and general purpose furnace (GPF). Furthermore, the total gas used in making furnace blacks today is too small a quantity to have much effect on the large supply of flare gas for which you are asked to find a market.

Sheet No. 2 From: Thomas D. Cabot To: Doctor S. H. Manian
April 16, 1954

In the long run oil furnace blacks should be cheaper to produce than gas furnace blacks or channel blacks because from oil one gets high yields and high production per furnace and per collecting unit. Oil blacks are made at yields of from 2.5 lbs. to 6 lbs. per gallon using highly aromatic petroleum tars. Channel black yields vary according to the richness of the gas. Pure methane gives yields below 1 lb. per thousand cubic feet, whereas gas rich in propane and butane will give from 2 lbs to 6 lbs. per thousand cubic feet. Average yields are about 1.6 lbs. from normal gas. Gas furnace black can be made with yields as high as 10-15 lbs. per thousand cubic feet.

Because carbon black manufacturers buy gas on short contracts and at low pressure, and largely from producers who shun dealing with pipelines for fear of regulation, the price paid in this country is often less than half the field price paid by pipelines and less than one-third of the price paid by most chemical manufacturers. The labor and capital costs of making black are therefore relatively more important than the cost of raw material.

Obviously the selling price of channel black today in the United States would not justify the building of a new plant here, but some existing plants can afford to continue operations. The declining market keeps the price depressed.

The aromatic tars used as raw material for oil furnace blacks are by-products of making high octane gasoline, or chemical raw materials such as ethylene, butene, and butadiene. These tars are usually sold as Bunker oil and are priced accordingly. We normally pay about 1¢ per gallon above the posted price for Bunker C and are willing to stand this premium because we must insist on uniformity, the problems of black manufacture being highly technical.

Sheet No. 3 From: Thomas D. Cabot To: Doctor S. H. Manian
April 16, 1954

Due to high rates of tire production last year and to the technological changes in the carbon black industry, an excess of carbon black production capacity has been created. Today the industry in the United States is operating at about 65% of capacity. Possibly more than 35% is shut down if one includes channel plants which are not likely to be revived. Since early 1952 channel plants with a capacity of 258,000,000 lbs. per year have been shut down completely and many of these are being abandoned.

You have asked the cost of building a channel plant. We have no recent estimates available because no channel plants have been built or even projected in recent years. The most recent we know of was an estimate made by our British subsidiary Cabot Carbon Limited for the Iraq Government in 1952. This estimate was paid for by the Iraq Government and was prepared with help from our United States subsidiary Cabot Engineering Company. The proposal was to burn a very rich gas containing more than 40% of ethane and propane. It cannot be readily applied to the conditions likely to be found in Arabia.

If you wish we will make some estimates for you but we would need to know a good deal about the conditions in Arabia. I think it safe to say that a new channel black plant in this country would cost today at least 5¢ per lb. of annual capacity and a good deal more than this where the capacity is small. Probably costs in the Middle East would be double this. As there are a number of channel plants idle in this country, it would surely prove more economical to buy equipment second hand and this should be investigated if the project is to be considered seriously.

I believe that these figures will be sufficient to indicate that the project of making channel black in Arabia is not worthy of serious consideration at this time.

Sheet No. 4 From: Thomas D. Cabot To: Doctor S. H. Manian
April 16, 1954

We have many recent estimates on the capital cost of furnace black plants. Recently we made some rough estimates of various types of furnace black plants for India. Here the capital cost came out roughly 10¢ to 20¢ per lb. of annual capacity according to the size and type of plant.

Today the trend is away from locating carbon black plants near raw materials. The newest plants are being built close to markets, as in England and Canada. We are presently being urged to consider plant locations in Italy, France, Brazil, Japan, Australia, India, and other consuming centers. The reason for this trend of course is the new technique of making better blacks from oil refinery residues than we can make from gas.

Yours very sincerely,

Thomas D. Cabot

TABLE A

% Channel Production of Total Carbon Black Produced in the United States

Year	%	
1930	92.2	
1931	90.9	
1932	92.5	
1933	87.1	
1934	89.3	
1935	89.7	
1936	89.2	
1937	87.0	
1938	93.5	
1939	89.3	
1940	87.4	
1941	83.0	
1942	74.7	
1943	64.0	
1944	51.7	
1945	51.2	
1946	49.8	
1947	49.6	
1948	52.2	
1949	51.3	
1950	44.6	
1951	38.5	
1952	35.2	
1953	28.2	
1954	25.0	estimate
1955	20.0	estimate
1957	15.0	estimate
1960	10.0	estimate

TABLE B

Quality	Relative Wear	Price f.o.b. U.S. works (in bags)
Channel Black (EPC or MPC)	100	7.4¢ per lb.
High abrasion furnace black (HAF)	105	7.9¢ per lb.
Intermediate super abrasion furnace (ISAF)	120	11.0¢ per lb.
Super abrasion furnace (SAF)	140	13.5¢ per lb.

From Table A which is attached to Mr. Cabot's letter, it will be seen that prior to the advent of synthetic rubber and prior to 1940, approximately 90 per cent of the total U.S.A. production of carbon black was of the channel type. Since 1942, the production of channel black in the U.S. has had a continuous and sharp decline until 1953 when it represented only 28 per cent of the total domestic carbon black production. This decline in the use of channel black has been replaced by a corresponding increase in the use of furnace blacks from oil, the latter being developed to a point of quality better than the channels, despite a somewhat higher price for the oil furnace type. Mr. Cabot is convinced that this trend will accelerate because even better oil furnace blacks are being introduced to the market.

Table III shows the U.S.A. exports of carbon blacks for the years 1949-1953 inclusive. It is broken down into contact blacks (mainly channel) and furnace blacks. The statistics in Table III show that the ratio of channel black to the total export of blacks has held up much better than the U.S.A. production ratio. This is in part due to the preponderant use of natural rubber outside of the U.S.A. It will be seen from the Table that the total U.S.A. exports for this period have ranged from 300 to 433 million pounds per year of which channel black has represented 167 to 281 million pounds per year. During the three years, 1949, 1950, 1951, channel black exports represented 65-68% of total exports while in 1952 and 1953 a <u>trend</u> away from channel became evident in the lower per cent of 57 and 54 respectively. Regardless of this trend, U.S.A. export of channel was the substantial quantity of 194,600,000 pounds in 1953.

The U.S.A. exports of channel black to certain countries, selected as favorable geographic locations for Saudi Arabian export and also because they are countries whose volume of imports are substantial, were analyzed for the possible existence of trends (Table III). The results are as follows.

	U.S.A. export of Channel Black as A Ratio of Total Black Exports
United Kingdom	No apparent downward trend
France	No apparent downward trend
Germany	Fluctuating
Italy	Downward trend
India	Downward trend
Indonesia	Slight downward trend in 1953 after increasing trends in 2 preceding years
Japan	Slight downward trend in 1953
Australia	No apparent downward trend
New Zealand	Definite downward trend beginning 1951
Union of South Africa	Definite downward trend beginning 1952

TABLE III

U. S. Exports of Carbon Black - Calendar Years 1949-1953 Census Bureau Report No. FT 410 Part II

Calendar Year	Total Export (C & F) Millions of lbs.	Contact Black (chiefly channel) Net Quantity Lbs.	Contact Black (chiefly channel) Value $	Contact Black (chiefly channel) Average ¢ per lb. f.o.b. Port of Export	Furnace Black Net Quantity Lbs.	Furnace Black Value $	Furnace Black Average ¢ per lb f.o.b. Port of Export	Per cent Channel over total
Total U. S. Export								
1953	358.6	194,634,019	19,252,083	9.90	163,986,122	12,802,371	7.80	54.3
1952	292.9	167,376,963	16,504,224	9.85	125,531,513	9,595,408	7.64	57.2
1951	433.5	281,994,336	27,726,196	9.83	151,498,952	11,428,520	7.55	65.0
1950	399.6	266,593,523	24,566,662	9.21	132,973,978	9,311,969	7.00	66.7
1949	303.2	205,341,968	19,840,269	9.67	97,902,253	6,959,688	7.16	67.8
United Kingdom								
1953	31.739	26,372,396	2,970,744	11.28	5,366,850	374,935	6.97	83.0
1952	11.122	8,279,614	1,078,529	13.10	2,842,050	195,863	6.87	74.4
1951	100.928	72,633,943	7,418,701	10.21	28,294,439	2,246,375	7.94	72.0
1950	107.142	78,665,334	7,458,067	9.50	28,476,554	2,073,502	7.26	73.5
1949	71.666	50,743,646	5,248,462	10.31	20,922,124	1,597,273	7.65	70.9
France								
1953	66.360	39,778,755	3,812,210	9.57	26,580,915	2,136,495	8.03	60.0
1952	54.661	34,907,756	3,353,139	9.60	19,752,975	1,588,213	8.04	64.0
1951	73.872	45,579,775	4,482,519	9.82	28,292,325	2,359,935	8.33	61.8
1950	52.393	31,826,375	2,987,320	9.38	20,566,550	1,659,519	8.07	60.8
1949	53.869	32,507,144	3,276,304	10.08	21,362,217	1,789,188	8.38	60.3

TABLE III (continued)

