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The Jordan Rift Valley
A Challenge for Development



THE JORDAN RIFT VALLEY

A CHALLENGE FOR DEVELOPMENT

The Jordan Rift Valley

A Challenge for Development

S. Gur

ACKNOWLEDGEMENTS

As anyone in the field knows, to write a book on the development challenges of the Middle East entails detailed research in diverse areas. The massiveness of the information is such that one man is simply incapable of handling and digesting it in any reasonable amount of time.

To complete this study involved consultation with many people who gave of their ideas and continually challenged mine. Some of these people I wish to thank publically now:

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©

S. Gur, 1970

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I was impressed and encouraged by his ideas regarding the immense possibilities which exist in this geographical area.

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To these and many others I offer my appreciation for their patience and ideas.

S. Gur
Tel-Aviv, 1970

Abbreviations

bsl	below sea level
billion	1000 million = 10
dwt	dead ton weight
Gw.	Gigawatt = 1 million kilowatt hours
kt.	kiloton = 1000 tons
mw.	megawatt = 1000 kw
mwe.	megawatt of electricity
Mt.	Megaton = 1 million tons
mtoe.	million tons of oil equivalent
oe	oil equivalent
Twh.	Terawatt hour = 1000 million kwh
mg/d	million gallons per day

E.N.E.A.	European Nuclear Energy Agency.
I.A.E.A.	International Atomic Energy Agency.
O.E.C.D.	Organization for Economic Co-Operation and Development.
O.E.C.D. Europe	Austria, Belgium, Denmark, France, Federal Republic of Germany, Greece, Iceland, Ireland, Italy, Luxemburg, The Netherlands, Norway, Portugal, Sweden, Spain, Switzerland, Turkey, United Kingdom.

O.E.C.D. North America . . . Canada and the U.S.A.

O.E.C.D. Japan

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PART ONE

The Jordan Rift Valley Development Scheme

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INTRODUCTION

The Jordan Valley is once again the scene of armed turmoil from the Lebanese border in the north all the way to the Gulf of Aqaba in the south. Four nations, all bordering on the Valley, are participating in the current martial games — Lebanon, Syria, the Hashemite Kingdom, and Israel.

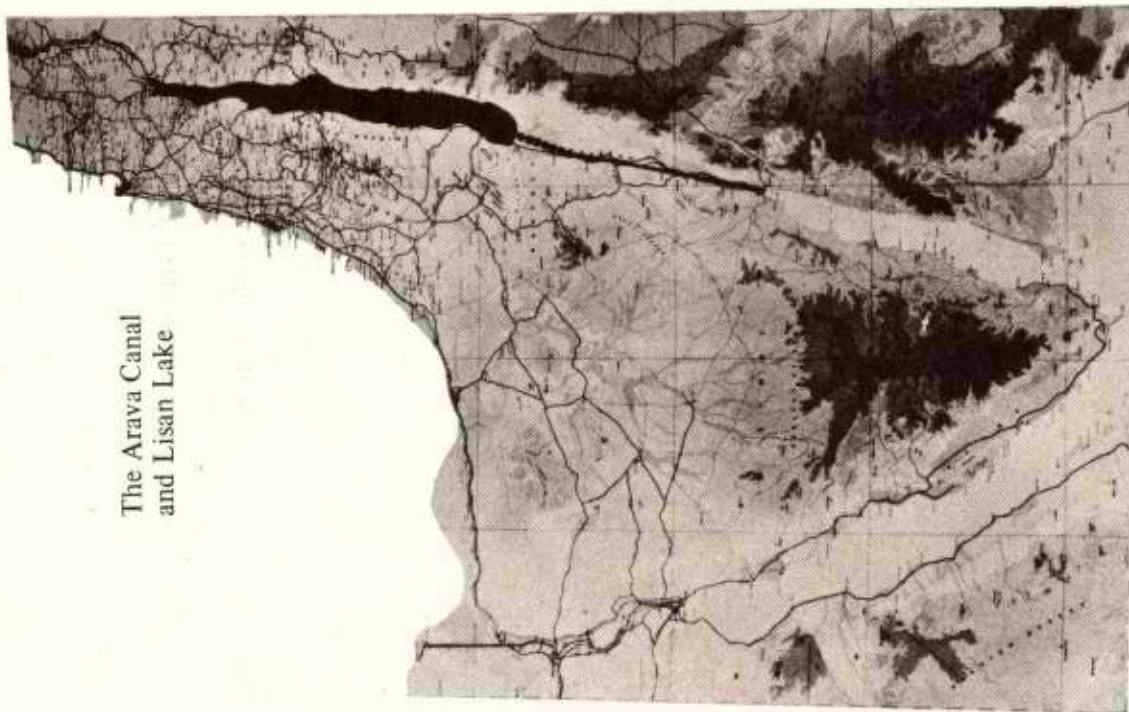
This tragic saga of ruin and destruction seems so infinitely purposeless in the Jordan Valley, a valley which has within it the seeds of development; a valley in which a society and economy could flourish. If the nations who are engaged in battle in this valley were to co-operate in a program of regional development, many accomplishments could be realized. Each accomplishment would be for each nation's own economic growth and development. In the process, the problem of the refugees, a most severe problem facing the Middle East, would be solved. Such a positive program of regional development would undeniably attract the active aid and interest of the predominant world powers along with other nations. These nations would provide technical and financial assistance for the creation and encouragement of new economic enterprises. It will probably be most felicitous to establish a partnership between the various governments concerned and the great industrial enterprises which possess stores of technical knowledge, flexible marketing tools, and sophisticated management.