U. S. Exports of Carbon Black - Calendar Years 1949-1953 Census Bureau Report No. FT 410 Part II

Calendar Year	Total Export (C & F) Millions of lbs.	Contact Black (chiefly channel) Net Quantity Lbs.	Value $	Average ¢ per lb. f.o.b. Port of Export	Furnace Black Net Quantity Lbs.	Value $	Average ¢ per lb. f.o.b. Port of Export	Per cent Channel over total
Italy								
1953	30.621	13,471,713	1,296,629	9.62	17,149,080	1,405,726	8.20	43.9
1952	17.989	9,591,876	934,489	9.75	8,387,175	724,407	8.64	53.2
1951	27.477	14,801,919	1,466,937	9.90	12,675,200	1,108,691	8.75	53.8
1950	20.233	11,582,180	1,130,959	9.77	8,651,200	729,798	8.43	57.1
1949	12.840	9,014,845	899,222	9.97	3,825,225	376,024	9.83	70.1
West Germany								
1953	1.570	1,104,226	152,274	13.83	465,600	49,192	10.80	70.3
1952	2.259	809,442	126,432	15.55	1,450,000	137,072	9.45	35.8
1951	2.367	1,412,474	197,949	14.02	953,950	91,351	9.58	59.6
1950	0.779	404,275	52,508	13.00	374,450	24,108	6.45	51.9
1949	1.773	1,631,164	175,960	10.80	141,400	11,905	8.43	92.0
India								
1953	9.181	5,213,112	518,915	9.97	3,967,550	313,260	7.88	56.8
1952	12.144	7,755,560	784,930	10.10	4,388,050	345,071	7.86	63.8
1951	11.960	8,241,928	777,647	9.45	3,718,050	272,858	7.34	69.0
1950	11.242	8,415,142	785,422	9.33	2,826,950	180,710	6.40	74.7
1949	6.627	4,198,100	386,471	9.21	2,428,700	155,425	6.40	63.4

TABLE III (continued)

U. S. Exports of Carbon Black - Calendar Years 1949-1953 Census Bureau Report No. FT 410 Part II

Calendar Year	Total Export (C & F) Millions of lbs.	Contact Black (chiefly channel) Net Quantity Lbs.	Value $	Average ¢ per lb. f.o.b. Port of Export	Furnace Black Net Quantity Lbs.	Value $	Average ¢ per lb. f.o.b. Port of Export	Per cent Channel over total
Indonesia								
1953	3.790	2,512,000	241,952	9.63	1,277,700	119,901	8.76	66.3
1952	3.515	3,135,000	343,939	10.62	579,700	41,762	7.20	84.4
1951	8.673	8,241,928	777,647	9.45	430,950	29,821	6.92	95.2
1950	3.464	2,446,750	224,225	9.17	1,016,550	86,851	8.53	70.6
1949	2.242	1,576,326	148,893	9.45	666,328	39,976	6.00	70.0
Japan								
1953	17.846	13,210,526	1,321,333	10.0	4,635,100	401,477	8.67	74.0
1952	7.497	6,290,051	627,469	9.97	1,207,300	111,674	9.26	83.9
1951	7.933	6,728,141	689,794	10.24	1,205,250	124,474	10.32	84.8
1950	1.812	1,554,285	182,594	11.72	257,953	32,029	12.43	85.8
1949	10.958	7,580,200	726,719	9.58	3,378,000	283,851	8.40	69.1
Australia								
1953	20.187	15,255,378	1,406,615	9.23	4,932,200	312,832	6.34	75.7
1952	16.475	13,188,858	1,251,636	9.48	3,285,830	193,638	5.88	80.0
1951	27.139	21,040,975	1,990,978	9.45	6,097,650	415,331	6.81	77.5
1950	24.454	19,744,485	1,782,789	9.03	4,710,300	311,981	6.62	80.7
1949	20.938	16,471,470	1,581,431	9.60	4,466,850	318,713	7.15	78.5

TABLE III (continued)

U. S. Exports of Carbon Black - Calendar Years 1949-1953 Census Bureau Report No. FT 410 Part II

Calendar Year	Total Export (C & F) Millions of lbs.	Contact Black (chiefly channel) Net Quantity Lbs.	Value $	Average ¢ per lb. f.o.b. Port of Export	Furnace Black Net Quantity Lbs.	Value $	Average ¢ per lb. f.o.b. Port of Export	Per cent Channel over total
New Zealand								
1953	2.320	1,191,675	121,250	10.18	1,127,950	85,017	7.55	51.3
1952	.705	343,550	34,693	10.10	360,950	30,325	8.40	48.8
1951	5.224	3,256,925	308,436	9.47	1,967,300	148,990	7.57	62.2
1950	4.209	2,960,725	271,420	9.17	1,248,300	87,439	7.00	70.4
1949	1.788	1,388,025	132,406	9.54	399,625	24,260	6.06	77.6
Union of South Africa								
1953	18.269	9,385,440	935,403	9.97	8,883,850	780,103	8.78	51.3
1952	14.131	7,701,525	752,792	9.78	6,429,100	557,415	8.66	54.4
1951	18.563	14,157,200	1,361,009	9.62	4,046,260	285,427	7.05	76.3
1950	16.723	13,088,300	1,222,160	9.33	3,635,150	233,651	6.43	78.2
1949	12.020	9,003,710	924,991	10.27	3,016,119	196,704	6.53	74.9

From this it is seen that

1. There has been no apparent downward trend of U.S.A. exports of channel black in the cases of the United Kingdom, France, Germany and Australia.
2. Slight downward trends became evident beginning 1953 in the cases of Japan and Indonesia.
3. Definite downward trends are evident in the cases of Italy (since 1950), India (since 1951), New Zealand (since 1949), and Union of South Africa (since 1952).

In all cases, the U.S.A. exports of channel black are still in substantial quantity. This situation should present adequate outlets for competitive entry of Saudi Arabian channel blacks of the proposed annual capacity of 15 to 20 million pounds for a number of years to come (estimated at not less than 5 years). The long range estimates to 1975 for the world use of natural rubber (in which the use of channel black is preferred in current formulations) are up to 2,500,000 long tons per year. This would appear to assure a continuing need for channel. This assumes that research and development in the carbon black field would improve the two types of carbon black at approximately the same rate.

It may also be noted from Table III that the price for channel black per lb. f.o.b. U.S. port of export has ranged from 9½¢ to 10¢ (higher in a few instances) and this indicates that an appreciable margin of profit for Saudi Arabia should be possible.

The possibility of using Arabian waste gas for the production of gas furnace blacks is also held by Mr. Cabot to be not very promising. While

admitting that there are substantial markets at the present time for certain types of gas furnace blacks, he believes "that the production and sale of such blacks will decline slowly from here on because of competition of newer oil furnace blacks" of special types.

Carbon Black - Costs

Capital Investment

The following are estimates of capital investment for channel black plants of two different capacities, one for burning 25 million CFD and the other for 50 million CFD of gas containing 3.42% hydrogen sulphide. The estimates are based on using presently operating units which can be made available and which can be dismantled, shipped in sections, and re-assembled at the proposed plant site for considerably less than all new material would cost today.

Plant No. 1 Capacity - using 25 million CFD
2 lbs. yield per 1000 CF = 18,250,000 lbs/yr
3 lbs. yield per 1000 CF = 27,375,000 lbs/yr

	U.S.A.	Saudi Arabia
Girbotol Treater Unit	$ 650,000	$1,300,000
Channel plant complete, including laboratory, warehouse, pelletizing plant for export packaging	1,768,000	3,536,000
Total cost	$2,418,000	$4,836,000

Plant No. 2 Capacity - using 55 million CFD
2 lbs. yield per 1000 CF = 40,000,000 lbs/yr
3 lbs. yield per 1000 CF = 60,000,000 lbs/yr

	U.S.A.	Saudi Arabia
Girbotol Treater Unit	$1,250,000	$2,500,000
Channel plant complete, including laboratory, warehouse, pelletizing plant for export packaging	4,377,100	8,754,200
Total cost	$5,627,100	$11,254,200

Production Costs per lb. Including depreciation, interest, etc., (estimated)

	U.S.A.	Saudi Arabia
F.O.B. cars	4.7¢	
F.O.B. ship		5.5¢

Present Prices of Carbon Blacks
and Relative Wear in Tire Treads (G. L. Cabot, Inc.)

Quality	Relative Wear	Price f.o.b. U.S. Works (in bags)
Channel Black (EPC or MPC)	100	7.4¢ per lb.
High Abrasion Furnace Black (HAF)	105	7.9¢ per lb.
Intermediate Super Abrasion Furnace (ISAF)	120	11.0¢ per lb.
Super Abrasion Furnace (SAF)	140	13.5¢ per lb.

Freight Rates and Additional Prices

The freight rate from Dammam to New York 1.7¢ per lb.

Carbon Black from natural gas - imported into the United Kingdom -

c.i.f. U.K. 12.6¢ per lb.

SYNTHETIC RUBBER

SYNTHETIC RUBBER

A synthetic rubber project is included for consideration for Saudi Arabian development for several reasons.

1. Outside of the United States there is very small production and consumption of synthetics.
2. It is believed that at least in part the limitation on the use of synthetic rubber by foreign countries resides in their difficulty in obtaining dollars for purchase from the U.S.A.
3. The raw materials for the commercially developed synthetic rubbers (GR-S and Butyl) are obtained from petroleum.
4. The long range world supply-demand forecasts (to 1975) indicate an increasing requirement for synthetic rubber beyond the existing U.S.A. producing capacities, even after accounting for the expected rate of increase of world production of natural rubber.
5. GR-S for bulk use in tire tread stock and Butyl for inner tube manufacture are now considered superior to natural rubber.

Consumption of Rubber

Table IV on page 93 gives the consumption of rubber for natural, synthetic, and natural plus synthetic, for the years 1948 through 1953, for the U.S.A., the United Kingdom, Germany and the total continent of Europe exclusive of U.S.S.R. It is noted that the consumption of natural rubber in Europe is 10 to 20 times greater than synthetic. In the U.K. it is 40 to 50 times greater but in the U.S. synthetic consumption is greater than natural.

There is great opportunity for increase in world consumption of synthetic rubber. This future world requirement for total rubber and the fractions to be supplied by synthetic and natural are discussed in the following sections on rubber.

Production and Position of Butyl Rubber

In Table V on page 95 the production of Butyl rubber in the U.S.A. and Canada for the years 1943-53 is given. By 1953, the annual production capacity in the U.S.A. and Canada were 90,000 and 17,000 long tons respectively.

In Table VI on page 95 the Butyl rubber position in various countries is given. As to consumption outside the U.S.A. and Canada, only France consumed any quantity worth mentioning (5,000 LT). No doubt Italy has some consumption of Butyl rubber but the data is not published.

Future Supply-Demand Relationships (based on information from Government-owned Rubber Producing Facilities, RFC, March 1, 1953)

The quality superiority of synthetic rubber over natural rubber for bulk uses may not be sufficient to overcome a large price differential in favor of the natural product. The possible effect of such disparity is considered in the following.

The price of GR-S since 1943 has ranged between 18½¢ and 26¢ per pound, as shown in Chart 1 on page 97, which also shows the price of natural rubber (No. 1 ribbed smoked sheets - New York) from 1928-1952. In March 1952, the price of GR-S was reduced from 26¢ to 23¢. For fiscal 1953, the profit per pound of GR-S and for Butyl was 4¢.

TABLE IV

Consumption of Rubber

(Adapted from Rubber Statistical Bulletin, London, March, 1954)

Date	France	Germany	Other* Europe	Total* Continent Europe	U.S.A.	U.K.
Natural Rubber						
1948	86,471	45,555	144,358	275,000	627,332	193,731
1949	91,163	65,948	171,916	327,500	574,522	184,255
1950	99,886	78,602	171,791	350,000	720,268	219,668
1951	117,815	81,776	191,643	391,250	454,015	234,234
1952	112,785	87,239	192,062	392,000	453,846	197,268
1953	108,305	100,398	207,000	417,150	553,434	206,591
Synthetic Rubber	(Buna-S, Neoprene) (Buna-N, Butyl)					
1948	7,401	4,422	3,606	15,000	442,072	2,555
1949	8,303	2,230	3,471	14,000	414,381	2,367
1950	7,400	3,372	5,303	16,000	538,289	2,757
1951	8,620	4,356	9,362	22,250	758,897	3,867
1952	11,264	9,090	14,486	35,000	807,037/	4,911
1953	12,924	10,954	15,500	39,750	781,939	4,862
Natural and Synthetic Rubber						
1948	93,872	49,977	148,000	290,000	1,069,404	196,286
1949	99,466	68,178	175,400	341,500	988,903	186,622
1950	107,286	81,974	177,100	366,000	1,258,557	222,425
1951	126,435	86,132	201,000	413,500	1,214,298	238,101
1952	124,049	96,329	206,500	427,000	1,261,413	202,179
1953	121,229	111,352	221,700	457,000	1,335,373	211,453

All figures are in long tons.

/ Since 1952, including Oil Content (av. about 85,000 LT/Y)

* Excluding USSR Imports, which varied from low of 42,000 in 1953 to a high of 123,000 in 1952.

TABLE V

Butyl Production in U.S.A. and Canada

(All figures are in long tons)

	U.S.A.	Canada	Total
1943	1,373	0	1,373
1944	18,890	2,767	21,657
1945	47,426	9,079	56,505
1946	73,114	12,211	85,325
1947	62,820	7,079	69,899
1948	52,603	7,952	60,555
1949	52,337	7,047	59,384
1950	55,832	12,921	68,753
1951	74,105	14,754	88,859
1952	79,368	16,899	96,267
1953	78,538	16,801	95,339

TABLE VI

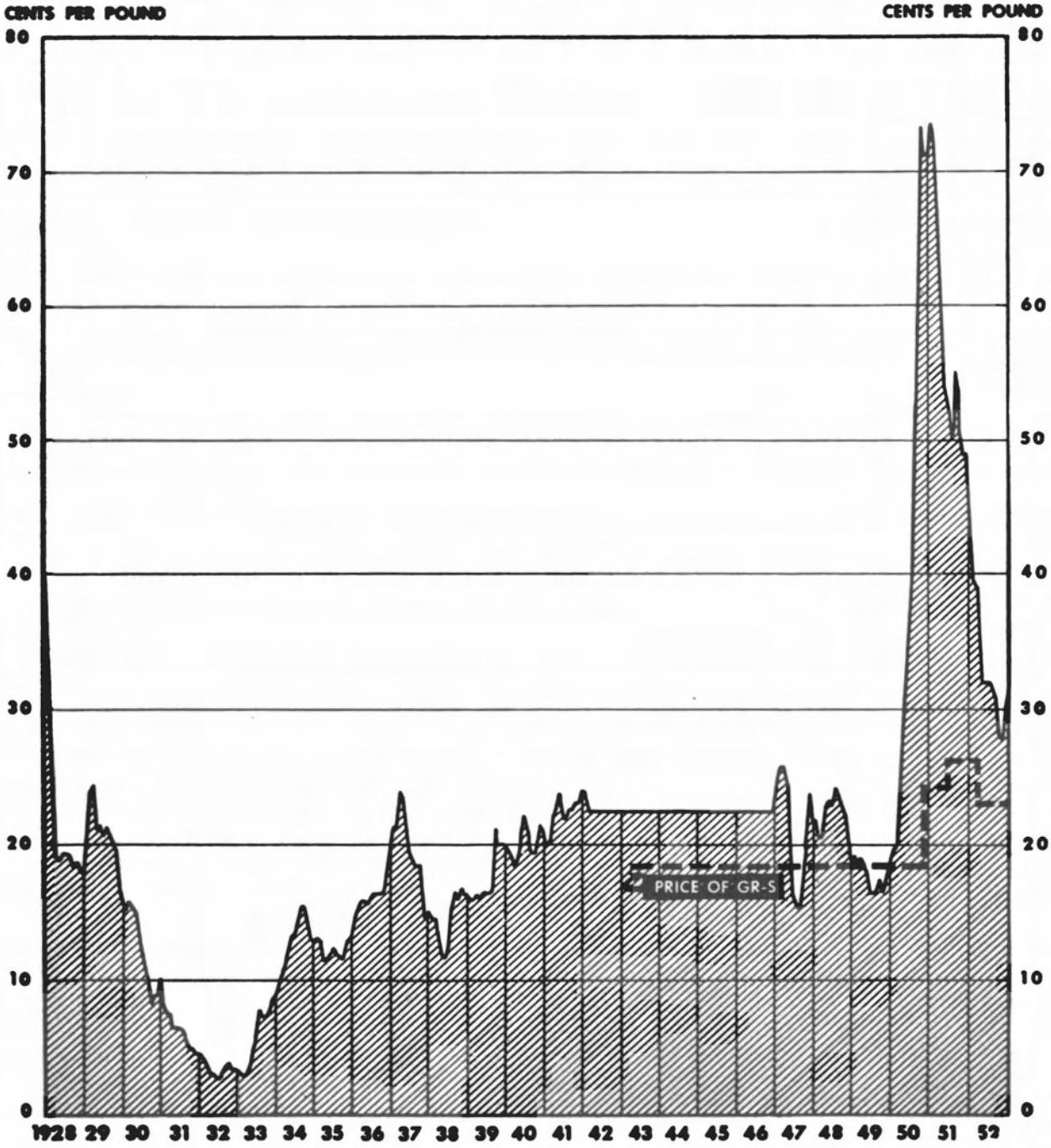
Butyl Rubber Position in Various Countries

(All figures in long tons)

	U.S.A. Jan/Dec/53	U.K. Jan/54	Canada Jan/Nov/53	France Jan/Dec/53	Brazil Jan/Oct/53
Production	78,538	-	15,268	-	-
Imports	1,263	206	-	4,937	98
Exports	237	-	(?)	-	-
Consumption	77,801	98	4,165	5,064	-
Stocks at End of Period	24,797	1,403	1,560	1,436	-
Stocks on January 1st	22,716	1,302	1,547	1,563	-

Above Data from Rubber Statistical Bulletin, London, March 1954

CHART 1



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An analysis of the major elements of production costs under government ownership versus future operation by privately owned industry has led the Natural Rubber Bureau, which represents the Malayan Rubber industry, to estimate the prospective price of synthetic rubber under private ownerhip to as high as 30¢ per pound (Natural Rubber News, January 1953). The future price of natural rubber is difficult to forecast. As shown in Chart 1, the historical market price of natural rubber has fluctuated widely, being in general, higher than GR-S. Rubber prices are quoted for No. 1 ribbed smoked sheets (R.S.S.). Although GR-S is not strictly comparable with any particular grade of natural rubber, it is generally considered interchangeable with No. 3 R.S.S. in tires which sells at prices ranging from 1/8¢ to 2½¢ below No. 1 R.S.S. depending upon the supply and demand status of the market.

The ability of synthetic rubber to compete with natural in the future will depend more firmly on supply-demand forecasts than on the possible future price relationships between the two commodities. Because the essentiality of rubber in modern civilization assures its continued usage, the gap between new rubber demand and natural rubber availability can be taken as the measure of minimum synthetic consumption.