The specific geographic location of this region bridging three continents — industrial Europe, developing Asia, and Africa — leads to important potential advantages which may be realized without insuperable difficulties.

To begin with, if the billions of gallons of fresh water which are available along the Jordan Rift for irrigation were used rather than unused each year, then thousands of families could be settled in the Valley. Moreover, fertile soil is found in sufficient amounts. Thus, the existing fresh water only needs to be stored in artificial reservoirs and canals constructed to conserve or carry it to the fields on demand. Modern scientific agricultural methods combined with the mild climate found in the Valley would result in

MAP ONE

The Arava Canal
and Lisan Lake



the production of several crops a year. Such a year-round growing season provides the basis for a continuous stream of fruits and vegetables which would be shipped to the world's markets in planes and refrigerated boats. The accomplishments of the farmers in the northern Jordan Valley near the Sea of Galilee provide ample evidence for the claim that the Jordan Valley can be converted into highly productive agricultural communities.

Besides the obvious agricultural possibilities, the industrial potential of the entire Valley is astonishing. As agricultural development needs water, industrial development demands abundant and cheap electricity. The unlimited use of atomic energy for peaceful purposes poses the advent of a new era in man's enlightenment through the release of vast quantities of cheap energy to handle difficult and time-consuming tasks. Production of minerals from the sea or the desalination of large quantities of water are projects which are prone to attract everyone's attention.

Realizing this, the atomic scientists and engineers of Oakridge, Tennessee, proposed the eventual application of atomic energy for the operation of agro-industrial centres where atomic power could be harnessed for the needs of huge food factories. Atomic power would aid in the desalination of sea water to provide water for the food factories and the power needed to convert seawater brine into fertilizers and light metals. But the production of high quantities of cheap energy depends upon the successful development of the "fast-breeder" atomic reactor.

The regional development ideas standing behind the Oakridge proposal can be implemented immediately in the Jordan Valley without the use of atomic reactors. One need only consider the possible exploitation of the physiography of the Jordan Rift Valley, particularly the depression of the Dead Sea. Consider first that the same operation which will utilize the flow of fresh water for irrigation and industrial purposes will also cut off the Dead Sea from its fresh water source. The operation, while desirable for agriculture, will be most undesirable for the Dead Sea. The Dead Sea would be converted into an arid salt field.

To prevent such a situation, a flow of water from other sources into the Dead Sea must be ensured. Accordingly, a proper solution is proposed here. It is suggested that water be brought from the

Bay of Eilat-Aqaba to the Dead Sea via a canal along the Arava. The flow of the water from the sea level of the Gulf of Aqaba to the Dead Sea, the world's lowest lying lake, will create a natural waterfall. As a result, a hydroelectric power station could be erected at the Dead Sea. This plant would produce great quantities of very cheap electric power meeting the needs of an enormous chemical, petrochemical, and light metal industry. These industries could be constructed in the Arava, in the area from the Bay of Eilat-Aqaba to the Dead Sea. The proximity of the area to oil resources only serves to heighten the attraction of the region as the locus of a petrochemical complex which would produce fertilizers, plastics, and chemicals, all of which are in an ever increasing demand in the world today. Dead Sea electric energy will not only facilitate the production of numerous fertilizers to be derived from the potash found in the Dead Sea, along with light metals such as magnesium and aluminum, but also numerous compositions of new materials lying in the range between light metals and plastics. Together with this industrial complex, it will be possible to develop a sizable industry composed of small and medium-sized enterprises engaged in the production of allied products.

To support the industrial complex, the construction of an inland navigational canal becomes a matter of highest importance. The feeder canal of the hydroelectric power station of the Dead Sea can be large enough to convey ocean-going vessels, bulk carriers, mammoth tankers, and container ships. These vessels will bring raw materials to factories in the Arava Valley and carry fertilizers and other finished products to all parts of the globe. The use of thermo-nuclear energy is attractive for this kind of construction.