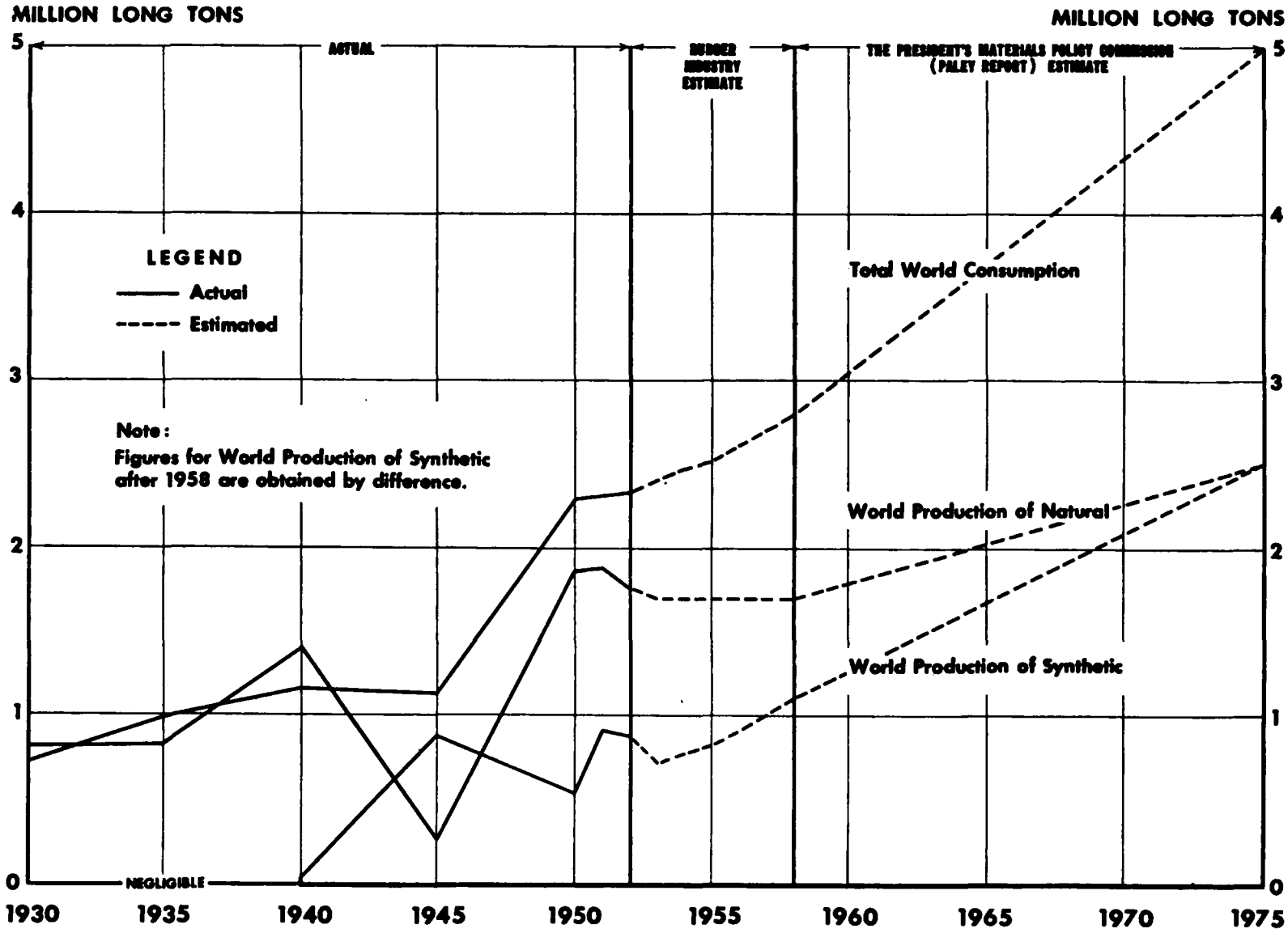
The supply-demand relationship for new rubber in the free world is presented in Chart 2 on page 101, which shows actual supply and demand for 1930 through 1952 and shows projections, first through 1958, and then to 1975 (exclusive of the data for the Iron Curtain countries). The forecast for the period through 1958 has been derived principally from industry sources. The forecast for the period of 1958 to 1975 is derived from the Paley Commission

Report. (The Paley Commission Report does not provide year by year estimates as might be assumed from the chart presentations. The report merely contains certain textual conclusions which are here portrayed in graphic form, Resources for Freedom, A Report to the President by the President's Materials Policy Commission, Vol. II, p. 99 et seq, Washington, June 1952.) The forecasts of natural rubber availability to the world for like periods are derived from the same sources.

Attention is called on Chart 2 to the widening gap between supply of natural rubber and the total demand for new rubber. The indicated deficiency of natural rubber in 1954 is 765,000 long tons and increases to 1,100,000 long tons in 1958. For all practical purposes, this deficiency must be satisfied by U.S.A. synthetic capacity. Exclusive of the U.S.A., Eastern Germany, and the U.S.S.R., synthetic rubber production is presently carried on only in Canada and Western Germany. Annual Canadian capacity is approximately 75,000 long tons and German capacity 5,000 long tons. While there has been a certain amount of planning for additional synthetic capacity in other nations, it has not progressed beyond the paper stage, and in any event, the aggregate capacity under discussion is not significantly large in relation to world tonnage. The U.S. capacity for synthetics of the GR-S and Butyl types is 900,000 to 950,000 long tons depending on the number of different types of GR-S produced. It is apparent that the short term demand (to 1958) for synthetic rubber will tax the productive capacity of all present facilities.

With respect to the possibility of natural rubber filling the short term demand, it is noted that new rubber plantings require seven years

CHART 2
WORLD CONSUMPTION AND PRODUCTION OF RUBBER 1930-1975



for maturity before giving any appreciable yield. Hence, even if new plantings far beyond present estimates have been undertaken, they could not substantially affect the availability of natural rubber in this decade.

The long range forecasts for world consumption of rubber indicate the necessity for a greatly expanded synthetic capacity. The estimate for 1975 demand for new rubber rapidly mounts to 5,000,000 long tons (see Chart 2), and this can be met only partially by the slowly accelerating production of natural rubber, estimated at 2,500,000 long tons. The indicated deficiency of 2,500,000 long tons compared with total world capacity for synthetics of less than 1,100,000 long tons, (exclusive of U.S.S.R.) suggests the need for greatly expanded synthetic rubber capacity. Even if these forecasts are discounted with extreme conservatism, there appears to be no real possibility that natural rubber may come into the market in sufficient amount, over a sufficient period of time, to present a real threat to the market position of the synthetic product.

Technology

The Office of Synthetic Rubber calls attention to the difficulties and complexities involved in any new private undertaking in GR-S synthetic rubber in obtaining complete know-how and releases excluding Butyl rubber. Patents and private information to which the U.S. government has full access by virtue of its agreements with private companies, would require considerable negotiation for clearance for foreign or even domestic private use. Information regarding processing, uses and costs for Butyl can be readily obtained from the Standard Oil Development Company which has sole ownership of patents in this area.

It should be stressed that the equipment and processes are complex and require close control and competent and experienced technical personnel for their operation and administration. It is probable that such personnel would have to come from the U.S.A. on a continuing basis for at least several years. Continuing research and development activities must be maintained and require highly trained and qualified scientists who also would have to be imported.

Water Requirements

Very large quantities of purified process water and cooling water are consumed in synthetic rubber plants. A detailed or complete water balance has not been developed for this report. The report section on butadiene records for fiscal year 1953 the consumption of 8 gallons of water for each pound of butadiene produced. Purified process water (both by lime and soda, and also followed by Permutit treatment) required for GR-S production is estimated at 8 pounds for each pound of GR-S produced.

Raw Materials - Feed Stocks from Petroleum Refinery

GR-S - Suggested capacity of 46,000 LT/Y

Butadiene (98% pure)	38,000 ST/Y
Styrene (99½% pure)	11,300 ST/Y

Butadiene: In the U.S.A. butadiene is generally made from "B-B" charge stock from petroleum refinery cracking operations. It can also be made from n. butane but this would require additional catalytic dehydrogenation equipment and processing and therefore increased capital requirement.

"B-B" (assuming 25% n. butylene content and 70% processing recovery)	216,000 ST/Y 600 ST/D

Aramco does not carry out cracking operations in Saudi Arabia. Hence, there is not available any of these light end unsaturates which could be used for a GR-S plant. Butane gas is available in Saudi.

n. butane (based on ultimate yield butadiene of 63%)	61,000 ST/Y 175 ST/D

Styrene: capacity 11,300 ST/Y

Propane (.70 lbs. per lb. of styrene)	8,000 ST/Y
Benzene (1.10 lbs. per lb. of styrene)	12,000 ST/Y

Propane is available in Saudi Arabia. Benzene would have to be purchased in the Mediterranean countries, France or Italy, from their coal tar operations since Aramco does not make any synthetic petroleum benzene.

Butyl Rubber - Suggested capacity of 46,000 LT/Y

Isobutylene (95-96% pure - .99 lbs. per lb. Butyl)	45,500 LT/Y 143 ST/D
Isoprene (93-94% pure - .25 lbs. per lb. Butyl)	1,150 LT/Y 7,300 lbs/D

Both of these monomers are obtained from feed stocks from refinery cracking operations. The isobutylene from a "B-B" feed stock containing approximately 20% isobutylene and a processing recovery of 85% would require 858 ST/D of feed stock. The isoprene is extracted from a C_4-C_9 unsaturated refinery stream. Neither one of these feed stocks are available in Saudi Arabia under Aramco's present operations.

It is possible to make isobutylene from isobutane, which again would require additional equipment for an added step of catalytic dehydrogenation. The quantity of isoprene involved (3.7 ST/D) is too small to plan on a separate extraction and purification system, even if the raw material were available, and it would be better to plan on purchasing the material if possible.

The Caltex Company has cracking operations in its refinery on the Island of Bahrein. We have conferred with its New York office staff as to the availability for Saudi Arabia of the feed stocks discussed above. They advised that Caltex uses all its light end unsaturates for upgrading of gasoline to increase the octane rating. The facilities are designed and equipped for this type of operation and it would cause a considerable number of dislocations to change, it would be expensive, and there are the currency complications of Bahrein being in the Sterling bloc while Saudi Arabia is in the dollar area.

Rubber - Costs

Capital Investments

Later in this report capital cost data are developed. The results based on Reconstruction Finance Corporation figures are summarized in the following. These costs do not include pressure tank cars which are needed for the transportation of volatile materials.

Summary Per Annual Ton Capacity

	U.S.A.		Saudi Arabia
	12/31/52	Estimated Replacement	New
GR-S LT	$193	$290	$ 580
Butadiene ST	379	570	1,140
Styrene ST	266	400	800
Butyl LT	$590	$540*	$1,080
Butyl - paid up royalty			200

* Supplied by Standard Oil Development Company

Based on information from industry, the U.S.A. replacement costs are estimated at $200, $375, and $250 per annual ton capacity for GR-S, butadiene, and styrene plants respectively. From this, the corresponding Saudi Arabian costs per annual ton capacity would be $400, $750 and $500. Improvement in technology, increased efficiency of labor and a peace time environment for construction are reflected in these lower cost estimates.

In the following estimates of capital investments for plant capacities in Saudi Arabia, the Reconstruction Finance Corporation figures for new plants have been used.

Capital Investment for Suggested Plant Capacities for Saudi Arabia

Plant	Suggested Capacity	U.S.A.	Saudi Arabia
GR-S	46,000 LT	$12,300,000	$26,600,000
Butadiene	40,000 ST	22,800,000	45,600,000
Styrene	12,000 ST	4,800,000	9,600,000
	Total GR-S	$40,900,000	$81,800,000
Butyl	46,000 LT	24,850,000	49,700,000
Butyl - paid up royalty @ $200/LT			9,200,000
	Total Butyl	$24,850,000	$58,900,000

Production Costs

Detailed breakdown of production costs are not available. An average overall cost for production of GR-S and Butyl rubbers is presented as suggested and outlined by the Director and Staff of the RFC Office of Synthetic Rubber.

The current selling price of GR-S and Butyl rubber is 23¢ and 22¢ per pound respectively, including profit of about 16% of the selling price. This would then lead to a calculated production cost of approximately 18¢ per pound which would include taxes (except income taxes), depreciation over a period of eleven years, interest expense, charges for research and development, etc.

It is suggested that a total cost of production for GR-S would be about 20¢ per pound in the U.S.A. and 26-27¢ per pound in Saudi Arabia, depending on the cost of raw material feed stocks. For Butyl rubber, the estimated cost of production would be 18¢ per pound in the U.S.A. and 25¢ per pound in Saudi Arabia.

The following is quoted from a letter from Mr. R. B. Wittenberg of the General Tire and Rubber Company -

"There is a very definite interest on the part of foreign rubber plants in GR-S, and I have no doubt that large tonnages of GR-S will be exported from the United States when and if the synthetic rubber plants are transferred to private hands. I cannot give you statistically the exact quantities of GR-S which might be sold abroad, but I am very certain that there would be no problem at all in disposing of 30,000 tons of GR-S per year from Saudi Arabia in the tire and rubber plants in Africa and the Southern European countries. There would likewise be no problem in disposing of the Butyl rubber made under the same conditions. "---and we feel that there is an extremely large opportunity for synthetic rubber both here and abroad."

DESCRIPTION AND ANALYSIS OF TYPICAL PLANTS

The following information is based principally on discussions with the Director and Staff of the Office of Synthetic Rubber, Reconstruction Finance Corporation, and from Government-owned Rubber Producing Facilities, RFC, March 1, 1953. Some facts and relevant material from other sources have been added.

GR-S Rubber

This is a general purpose synthetic rubber, which is produced from butadiene and styrene by processes of copolymerization. Its bulk uses are principally in transportation items. For passenger car tires it is considered superior to natural rubber. Other uses are in footwear, soles and heels, wire and cable insulation, and mechanical goods. It is made available either as dry rubber or as latex. Natural latex is considered superior to synthetic; however, the latter is significantly less costly and is finding increasing application in the manufacture of foam rubber and bedding.

Materials Butadiene and styrene are the two principal feed stock materials, charged in a ratio of approximately 70 to 30, and monomer conversion carried to 60% for cold rubber. The monomers are generally received by pipeline from adjacent plants or by tank car from various suppliers.

Other important materials required for the operation are:

Material	Application
Mercaptan	Modifies the plasticity of the polymer
Catalysts	For the polymerization reaction
Fatty acid soap	Emulsifier in the polymerization reaction
Rosin acid soaps	Emulsifier in the polymerization reaction
Shortstops	Stops polymerization
Antioxidant	For finished product
Sulfuric Acid (93%)	Coagulates the rubber from the latex
Caustic soda	Increases the stability of the latex
Activators	For the polymerization reaction
Electrolyte	To lower the viscosity of the latex
Salt (sodium chloride)	Coagulates the rubber from the latex
Soapstone	Dusting powder to prevent the rubber from sticking to the paper bag
Emulsifiers	Emulsifier for processing oils and polymerization recipes
Defoamer	Added to latex to reduce foaming
3 & 4-ply bags	Packaging polymers in 75-pound bales
Caustic (potash)	Polymerization - latex soap make-up
Inhibitor	To prevent polymer formation in the vapor phase
Brine (satd. soln. NaCl)	Polymer coagulation

Process The original process carried out the polymerization at 122°F in a soap emulsion, batchwise, in glass lined jacketed reactors, using circulating water in the jackets for cooling. A later development permitted carrying out the reaction at 41°F ("cold rubber"), using alcohol-water solution in the jacket for cooling. A further development uses the present method of the direct expansion of ammonia in cooling coils placed in the reaction vessels for refrigeration.

At the polymerization temperature of 41°F the reaction time cycles are generally 9-10 hours for the polymer reactors and 40-45 hours for the latex preparations. The reaction is stopped at 60% monomer conversion by the addition of a short-stopper to the latex at the appropriate time. Reaction rates and plasticity of the polymer are controlled by use of activators, catalysts and modifiers.

Unreacted butadiene and styrene are removed as vapors by vacuum flash techniques, compressed and condensed for use in blending for recycle process. The stripped latices are blended, antioxidant added, the mixture creamed by addition of saturated brine solution, and the polymer is coagulated by means of sulphuric acid serum. The polymer crumbs are screened, washed, filtered, shredded and dried to a moisture content of less than 0.5%.

Latex The stripped latex containing about 20% polymer is concentrated up to 60-65% by vacuum evaporation, and is ready for delivery into tank cars for shipment.

Maintenance All repairs, maintenance work, and equipment cleaning can be carried out by regular plant maintenance crews. No complete shutdown of the plant for maintenance is necessary as contrasted to methods of scheduled shutdowns for butadiene, Butyl rubber and petroleum plants.

GR-S - Costs

Capital Investment

The capital cost for a GR-S plant is presented for one specific plant and also the average capital cost of the 13 government-owned plants throughout the country. The figures for 1946 substantially represent the original construction cost and those for 1952 substantially represent the original construction cost plus additions (including construction in progress at December 31, 1952), less retirements.

	Maximum Annual Capacity	Cost (thousands) Jan.1, 1946	Cost (thousands) Dec.31, 1952	Cost per Annual Long Ton Dec.31, 1952
GR-S-1	49,000 LT	$ 6,956	$ 9,276	$190
13 plants	860,000 LT	142,235	165,895	193

The staff of the Office of Synthetic Rubber suggests increasing this capital cost by 50% in the U.S.A. to represent the increases in costs of materials, equipment, labor and construction to current levels, giving approximately $290 per annual long ton. For Saudi Arabia, applying a conversion factor of 2 to the U.S.A. cost, yields an estimated capital cost of $580 per annual long ton.

Butadiene (Petroleum)

Butadiene for synthetic rubber is produced either from ethyl alcohol or from butylene extracted from petroleum refinery butane-butylene stock. The process and financial data herein presented is for a petroleum butadiene plant.

Materials Butadiene of 98.0% purity is produced from normal butylenes contained in refinery "B-B" charge stock (butane-butylene). This stock normally contains 20-30% isobutane, 10-20% isobutylene, 25-30% n. butylene, 25-30% n. butane, and the balance consisting of light and heavy ends.

Other important materials required are sulfuric acid, caustic soda (liquid), furfural (selective solvent for butylene), catalyst, absorption oil (for propane and lighter gases), triethanolamine (neutralize furfural), ground alum and flake caustic for water treating, liquid chlorine for drinking and cooling water.

Process The "B-B" charge stock is put through a series of fractionators, absorbers, strippers, etc. to separate the normal butylenes for further processing. The other components may be piped back to the area refinery. Here also the isobutylene is polymerized with acid and removed for return to the refineries.

Dehydrogenation Essentially the butylenes are converted catalytically to butadiene with the release of hydrogen gas. Numerous fractionations, selective absorptions and stripping operations follow for the separation of the C_3 and lighter fractions, hydrogen, carbon dioxide and water. Waste heat boilers produce steam. The recovered hydrogen and C_3 fractions are used for fuel.

Butadiene Purification The crude butadiene containing some butylenes (-1 and -2) are processed through towers, furfural absorbers, strippers and fractionators. Finally specification butadiene is obtained. The butylene -1 and butylene -2 separated at different stages of the process are fed back to the catalytic dehydrogenators. Some heavier C_5 fraction is obtained.

In the process described above, furfural is employed as the selective solvent in both the feed preparation and butadiene purification units. There is another process commercially used where cuprous ammonium acetate is utilized as the selective solvent in the butadiene purification unit. This is called the Cuprammonium Process. The difference in solvents naturally results in different equipment and processing conditions. Facilities must be available for waste water disposal but no treatment is required for water disposal.

Maintenance All equipment other than tankage should be removed from service once a year for annual test, inspection, repairs, and replacement. The inspection schedule for tank farm equipment may be once every three years, and for the boilers every six months. Appreciable manpower is required for the broad maintenance program.

Butadiene - Costs

Capital Investment

The capital cost for a butadiene plant is developed for the particular plant at Port Neches, Texas and also average capital cost of the 7 government-owned plants throughout the country. The figures for 1946 substantially represent the original construction cost and those for 1952 substantially represent the original construction cost plus additions (including construction in progress at December 31, 1952), less retirements.

	Maximum Annual Capacity	Cost (thousands) Jan.1, 1946	Cost (thousands) Dec.31, 1952	Cost Per Annual Short Ton Dec.31, 1952
Butadiene (Port Neches)	197,000 ST	$ 54,465	$ 58,357	$296
7 plants	539,200 ST	190,668	204,472	379

The staff of the Office of Synthetic Rubber suggests increasing by 50% this U.S.A. capital cost to reflect current levels of costs of materials, equipment, labor, and construction. This would result in a capital cost of approximately $570 per annual short ton for the average cost of the seven butadiene plants. For Saudi Arabia, applying a conversion factor of 2 to the U.S.A. cost gives an approximate capital cost of $1,100 per annual short ton.