As a result of the flow of water in the Red Sea - Dead Sea canal, the level of the Dead Sea will be raised to create a lake three times the size of the present lake. As a consequence, increasing the area of the lake will increase the amount of evaporation on its surface and permit more water to be discharged into the Jordan Valley, ultimately producing more electricity. An equilibrium will thus be maintained between the amount of water entering the Dead Sea and the amount of water evaporating from its surface

While the Oakridge plan of constructing agro-industrial complexes is based upon atomic energy power centers, the agro-industrial complex at the Dead Sea can be erected immediately based upon the artificial waterfall coursing from the Red Sea to the depression of the Dead Sea. Here, in a region characterized by a maximum rate of evaporation (because it has the greatest number of sunny days) and because of an impressive concentration of minerals in the Dead Sea, a flourishing chemical industry based upon Dead Sea brine promises to be highly successful. The Oakridge concept is thus implemented but with hydro-electric power for industry, natural water for agriculture, and Dead Sea brine for fertilizers and light metals.

In another generation or two, as industry continues to develop, the need for more cheap energy and more fresh water will be imperative. At that time, fast-breeder reactors will have reached their ultimate stage of development, and the technology of desalination will be economically practical, making possible single and dual purpose power centers. The proposed plan will not bring peace even in its most persuasive element. Logic fails in war. This plan can only be realized in peace time. However, even at this stage, at this time in the history of the Middle East, such a plan must be examined, studied, and weighed, keeping in mind the results which can and should accrue to each nation. Those people in the Middle East and those outside the Middle East who have positive aspirations for the development of the Middle East should seize the initiative to put such a plan into effect.

1

THE JORDAN RIFT VALLEY

The Valley in which the Dead Sea is located is a geological saga in itself, a limnological wonder, and the source of a rich and ancient chapter in human history.

The Jordan Rift begins in Northern Syria, between the Lebanon and Anti-Lebanon, and continues through the Jordan Valley south through the Gulf of Aqaba to the Red Sea. From there it proceeds through the Strait of Aden to the Indian and Atlantic Oceans. The Rift is deep and narrow, running between mountains that rise to a height of 1,500 to 1,700 meters above sea level and wending its way 105 kilometers southward from the Sea of Galilee (210 meters below sea level) to the Dead Sea (397 meters below sea level). From the Dead Sea, the Rift continues through the Arava to the Gulf of Aqaba-Eilat, covering a total distance of 375 kilometers from the Sea of Galilee.

Summer temperatures along the Rift are among the highest in the world, ranging up to 50°C. The maximum number of sunny days in the year averages 90 percent. The Rift is distinguished by strong, dry winds, relatively low humidity (55 percent) with recorded data revealing records even lower than that and a comparatively high level of aridity. The conditions being ideal for a high evaporation rate, it is not surprising to find that the yearly evaporation rate in this area is among the highest in the world.

The Dead Sea currently lies in an area where a large lake had once existed. Called Lisan Lake, it had an area of 3,000 square kilometers and began to rise approximately 100,000 years ago, reaching a maximum level of 180 meters bsl about 25,000 years ago. Lisan Lake extended from the Sea of Galilee in the North, to

Hatseva south of the Dead Sea. Lisan Lake receded and dried up between 15 – 17,000 years ago, leaving behind two separate lakes, the Sea of Galilee in the North and the Dead Sea in the South.

The Dead Sea, bounded by the vast Arabian desert, is the lowest lake in the world, its surface lying 397 meters below that of the Mediterranean Sea. The yearly rainfall is scanty: 101 millimeters in the northern basin of the Sea and 55 millimeters in the southern basin. The area of the Dead Sea is approximately 1,000 square kilometers; its length about 80 kilometers. The maximum width of the lake is approximately 18 kilometers and the maximum depth reached 400 meters. The Dead Sea contains approximately 136 billion cubic meters of water and 44 billion tons of dissolved salts. The concentration of salt increases as the water depth increases; 300 grams to a liter of water at a depth of 40 meters; 320 grams at 100 meters; and 332 grams at 400 meters. In comparison, the waters of the Mediterranean Sea contain 30 grams of salt to a liter of water.

Total Quantity of Salt in the Dead Sea

	Average Salinity	Depth Range	Volume	Weight of Salt
	gm/l	m	km ³	10 ⁹ tons
Upper Water Mass	299.9	0-40	28	8.4
Lower Water Mass				
Transitional Member	319.3	40-100	32	10.2
Deep Member	332.1	100-400	76	25.2
Total Water Volume	322.1	0-400	136	43.8

Source: David Neev and K.O. Emery,
The Dead Sea, (Jerusalem, 1967)

The Dead Sea is cut off from the Mediterranean and Red Seas by two major topographical barriers: the Jezreel Valley, which is 59 meters above sea level, separating the Jordan Valley from the

Mediterranean Sea; and the Arava, which is 220 meters above sea level, separating the Dead Sea from the Red Sea.

At present, there is less of an inflow of water into the Dead Sea than there was 30 years ago. There are several reasons for this decline. Waters from the Jordan River now flow into a national water carrier for irrigation purposes. The waters from the Yarmuk River are partly being drawn off by the irrigation system in the Kingdom of Jordan. In process are plans to use the remainder of the water for the irrigation of the eastern slope of the Jordan Valley. In the future, all the sources of fresh water from the Jordan Valley will be utilized for irrigation. As such, there will be no obstacles to desalinate the brackish springs (among these include Ein Fashka which has a salt content of 2,000 mgs./liter) for agricultural purposes. With the development of agriculture in the region, even precipitation run off will be collected. Except for rainwater which falls directly on the surface of the lake, expropriated run off and the limited flow of groundwater (a total quantity of approximately 300 million m³/year), it is expected that all the sources of water which flow into the Dead Sea will eventually be exhausted.

The Dead Sea currently contains massive reserves of chlorine, magnesium, sodium, calcium, potash, and bromine. In addition, sizable amounts of sulphates, secium, cobalt, lithium, rubidium, and manganese are to be found, along with traces of a large number of metallic and non-metallic minerals. These minerals furnish the raw materials for innumerable products.

Even though the same minerals can be found and extracted from the oceans, their concentration in the Dead Sea is several times greater. It can be surmised, therefore, that the exploitation of these resources would be of even greater value.

If alternative water resources are not found, the Dead Sea will evaporate and be converted into a salt deposit and dry mine (which is the history of the world's potash deposits). For the Dead Sea, this process will take several hundred years and will leave an area rich in minerals.

Two sources of water for the Dead Sea, however, exist not far away: the Mediterranean Sea and the Red Sea. If the topographical barriers in the Jezreel Valley or the Arava Valley could

Distribution of Minerals Found in the Dead Sea

Ion (gm/l)	Depth in meters				
	0	35	45	100	310
Magnesium	37.00	37.68	41.08	44.35	44.54
Calcium	13.78	13.57	14.55	15.81	16.08
Sodium	36.51	37.32	37.05	38.18	38.60
Potassium	7.26	7.27	8.19	8.52	8.54
Sulphate	0.60	0.48	0.49	0.37	0.71
Bromine	4.56	4.64	5.01	5.39	5.45
Chlorine	194.44	195.20	207.74	219.55	221.95
Strontium	0.24	0.24	0.24	0.25	0.25
Lithium	0.012	0.012	0.012	0.025	0.025

(These analyses were made by the Dow Chemical Company, U.S.A.)

Source: Neev-Emery

be eliminated, then any quantity of water would be available to flow from the Mediterranean or Red Seas to the Dead Sea, allowing the Dead Sea to keep its balance and increase its area.

These new sources of water are chemically and financially more advantageous than currently imagined. While the sources of the Jordan River pour approximately two million tons of minerals into the Dead Sea per year, the Mediterranean and Red Seas could deposit 45 million tons annually. On the basis of the minerals available in the Dead Sea, a huge chemical complex could be developed on an international scale.

Chemical industries of this size and complexity, however, require cheap and plentiful electricity and large quantities of water for production and condensation. Markets to the East and West, to which the processed materials would be exported, must be reached

by efficient and economical means of transportation. The industry based on the resources of the Dead Sea, then, must have access to water transportation. Water, then is the solution to these problems. Water for electricity, chemical production, and transportation.

The Jordan Rift Regional Development Scheme is proposed here as a plan which utilizes the natural resources of the area by recreating and improving upon earlier natural phenomena.

HYDROELECTRICITY

The physiography of the Jordan Rift is conducive for the production of sizable quantities of electrical energy. To produce electrical energy cheaply and in large quantities, advantage must be taken of the difference in height of the water level between the Mediterranean or the Red Seas and the lowest point in the world, the Dead Sea. An artificial waterfall could be created which would operate hydroelectric power generators with a potential capacity of 1,000 mw. Besides the tremendous force of gravity of the waterfall, the rate of evaporation is taken advantage of. By transporting water from the Red or Mediterranean Seas to the Dead Sea, the level of the Dead Sea is raised to a height of 212 meters below the level of the Mediterranean Sea. The area of the lake will expand to 3,000 square kilometers thus enlarging the potential evaporation area. Under the influence of the high temperatures which prevail here most of the year, the numerous days of sunny weather, the relatively low humidity, and the presence of intense, dry, desert winds, ideal conditions for rapid evaporation rates are realized. Now, with the enlarged lake, correspondingly larger quantities of water that the sun has been evaporating during the year can be discharged into the Jordan Valley. Thus, waters from one of the two large Seas will, if brought to the Dead Sea, generate electricity and add water to the atmosphere.

Approximately 330 billion cubic meters of water will be required to flow from the Red Sea to the Jordan Valley to raise the water level to 212 m. bsl. As previously mentioned, approximately 44 billion tons of salt are found now in the basin of

the Dead Sea. This quantity of water (330,000 million m³) will bring with it approximately ten billion tons of minerals to the Dead Sea. After the level of New Lisan Lake has been raised to 212 bsl, the constant yearly flow of five billion cubic meters from the Mediterranean or Red Seas will bring with it 150 million tons of salt per year as compared with two million tons per year that the Jordan waters pour into the Dead Sea.