Styrene

Styrene is manufactured from propane and benzene as principal raw materials.

Materials Industrial grade benzene is supplied in the U.S. both from the manufacture of coke (coal tar processing) and from petroleum synthetic benzene. Propane is supplied by petroleum refinery operations. Other important materials required are liquid ammonia, aluminum chloride (alkylation catalyst), sodium hydroxide solution, sulfur (polymerization inhibitor), catalyst (dehydrogenation), dolomite lime and liquid chlorine (for water treating), and sulfuric acid (for crude benzene purification and water treating).

Process The plant carries out several principal reaction processes - propane to ethylene, to ethylbenzene, to crude styrene and finally to styrene purification.

Ethylene production Propane is thermally cracked in vertical furnaces to produce ethylene. The cracked gas is compressed, dried with a solid desicant and refrigerated to permit separation of components by distillation. The separated ethylene is sent to the alkylation reactors in the ethylbenzene unit. Higher boiling materials are separated into C_2, C_3, and C_4 fractions and a residue oil fraction. The C_2 and C_3 fractions can be recycled to the cracking furnaces.

Benzene purification The crude benzene fractions are purified by a combination of fractionations and acid and alkali washes to remove heavy ends, unsaturated components and sulfur, and finally

separated into pure benzene and toluene. The benzene and toluene produced in the styrene production unit (dehydrogenators) are also purified in this unit.

Ethylbenzene production Ethylbenzene is formed by an alkylation reaction wherein the benzene and ethylene are fed into acid brick-lined reactors with aluminum chloride. The reaction product is further processed for separation of components and purification of ethylbenzene.

Styrene production (dehydrogenation) Hydrogen removal from ethylbenzene yields crude styrene. The dehydrogenation is carried out at high temperature, atmospheric pressure, in the presence of steam using a catalyst. The crude product constitutes the feed to the styrene purification unit. It contains from 35-40% styrene and small amounts of benzene and toluene, the remainder being ethylbenzene.

Styrene purification Purification of crude styrene is principally by fractional distillation through towers. Benzene and toluene are first removed, and then, ethylbenzene, tar and sulfur, yielding styrene of 99+% purity. The entire purification is conducted under vacuum. Sulfur is introduced into the reflux of the various towers to inhibit thermal polymerization of styrene.

Maintenance General maintenance is carried on as needed without production shutdowns. A yearly shutdown should be scheduled for cleaning, inspection, repairing, replacement and testing of major pieces of equipment. The work can be performed by the regular plant maintenance personnel.

Styrene - Costs

Capital Investment

This plant is the only government-owned styrene facility and the costs are as follows. The figures for 1946 substantially represent the original construction cost and those for 1952 substantially represent the original construction cost plus additions (including construction in progress at December 31, 1952), less retirements

Maximum Annual Capacity	Cost (thousands) Jan.1, 1946	Cost (thousands) Dec.31, 1952	Cost Per Annual Short Ton Dec. 31, 1952
57,000 ST	$11,932	$15,131	$266

The staff of the Office of Synthetic Rubber suggests increasing by 50% this U.S.A. capital cost to reflect current levels of costs of materials, equipment, labor, and construction, giving approximately $400 per annual short ton. For Saudi Arabia, applying a conversion factor of 2 to the U.S.A. cost gives an estimated cost of $800 per annual short ton.

Butyl Rubber

Because of its superior air retention properties, Butyl rubber is used principally in the manufacture of inner tubes and in the production of tubeless tires. For inner tube use it is superior to natural rubber and has practically supplanted it. It also happens to be the cheapest of the synthetic rubbers to produce. There are two Butyl rubber plants in the U.S.A., total capacity of 90,000 LT per year, one 43,000 and the other 47,000 LT capacity. Domestic consumption is approximately 70,000 LT per year. Canada has a small plant of 17,000 LT annual capacity.

Materials Butyl rubber is a copolymer of isobutylene and isoprene in the approximate ratio of 98 parts of isobutylene and 2 parts of isoprene. Isobutylene of 95-96 wt.% purity is prepared from a stream of mixed butane and butylene produced from catalytic cracking operations in a petroleum refinery and transported by pipeline to the Butyl plant. The butane - butylene stream after removal of the isobutylene is routed to an adjacent butadiene plant for the recovery of normal butylene before being returned to the refinery. Isoprene is produced in only one of the Butyl plants. For Saudi Arabia, an isoprene producing facility should not be planned but the relatively small quantity required should be purchased, if available, from the Caltex refinery on the island of Bahrein. This possibility has been discussed previously in this report.

Other important required materials are

Material	Application
Ethylene	Refrigerant
Methyl chloride	Reaction diluent
Phenyl-Beta-Naphthylamine	Antioxidant to prevent oxidation of the finished product
Propane	Refrigerant
Wash oil	To clean reactors
Aluminum chloride	Catalyst
Activated alumina	To dry recycle gas
Sulphuric acid	Absorption medium for isobutylene
Zinc sulphate	To prepare anti-tack agent
Stearic acid	To prepare anti-tack agent
Sodium hydroxide	Acid neutralization

Process

Isobutylene extraction Isobutylene is recovered of approximately 95% purity from a mixed butane-butylene stream from catalytic cracking operation containing approximately 20% isobutylene. The isobutylene is absorbed in 65% sulfuric acid solution in a counter current liquid-liquid extraction system. The spent butane is caustic and water washed in a tower and then routed either to the butadiene plant or returned to the refinery. Regeneration of the acid extract is carried out in a plate tower by counter-current treatment with steam. The released isobutylene is taken overhead

as a vapor, and the diluted acid at the bottom and reconcentrated and reused. The regenerated isobutylene is further purified by caustic and water scrubbing to remove alcohols, compressed, condensed and pumped to storage. There are by-products which are recovered and ultimately regenerated into isobutylene. The yield of the isobutylene product (95-96% purity) is approximately 85% of the isobutylene in the feed.

Polymerization The isobutylene and isoprene monomers are copolymerized to the crude Butyl rubber for later finishing operations. The butylene is first highly purified by successive distillations. The total mixed feed containing the added isoprene and make-up methyl chloride at a very low temperature is led to the reactor where the catalyst is introduced through nozzles. The reactors are ethylene jacketed to permit temperature control of the reaction. The reaction product (the Butyl polymer) along with unreacted hydrocarbons and methyl chloride diluent is discharged from the top of the reactor, separated from the reaction mixture and the rubber remaining as a slurry in water is pumped to the finishing operation. The unreacted hydrocarbon and diluent vapor are separated, purified through compression, dried by activated alumina, fractional distillation and subsequently recovered for recycle.

Finishing The polymer-water slurry is vacuum filtered and the water returned to the polymerization section. The polymer crumbs are tunnel dried and the resulting rubber mat is then broken into

small pieces, charged to an extruder, to a hot mill, discharging to a finishing mill. Here a strip of rubber of desired shape and size is produced, cooled, cut, stacked and packaged.

Products A number of grades of Butyl rubber are produced but the large volume item is GR-I-18 followed by GR-I-15, and GR-I-25.

Maintenance Maintenance is generally divided into three parts

Routine maintenance of individual pieces of equipment as needed, while the plant is in operation.

"Minor turnaround" - to inspect and repair at scheduled intervals major pieces of equipment which can be temporarily removed from service without stopping production of Butyl (e.g. isobutylene extraction section, every two years).

"Major turnaround" - the purpose of which is to remove major pieces of equipment from service at scheduled intervals for cleaning, inspection, major repair or replacement, and testing, during which time the production of Butyl is stopped, (e.g. the polymerization unit).

Butyl - Costs

Capital Investment

The capital cost for a Butyl plant is presented for each of the two government-owned plants and then an average taken of the two. The figures for 1946 substantially represent the original construction cost and those for 1952 substantially represent the original construction cost plus additions (including construction in progress at December 31, 1952), less retirements.

	Maximum Annual Capacity	Cost (thousands) Jan. 1, 1946	Cost (thousands) Dec. 31, 1952
Plant No. 1	43,000 LT	$25,330	$24,690
Plant No. 2	47,000 LT	25,387	28,491
Total	90,000 LT	$50,171	$53,181

This makes the average capital cost per annual long ton capacity in the U.S.A. $590.

Standard Oil Development Co. advises that it has developed costs for a new Butyl plant incorporating the numerous improvements in its technology. The results are

Plant Capacity	Capital Requirement for a New Plant
46,000 LT	$540 per annual long ton
20,000 LT	$800-900 per annual long ton

In considering a Butyl plant for Saudi Arabia this report utilizes the cost figure for a 46,000 LT plant supplied by the Standard Oil Development Co. who also advises that it would require a "Paid Up Royalty" of $200 per annual long ton of capacity. It is suggested that this may be considered as a part of the capital requirements.

Saudi Arabian Feed Stocks for Synthetic Rubber Plants In Europe

There is a final thought in connection with the broad concept of locating and operating synthetic rubber plants as suggested by Aramco, which would tie in with the proposed "Transportation of Liquefied Natural Gas" by tankers, as described on page

It is proposed that such feed gas fractions as could economically be obtained locally in Saudi Arabia, be liquefied and transported to a suitable European location for conversion to synthetic rubber, where the producing plants would be located near centers of consumption.

European capital investment costs and operating costs for synthetic rubber would be lower than in Saudi Arabia.

It might be better to fractionate the liquefied petroleum gas to obtain feed gas fractions after tanker delivery in Europe rather than in Saudi Arabia.

All these are suggestions which would be considered by qualified specialists handling the rubber program as a whole.

POWER

POWER

It is not advisable to set up a definite power project or program until after decisions have been made regarding plants to be established in Saudi Arabia. The capacity of the plants and the processes chosen will determine the size and type of the power plant and the local power distribution systems.