Elements Present in Sea Water

Milligrams per liter

Chlorine	19,441.0
Sodium	10,812.0
Magnesium	1,302.0
Sulphur	905.0
Calcium	410.0
Potassium	389.0
Bromine	66.0
Carbon	28.0
Strontium	13.1
Boron	4.6

Source: H.U. Sverdrup, et al., *The Oceans*, 1942

It would seem that, in another two hundred years, the quantity of salt in the Dead Sea will double and reach 80 billion tons, and the quantities of water will reach approximately 466 billion cubic meters in a lake whose area will be triple that of the present body of water. The level of New Lisan Lake (212 m. bsl) will result in a further increase in the boundary of the saline areas that constituted, in earlier generations, the contours of the old Lisan Lake. Its width by comparison with the boundary of the present lake will not change much (approximately 20 kilometers), and its length from north to south will be approximately 215 kilometers.

According to Dr. R.M. Bloch and Messrs. David Neev and K.O. Emery, the waters of the Dead Sea will not combine or mix with the waters of the Mediterranean or Red Seas. The waters of one of these two Seas will gradually constitute an upper layer of water — above the surface of the Dead Sea. The two water masses will be separated by a stable interface due to which the specific mineral composition and concentration of the Dead Sea brines will be preserved in the lower water mass. With the change in the Dead Sea level, it will be possible to pump the brine from the lower water mass to the evaporating ponds above.

When the time comes, it will be necessary to trap the healing springs on the shores of the Dead Sea (Zohar, Ein Gedi, Ein Bokek, and others) for the purpose of conserving them as spas under the new topographical conditions. There is no doubt that, by that time, all other springs, even brackish springs such as Ein Fashkha, will be conserved for irrigation and desalination.

It will be advisable to relocate the present potash plant (and its evaporating ponds) at Sodom, to the southern bank of the new lake. There, a large area is to be found, suitable for the creation of new evaporating ponds. A plentiful supply of sea water will be available to wash the salt sediment that settles underneath in the ponds. The evaporation rate in this area is as high as the rate of evaporation on the surface of the southern basin of the Dead Sea. Possibly by that time, the present plant will be obsolete, and it is reasonable to assume that the technological development of the industry will then demand a new plant with a greater production capacity.

The same quantity of water, 330 billion cubic meters, that will flow from the Red Sea to the Jordan Valley to raise the level of the water to -212 m., will generate energy amounting to 120 billion kwh. The hydroelectric power plant will be integrated into the regional grid of the electrical system.

It is extremely beneficial if, in the country-wide electrical system geared to supply and demand, a hydroelectric power station is available, capable of releasing energy into the grid at peak hours of daily demand. In the present instance, it will be possible to regulate the water flow in the canal from a minimum to its maximum flow capacity of 700 cubic meters per second

which corresponds to an installed capacity of 1,000 mw. There must be a possibility of regulating water flow to provide flexibility according to daily or seasonal variations. Such a system will be much more efficiently realized in an integrated regional electrical system.

It is evident that raising the annual electrical potential will be gradual, corresponding to a rise in consumption. This amount of electrical energy will make it possible to produce approximately 50,000 tons of magnesium, for example, and to desalinate 100–200 million cubic meters of water yearly for agricultural and industrial purposes. Great quantities of electricity will remain for the development of the chemical industry in the region. The hydroelectric power plant is not dependent upon the rate of evaporation of the surface of the lake but rather upon the rate of the annual electrical demand corresponding to the rate of the yearly flow. Therefore the number of years required must be extended to allow 330 billion cubic meters of water to flow to the Jordan Rift in order to create the New Lisan Lake. This power will provide the impetus for regional development. For the basic development period, an installed capacity with a potential of 1,000 mw is selected, since it is assumed that such a power station would provide a flexible supply to meet the base and peak load required.

In the future, for example in another 20–25 years, when the level of the water of New Lisan Lake will reach 212 m. bsl, the flow of water from the Red Sea will have to be regulated to correspond to the annual evaporation rate, and to act in correspondence with the water balance of the great reservoir. Under the climatic conditions of the Jordan Rift, what will be the yearly evaporation rate over New Lisan Lake which is composed of waters from the oceans and the oceans and the ultrasaline Dead Sea? The present calculation of evaporation over the surface of the Dead Sea is estimated to be 1.70 meters per year. In his article, "Tentative Energy and Water Balances for the Dead Sea," Dr. J. Newman suggests the number 1.5 m. per year for the yearly rate of evaporation of the northern basin, 1.8 m. per year for the southern basin and an average at the Dead Sea of 1.55 meters per year. Dr. C.E.Jacob, Brigham Young University, Provo, Utah,

U.S.A. also reported an evaporation rate of 1.70 m. per year. Dr. R.M.Bloch, Research Laboratory, Dead Sea Works, Ltd., however, estimated 1.80 meters per year, while Prof. A. deLeeuw suggested 1.70 m. per year. James B. Hays estimated 2 m. per year as did Mr. S. Blass and John S. Cotton.

An average yearly flow of 1600–1700 million cubic meters into the Dead Sea was recorded before the Jordan resources were utilized for irrigation. This constituted a flow of 52–53 cubic meters per second. This quantity of water is relatively small and would produce a small quantity of potential electricity, a fact which places in doubt the profitability that would eventuate from construction of a canal or tunnel from the Mediterranean or Red Seas to the Jordan Rift.

The rate of evaporation of fresh water is higher than that of water with a high salt content. Measurements made by the Dead Sea Works between 1926 and 1944, under the supervision of Dr. D. Ashbel, indicate that the average annual rate of evaporation of fresh water is 3,642 m. in the northern basin of the Dead Sea, 3,499 m. in the southern basin, at the Sea of Galilee 2.15 m. and at Tiberias 2.56 m. and according to Tahal 1.78 m. per year. Compare this to the annual evaporation of fresh water at the Gulf of Aqaba-Eilat, which is 3.445 m.

The measure of evaporation of the waters of the Mediterranean or Red Seas, with climatic conditions corresponding to the Dead Sea, will be higher than the present measure of evaporation over the surface of the Dead Sea (1.70 m./yr.) The waters of the Mediterranean Sea may be considered nonsaline because of the relatively low concentration of salt (30 grams per liter). The measure of evaporation is increased by means of an upper mass of Mediterranean Sea water to a depth of 190 meters, that is, between the level of the concentrated Dead Sea mass (approximately 400 meters below sea level) and the surface level of the new lake (212 meters below sea level). Since New Lisan Lake will extend 215 kilometers from Hatseva to the Sea of Galilee, it will be affected by the various climatic fluctuations with differing rates of evaporation all along its length.

A reasonable suggestion adopts the figure of 1.85 m. per year as the average rate of evaporation of New Lisan Lake. The figure of

1.85 may seem on the low side as it is known that the evaporation on the northern end of the proposed Lisan Lake (Sea of Galilee) is 1.78 m. per year, and on the southern end of the proposed Lisan Lake (over the surface of the Dead Sea) is much greater. The upper mass of water to a depth of 190 m. consists of water from the Seas. Therefore, the average evaporation of the whole lake could be greater than the above mentioned 1.85 m. per year.

But what is the constant quantity of water that will, nevertheless, continue to flow to the great lake after all the fresh water is utilized for agriculture? Into New Lisan Lake an estimated total of 500–600 million cubic meters of water per year will continue to flow, including wild run-off, ground water, and rain that will fall on the surface. Since the evaporation rate of the lake is estimated to be approximately 5,500 million m.³, the balance of 5,000 million m.³ yearly flow from the Gulf of Eilat-Aqaba and produce electricity.

The rate of evaporation permits a flow corresponding to 160 m.³ of water per second all year round. But, if the hydroelectric power plant is operated only at peak hours, to meet the heavy operational daytime load, a flow of 700 m.³/second can be achieved; it will be capable of operating at full capacity, that is the power potential of the turbogenerators (1,000 mw) with which the plant is equipped. The flexibility of the power plant is of a high order. The price of producing a unit of kwh of electricity at this plant is lower than at plants requiring fossil combustible or nuclear fuel. Furthermore, fossil fuel or uranium is not required. The source of energy is unlimited because of the unlimited quantities of water derived from the Mediterranean or Red Seas, and the solar energy cycle.

If the above proposal is rejected, then in the future it is expected that, in the process involved in the production of electricity, both conventional power facilities and thermal-nuclear power stations must be employed. Both fossil fuel and the uranium needed for these operations will have to be obtained from foreign sources. The acquisition of uranium will not be a routine matter not only because of price fluctuations and sources of supply but also because of disturbances which may be expected to occur during local or global emergencies.

However, by utilizing sea water and the energy of the sun's rays, a basic electrical supply independent of external energy sources is at hand.

Another 1,000 mw can be generated by a power station operating as a pumped-storage hydroelectric power plant. Fundamentally, a pumped-storage hydroelectric power installation collects the unused energy of all the conventional power plants available in the system by means of night pumping. The next day, the collected water flows to the turbogenerators at the peak hours. Pumped-storage plants possess operation and design flexibility; they are reliable, particularly in case of a blackout; they are hydrologically independent, being immune to seasonal variations since they operate as closed-circuit installations.

The United States Federal Power Commission has predicted 20 million kwh of pumped-storage capacity by 1980. The public utility industry bases construction estimates upon a formula of 80 percent nuclear and 20 percent pumped-storage in predicting construction. Topography, costs, and power loads will determine the geographical pumped-storage pattern. It is possible that "reverse" pumped-storage will make pumped-storage practical in areas of unsatisfactory terrain. Here, water is dropped through a turbine into an underground storage cavern in times of peak electrical demand and pumped out during slack hours in preparation for another generation cycle. Pumped-storage plants, in conjunction with conventional hydroelectrical plants, will make sites practical that cannot be economically developed for conventional hydroelectric power alone.