The projects under consideration require not only firm power but also process steam. The latter is a stepping stone to relatively cheap energy in the form of electric power. Steam may be generated at relatively high pressures and temperatures suitable for power generation in turbines or other prime mover, which extract a fraction of the total heat of the steam. The turbines exhaust the steam at lower pressures and temperatures required for the processes in question where practically all of the remaining heat of the steam is utilized. Normally the turbine would exhaust to a condenser where final discharge contains the greater percentage of the original heat of the steam but at too low a heat level to enable practical utilization of the BTU content.

It is advisable to determine as closely as possible the so-called steam balance of all the projects that may be constructed so that advantage may be taken of the power generation in connection with process steam supply.

For that portion of power requirements that cannot be economically tied in with process steam, several types of power plants may be considered - internal combustion engines and steam turbines.

Because of water shortage and cheap gas the internal combustion engine has interesting possibilities especially in lower range of power plant capacities.

Power Distribution

At the present time there is no substantial market for power for non-industrial domestic use in Saudi Arabia but future possibilities should be considered along with industrial development. The suggestion is made for the establishment of a power and distribution system in the Dammam area to the usual limit, which is about 200 miles, but only to points where there are lead centers of sufficient density potential to justify. In the beginning, the distribution from Dammam would be more or less local and the magnitude would have to be determined by survey.

Power - Costs

It has not been possible to estimate costs for Saudi Arabia. We are informed that actual experience in power generation by Aramco in Saudi Arabia lead to power costs which are not less than 7 mills per KWH. The following estimates are for a plant erected in the U.S.A. near the Eastern seaboard.

Capital Investment

Capacity of plant - 40,000 KW	U.S.A.
Electric generating plant including 29 Nordberg type radial, spark fired, gas burning engines, each developing 1,400 KW - based on shell and tube heat exchangers.	$6,257,000
Investment per KW	$154.11
Same, except based on radiator cooling or jacket water and lubricating oil	$6,451,000
Investment per KW	$158.89

Product Cost

Operating costs (based on gas at 3¢ per MCF)	U.S.A.
Full load operation	1.15 mills/KWH
3/4 load operation	1.40 mills/KWH

The operating costs are for U.S.A. operation and are exclusive of amortization, depreciation, interest on investment, insurance, taxes and company overhead. Transmission and distribution would be a separate item to be determined in accordance with the number, type and location of plants selected.

Gas Requirement

Full load operation	406,000 x 24	9,744,000 CFD
3/4 load operation	438,000 x 24	10,512,000 CFD

PIPE LINE AND OTHER TRANSPORTATION OF NATURAL GAS

PIPE LINE AND OTHER TRANSPORTATION OF NATURAL GAS

PIPE LINE

In 1951 the Bechtel International Corporation published results of a comprehensive survey of a 2,500 mile pipe line connecting the Middle East natural gas supply from Kirkuk in Iraq to Paris. Stage I would be a single pipe line with pumping plants and Stage II would be an additional duplicate pipe line with increased pumping plant capacity. The plan provided for three branch lines of 300 miles length to extend into large population and industrial centers of Europe.

The salient statistics of the survey follow.

Suggested Pipe Lines

Capacity and Cost

	Stage I	Stage II	Combined
Capacity, CFD	500,000,000	500,000,000	1,000,000,000
Capital Requirement, $	425,000,000	350,000,000	775,000,000

Size of Pipe in Each Stage

	1,800 miles	34" - 36"
	700 miles	24" - 26"
Total	2,500 miles for each stage	

Estimated Delivered Cost of Gas

Operation of Stage I: Single pipe line delivering 500,000,000 CFD, annual load factor at 90%, including interest expense (average 2%), amortization over 20 years (5%), maintenance, operation, administration, etc., and field purchase price of gas at 3¢ per 1000 CF, yields for the main line

Delivered cost per 1000 CF	25¢

Operation of Stage II: Cost of transmission of gas per unit would be substantially the same.

Branch Line: 300 miles of 24" pipe line to deliver 150,000,000 CFD

Capital investment	$35,000,000
Transmission cost per MCF	7¢

At the end of the branch line, the total delivered cost of gas per MCF or per million BTU 32¢

Present European Consumption

Gas

	Europe	U.S.A.
Population	330,000,000	150,000,000
Natural Gas Consumption, CF (Per capita per day)	5	77
Manufactured Gas Used	1,700,000	n.a.

Solid Fuel

In 1948, the solid fuel (coal) consumption of Europe amounted to 361,600,000 tons and the quoted sales prices of coal per 1,000,000 BTU ranged from a low of $.66 in Paris to a high of $1.75 in Milan, Italy.

Fuel Oil

Imports and production in Europe in 1948 amounted to 88,300,000 and 12,570,000 barrels respectively. Quoted sales prices of fuel oil per 1,000,000 BTU ranged 42¢-44¢ for Bunker fuel at ports, and 55¢ (at Paris) to $1.20 (at Bucharest) for industrial boiler fuel.

Markets

500 million cubic feet of gas capable of delivery by Stage I of the Kirkuk-Paris pipe line could only lift European consumption from five cubic feet per person per day to six and a half; Stage II with similar volume would add another foot and a half. This compares with U.S.A. usage of 77 cubic feet. Thus, the increased gas supply, far from being a drug on the market, would result in competitive bidding between household and industrial users.

Governments have shown interest in the survey and the possibilities of supplying cheap fuel to Europe. Its implementation is conceived as one for some international agency to assume. There are many political complications such as the crossing of national boundaries and problems of financing and administration in each sovereign country.

The Bechtel report is referred to as adjunct but not as a part of this report on the utilization of waste gases in Saudi Arabia.

TRANSPORTATION OF LIQUEFIED NATURAL GAS BY TANKERS

Recent developments in the construction of special insulated barges and tankers for the movement of liquefied natural gas may have important application and implications to the general problem of the utilization of the waste gas in Saudi Arabia (Oil and Gas Journal, March 22, 1954, p. 104 and National Petroleum News, April 21, 1954, p. 15).

The general principle in this development is to liquefy the pre-sweetened natural gas and store it within the country of origin and then to transport it at atmospheric pressure in special tankers to the required markets.

The development is sparked by W.L. Morrison and his associates near Chicago who have been in the field of refrigeration for a good many years. Their plan entails barging about 18 million cubic feet per day of liquefied natural gas (principally methane) in the Chicago markets. They hope to bring in additional revenue by selling (to the Chicago meat packing industry) the refrigeration obtained in revaporizing the gas. Transportation barges are under construction at the present time. For the Morrison project, liquefaction is to be accomplished on a special barge carrying the necessary compression and condensing equipment.

The insulation in the tankers is one foot thick consisting of laminated layers of balsa wood on the inside of the steel tanks. This should eliminate the former difficulty of embrittlement of the containing tanks by the low temperatures (-258° F) of the liquefied gas. Proponents of this development represent that the capital investment required would

be less than half of that for pipe line transmission of equal quantity of gas for distances of 1,000 - 3,000 miles. They also represent that the operating costs of the delivered gas would be less than 50% of the cost of manufactured gas on the basis of equivalent BTU content. There are added advantages of reduced political hazards and the flexibility of delivering gas to centers of small consumption.

It is suggested that the application of a development of this type to Saudi Arabia would entail long-term agreements between Saudi Arabia and the consumer country. For example, if Saudi Arabia were to ship gas to Great Britain, agreements should be made so that either the government or private companies in Great Britain would be the builders of the tankers, transporters and purchasers of the gas. With this approach, the Saudi Arabian activity would include capital investment for

1. Pipe line collection system of the natural gas from its various fields - approximately 100 miles long.
2. Gas sweetening plant.
3. Liquefying plant with storage tanks for the liquefied gas.
4. Loading facilities, including piers and auxiliaries.

Costs

The following data are submitted as rough estimate of capital requirements and operating costs. They are supplied by Mr. Carl Flesher, an engineer with the International Bank for Reconstruction and Development (World Bank). The capital costs are developed on the basis of handling 500 million cubic feet per day of purified, sweetened gas of which approximately 100 million cubic feet would be used as fuel in the liquefying plant and in the transportation of the tankers. This would leave actual delivery to consuming markets of approximately 400 million cubic feet per day of gas.

Capital Investment

20 tankers - 15,000 ST each @ $9,000,000	$180,000,000
Liquefying plant to handle 500,000,000 CFD (purified, sweetened gas)	95,000,000
Collection - pipe lines 24" - 300 miles	35,000,000
Loading and unloading facilities (both ends) piers, storage tanks and auxiliaries	20,000,000
Contingency	20,000,000
Total	$350,000,000

The capital requirement of $180,000,000 for the construction of the twenty tankers is based upon European shipbuilding costs which are considerably lower than U.S.A. construction costs.

Considering Saudi Arabian participation to be 250,000,000 CFD, its capital investment requirement is estimated at

Liquefying plant	$50,000,000
Pipe line collection system, 100 miles	15,000,000
Port facilities, storage tanks, auxiliary	12,500,000
Contingency	12,500,000
Total	$90,000,000

It is noted that the capital costs for a gas sweetening plant have not been included since Mr. Flesher believes that income from the sale of recovered sulfur would make this part of the operation self-sustaining.

Annual Charges and Costs (on overall investment of $350,000,000)

Average interest expense 2.73% (4.75% on original principal)	$ 4,768,000
Depreciation over 15 years	23,333,000
Insurance - 1% of capital investment	3,500,000
Maintenance	3,000,000
Salaries and labor (European labor crews) Administration (exclusive pipe line operation)	3,500,000
Suez Canal fees	1,800,000
Total	$39,901,000

Cost per 1000 cubic feet

Cost of transportation of gas delivered to market (124 billion cubic feet)	$0.32 MCF
Net charges of purchased gas*	.04 MCF
Pipe line operating cost	.07 MCF
Total delivered to London	$0.43 MCF

* Based on charge of 3¢ per 1000cubic feet for raw gas and eliminating without credit the use of gas for liquefication plant and for fuel in tanker movement.