The development of thermal-nuclear reactor plants in conjunction with pumped-storage plants results in the thermal nuclear plants taking care of the base loads and pumped-storage plants meeting the needs for peaking power. Thus, both fuel costs and the need to keep thermal plants operating as continuously as possible are considered. Nuclear reactor power plants are able to lift water into a pumped-storage plant reservoir at an incremental fuel cost of approximately 1.2 mills/kwh which allows the pumped-storage plant to produce power more cheaply than by alternate means, even though it takes 3 kwh of pumping to produce 2 kwh of power.

Pumped storage plants also assist modern thermal plants in operating more efficiently. While modern thermal plants are expensive to install, they are cheap to run on an incremental fuel basis, and are best operated around the clock and calendar at full capacity. Every night in the hours of low consumption it will be possible to pump 25 million m.³ of water from New Lisan Lake to the upper regulatory reservoir and to the main canal. The following day, this water returns through the turbo-generators, and thus operates the power plant of 1,000 mw. The flexibility of the flow is then high. It is possible to cause larger quantities of water to flow into the lower lake in the summer, and to return the water to the upper reservoir and the canal by means of graduated night or seasonal pumping to meet seasonal and daily electrical demands efficiently. Thus quantities of up to two billion kwh can be collected in the low hours for peak demand of unutilized energy of the conventional stations by means of a hydroelectric plant, without disturbing the water balance of New Lisan Lake.

WATER SOURCES

The basin of the Jordan Rift generally attracts 1.7 billion m.³ of water. From this amount, Israel takes 600 million m.³ of water from the northern sources of the Jordan. The remaining 1.1 billion m.³ are unused, running off either into the Dead or Mediterranean Seas. There has been no exploitation of the benefits derivable from this run-off. The efficient exploitation of these water resources would permit the tilling of the fertile soil of the Jordan Valley. Because of the perfect climatic conditions which allow for the growing and marketing of those agricultural products preferred by Europe in the seasons in which Europe lacks fruits and vegetables, extensive use of the run-off waters would convert this valley into an ideal area for intensive agriculture. Although a market for these agricultural products from the Jordan Valley exists, all that is required to be done here is to collect and store the water by means of the proper engineering installations and convey it to the fields to be irrigated; construct a system of dams

and canals to supply water; and to plan a flourishing agricultural region of towns and villages, bringing back previous residents of the valley and encouraging new settlers. With the influx of new farmers to the valley, use can be made of the agricultural knowledge exhibited by the Israeli farmers who in the past had to overcome the unique climatic and soil conditions of the area.

This large quantity of useable water demands agricultural settlement in the Jordan Valley, and industrial development in the Arava Valley between the Dead Sea and the Bay of Aqaba. Although the quantity of water is great and impressive, according to all the criteria for similar large development projects in the world, it is expected that in one generation there will be a need for more water for agriculture, and for industrial development. The only water resource at our disposal will be sea water and it must be desalted.

It will be necessary, then, to exploit the water resources discharged into the Jordan Valley and on her borders. These include the waters of the Yarmuk River with 480 million cubic meters of water per year; approximately 180 million cubic meters of water flowing from springs some of which contain fresh water and some brackish which permits desalination; and runoff from the Litani River which discharges into the Mediterranean Sea, squandering approximately 440 million cubic meters of water per year.

These water sources need to be examined in a bit more detail here. The yearly flow of the Yarmuk River is approximately 480 million m.³ of water per year. As far as the planning is concerned, the Yarmuk Irrigation Project has almost been completed, and excavation work has begun on the site of the first dam in a proposed system of dams. A concrete canal is being constructed which should transport the water to irrigate the fields east of the Jordan. The Six Day War, however, has brought the development work to a halt and has even damaged sections of the Gore Canal. The Litani River rises in the Lebanon Valley, flows south where it is confronted by the configuration of the Jordan Rift in the north. It continues flowing west through a narrow opening in a very deep ravine to the Mediterranean Sea. Approximately 440 million m.³ of the Litani water surplus can be diverted to the Jordan Valley.

There are several engineering alternatives to accomplish the diversion of the Litani water surplus. It is possible to store the overflow of the Litani at a topographical level of 600–650 meters above sea level, and to let it fall to the original bed (175 meters above sea level). This water fall could then operate a hydroelectric power station which would supply Lebanon with 480 million kwh of electricity at a cost of less than two mills (American) per kwh, quite an inexpensive source of electricity from any standpoint. The tail waters can be diverted through a tunnel to the Jordan Valley. Thus, for a contribution of 440 million m.³ of water per year, the government of Lebanon would be entitled to three cents/m.³ of water which would total an annual income of \$13 million.

Approximately 180 million m.³ of water is discharged from Jordan Valley springs, of which approximately 70–80 million m.³ consist of brackish water. If it is necessary to desalt this water, a system of electrodialysis or reverse osmosis can be made available. Brackish water may be used for industrial purposes if mixed with fresh water. If the three water sources above are carefully exploited as suggested, there will be enough fresh water in the area and a sufficient quantity of cheap energy generated by the hydroelectric plant. Until the twenty-first century there is no need for integrated thermal-nuclear power centers to produce electricity and to desalinate water.