Note: The indicated cost of 43¢ per 1000 cubic feet is stated to be less than 50% of the cost of manufactured gas in London. No comparison is made between this detailed cost with the corresponding cost of equivalent heating value of other fuels such as coal or fuel oil.

The installation discussed above is so large that little change could be expected in unit costs as the size of the installation is changed. Thus, any additional capacity over 20 million cubic feet per day could be in the form of duplicate units at essentially the same cost per unit. This means that the large capacity of 500 million cubic feet per day mentioned above could be built up gradually rather than in one jump, since the large size is not necessary in order to achieve reasonable unit costs.

The proponents of this plan are confident that all of the available gas in the Middle East region can be consumed at European markets by this type of movement. The potential consumption in Europe is supported by the statistics presented in the Bechtel study. This would be the simplest and most direct solution of the Saudi Arabian problem of gas utilization as compared to the more complicated details of a petro-chemical industry. For a recommendation on this project it will be necessary to study the development in greater detail and it is suggested that this could be made a part of a subsequent study. It is suggested that the results of the Chicago undertaking be awaited before any firm conclusions are made regarding the process.

MISCELLANEOUS

MISCELLANEOUS

There are a number of projects which were considered by the Staff and discussed by the Panel which were not found of further interest to the Panel after the preliminary investigation. Some of these proposals may be found profitable in the future due to changing conditions. Therefore, the Staff is including in this section, descriptions of such projects as a matter of record and so that they will be available for reference in the future should the occasion arise.

Aluminum

Aluminum is produced by an electrolytic process from a fused "bath" of alumina dissolved in cryolite (3 NaF. AlF_3), aluminum fluoride (AlF_3), a small amount fluorspar (CaF_2), and several other minor items. Because of the scarcity of natural cryolite, this has now been mostly replaced with synthetic cryolite. The electrodes are carbon type and the pot holding the "bath" is lined with refractories and carbon.

Alumina is manufactured generally by the Bayer process - by digesting a relatively high grade bauxite in a caustic soda solution; the dissolved alumina is filtered off from the relatively insoluble iron oxides, silica, etc. The clear filtrate containing sodium aluminate is

agitated with precipitated alumina from a previous batch where about 70% of the alumina precipitates in the form of hydrate. The alumina hydrate is filtered, washed, dried and calcined and is ready for use. The filtrate is recycled.

The starting point for the manufacture of cryolite and aluminum fluoride is hydrofluoric acid and this is produced by reaction of sulfuric acid with fluorspar. The generated hydrofluoric acid is then reacted with sodium aluminate to produce synthetic cryolite, and with alumina to form aluminum fluoride. The preparation of the bath materials involves large capital investments and is only considered practical on a large scale and is not economically adaptable to a small operation which could be considered for Saudi Arabia. It is suggested for the relatively small aluminum production which could be set up in Saudi Arabia that the cell bath materials be purchased in the Mediterranean area, in such countries as Greece and Italy.

Bauxite deposits in Greece are being developed with the support of the Foreign Operations Administration and it might be possible to purchase the required alumina in Greece. The fluoride salts could be purchased in Italy. Numerous other raw materials would have to be purchased outside of Saudi Arabia, i.e. graphite electrodes, petroleum coke, small amounts of caustic soda, soda ash, fluorspar, etc.

Aluminum - Costs

Plant investment costs are approximately $1,000 per annual ton capacity of aluminum in the U.S.A., including power plant, but excluding plants for manufacture of alumina, aluminum fluoride and synthetic cryolite and also exclusive of housing, health and other fringe facilities.

A plant with a capacity of 15,000 NT per year is estimated to cost $15,000,000 in the U.S.A. or $30,000,000 in Saudi Arabia.

The production costs are estimated at 18¢ per lb. in the U.S.A. and 20¢ per lb. in Saudi Arabia.

The present market price, U.S.A. is estimated at 20¢ per lb.

Note: There is presently a substantial production of aluminum in the general Mediterranean and Asian areas and also projects are under way in Yugoslavia and on the Gold Coast of Africa.

Caustic Soda and Chlorine

Caustic soda is produced by electrolyzing a salt solution which produces a solution of caustic soda with evolution of chlorine and hydrogen. The hydrogen may be wasted or recovered and used but it is not practical from air pollution or health reasons to waste chlorine to the air. A fairly pure common salt (NaCl) is needed for make up of the electrolyte. Ordinarily the salt is dissolved to make a saturated brine and filtered. If necessary, certain impurities may be precipitated, such as sulphates, and removed in the filtration step before going to the process.

For the purpose of this report we have selected Hooker cells as being relatively simple as they will produce caustic of sufficient purity for local and Middle East consumption without purification. If a high purity caustic is required, as for synthetic fibres, then a Mercury cell usually would be adopted in modern plants. However, the brine must be of rather high purity.

Direct current is used and may be supplied by using alternating current and a rotary converter, mechanical rectifier, mercury arc rectifier or motor generator set, depending on conditions. We would not recommend a mercury arc rectifier for Saudi Arabia though a sealed tube rectifier might be considered. It might be desirable to generate direct current with a gas engine driven generator for higher efficiency and simplification.

The chlorine would be compressed and shipped in cylinders as a liquid. Unless used "over the fence" the caustic solution would be evaporated to a 50% to 70% NaOH and shipped in tanks or further boiled down to a solid and shipped in steel drums as a flake or solid. This is necessary because the caustic is very hygroscopic.

The raw materials would be salt and process water. The salt would be obtained locally and local well water would have to be purified before using or if used direct, the brine would have to be purified and filtered. The graphite electrodes used in the cells would be imported from Italy or the U.S.A.

A small unit of 10/11 NT of caustic and chlorine respectively per day was selected because of limited market outlets. While this size plant would not be competitive in the U.S.A., units of this size are often used in foreign countries.

Caustic Soda and Chlorine - Costs

Capital Investment

Capacity of plant - 10/11 NT per day

	U.S.A.	Saudi Arabia
	$1,000,000	$2,000,000

Production Costs per NT

	U.S.A.	Saudi Arabia
Solid caustic	$60	$61.60
Liquid chlorine	88	90.50

Market Prices

U.S. A. March, 1954

Solid caustic	$74.00
Liquid chlorine	56.60

Freight on caustic from U.S.A. to Saudi Arabia is estimated at $34 NT c.i.f.

APPENDIX

AGENCIES, GOVERNMENT AND PRIVATE, COMPANIES AND CORPORATIONS WHO HAVE COOPERATED AND CONTRIBUTED INFORMATION

U.S. Government Agencies

- Foreign Operations Administration
  - Middle East and North African Division
  - Saudi Arabian Foreign Operations Office
  - Industrial Specialists Division
- Department of Commerce
  - Bureau of Foreign Commerce
  - Commercial Intelligence Division
  - Office of International Trade
  - Business and Defense Services Administration
  - Census Bureau
  - National Bureau of Standards
  - Maritime Administration
- Department of the Interior
  - Geological Survey
  - Bureau of Reclamation
  - Bureau of Mines
  - Division of Saline Water Conversion
  - Oil and Gas Division

Department of Agriculture

Foreign Agriculture Service

Agricultural Research Service - Beltsville, Maryland

Conservation Service

Reconstruction Finance Corporation

Rubber Producing Facilities Disposal Commission

Office of Synthetic Rubber

Tennessee Valley Authority, Wilson Dam, Alabama

U.S. Congress, House of Representatives

Interior and Insular Affairs Committee

Office of Defense Mobilization

General Services Administration

Emergency Procurement Services

United Nations

Information Office, Washington, D.C.

Technical Assistance Board and Delegate Agencies, New York, New York

Middle East Division, New York, New York

Department of Economics, New York, New York

Food and Agriculture Organization

Washington, D.C. Offices and Headquarters, Rome, Italy

Industry

American Arabian Oil Company, Washington, D.C. and New York, New York

California Texas Company, New York, New York

Chemical Construction Corporation, New York, New York

Foster Wheeler Corporation, Washington, D.C. and New York, New York

The Fluor Corporation, Ltd., New York, New York

Nordberg Manufacturing Company, Washington, D.C. and Milwaukee, Wisconsin

Allis Chalmers Manufacturing Company, Washington, D.C. and Milwaukee, Wisconsin

Godfrey L. Cabot, Inc., Boston, Massachusetts

Witco Chemical Company, Washington, D.C., New York, New York, and Amarillo, Texas

The Dorr Company, Stamford, Connecticut

International Minerals and Chemical Corporation, Chicago, Illinois

Cleaver-Brooks Company, Milwaukee, Wisconsin

Westinghouse Electric International Company, Washington, D.C.

Food Machinery and Chemical Corporation (Westvaco Chlor-Alkali Division), New York, New York

Union Carbide International Corporation, New York, New York

Lighthouse Shipping Corporation, New York, New York

Aluminum Company of America, Washington, D.C.

Aluminum Company of Canada, New York, New York

Tennessee Gas Transmission Company, Houston, Texas

Bechtel International Corporation, Washington, D.C.

Bradley Container Corporation, Boston, Massachusetts

Allied Chemical and Dye Corporation
Nitrogen Division, New York, New York

Inchemtex, Inc. (representing Chemique Belge), New York, New York

General Tire and Rubber Company, Akron, Ohio

Standard Oil Development Company, New York, New York

Daiichi Bussan Kaisha, Ltd., New York, New York

Shea Chemical Corporation, Baltimore, Maryland

Virginia Carolina Chemical Company, Richmond, Virginia

Atlantic Coast Line Rail Road
Freight Traffic Department, Washington, D.C.

McBride and McBride, Washington, D.C.

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National Fertilizer Association, Washington, D.C.

American Coke and Coal Chemicals Institute, Washington, D.C.

U.S. Chamber of Commerce, Washington, D.C.

Carbon Black Export, Inc., New York, New York

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