In the same period, the area itself will reach a more advanced stage and will require more electricity and more water for the needs of a larger population. The chemical and metallurgical industries will need additional quantities of cheap energy and agriculture will need more water. It is expected that within 20–30 years, the fast breeder atomic reactors will produce cheap electricity, and the technology of water desalination will advance to the point that the low price of desalted water will make it attractive for agricultural use. Only at this stage will it be appropriate to erect a nuclear energy power center to produce electricity and fresh water.

THE SEA OF GALILEE

The Sea of Galilee is located on the northern extremity of the Jordan Depression. It is the deepest fresh water lake on the surface of the globe, 210 meters below sea level. It has an area of approximately 168 square kilometers, a volume of approximately 4,300 million m.³, and a maximum depth of approximately 44 m. It is used as a central storage reservoir for supplying the Israeli national water system.

Approximately 500 million m.³ of water flow into the Sea of Galilee from the sources of the northern basin of the Jordan (excepting flood and rain water which fall on its surface), but the Israeli national water system pumps only 320 million m.³ of water per year, and a similar quantity evaporates over the surface of the lake. Average evaporation here is 178 cm./year with a maximum of 11.5 mm./day during the month of January. The average evaporation rate calculated over fifty years is approximately 300 million m.³/year (according to Tahal, January, 1964).

The salinity of the Sea of Galilee is high, reaching approximately 327 – 380 mgs. of chloride/liter of water. The salinity of the Sea of Galilee is caused by a group of mineralized thermal springs with a varying level of salinity between 1,000 – 22,000 ppm. There is, though, an unimportant quantity of chloride (14 – 24 mg./liter) in the waters of the northern basin of the Jordan (at the Daughters of Jacob Bridge) before the Jordan empties into the Sea of Galilee.

The Sea of Galilee, as a principal storage reservoir, is beset by problems, first because of its high salinity content, and second because of the large loss of water due to the high rate of evaporation. The lake is also too low in level with relationship to its major sources of the Jordan which rise 170 meters above sea level. Water must be raised to the irrigated lands where it must flow 150 meters above sea level. Because of the natural depression of the lake, water must be pumped to a height of 368 meters to the national water carrier.

A strange picture is presented – approximately 500 million cubic meters of water from the sources in the northern basin of the Jordan flow into the Sea of Galilee creating in their path a

waterfall of 270 meters. This water is fresh with almost no salinity. Only 320 million m.³ of water are pumped from the lake – its salinity is critical (330–380 milligrams of chloride). This salinity must be reduced by mixing the pumped water with fresh water in the national water carrier thus reducing the salinity to 170–250 milligrams of chloride to render the water suitable for irrigation. Of the remaining 180 million m.³ of water from the sources of the northern basin of the Jordan that flow into the lake, only some is used for irrigating the land bordering the lake and the Jordan valley south of it; a part is dedicated to preserving the balance of the water level and simply evaporates. While success is achieved in preventing saline springs from flowing into the Sea of Galilee, more fresh water is wasted by evaporation. In addition, the surface level of the Sea of Galilee is balanced by ground water, by the flow of subsurface springs, by runoff, by shore springs, and by surface rainfall.

If, however, all the 500 million m.³ of water from the sources of the northern basin of the Jordan would flow directly through the national and regional irrigation structure and not into the Sea of Galilee, several advantages would ensue. As the Jordan water is not saline, there will be no need to mix this water to reduce its salinity, nor would it be necessary to pump it to a height of 368 meters to the national water carrier.

Even if this plan is put into effect the Sea of Galilee could continue to be used as a storage reservoir for many years. It will receive its water from rain water falling onto it, from the flood-waters of the northern basin of the Jordan, from floods around the Sea of Galilee, and from underground saline springs that gush into the lake. It could also be possible, perhaps, to divert the flood surplus of the Yarmuk waters, which during rainy years are above the volume capacity of the Yarmuk reservoirs and dams. These flood waters would pour directly into the Sea of Galilee. It would be possible to pump water from the lake to the national water carrier and mix this water with the fresh water flowing in the water carrier. But this would only be done at the hours of need. The same is true of the surplus water of the Yarmuk which could be stored in the Sea of Galilee and flow into the carriers to the Jordan Valley.

Diverting the waters of the northern basin of the Jordan from the Sea of Galilee can add approximately 200 million m.³ water per year to the irrigation system by preventing the evaporation of the Jordan waters over the surface of the Sea of Galilee. There exists the possibility of mixing in the Jordan fresh waters large quantities of saline water with a relatively high content of chloride still not utilized for irrigation.

If the above mentioned process is not undertaken, it will be necessary sometime in the future to tap the ocean waters. It will be necessary to desalinate 200 million m.³ in order to replenish a shortage in the national water balance to meet the needs of agriculture and industry. Plans must be made for huge sea water desalting projects with heavy financial investments in costly installations resulting in a price for water which is greater than the value of the agricultural commodity to be produced.

The financial investment in the equipment of a dual-purpose nuclear powered desalination plant with a production of 200 million gallons of desalted water per day, based on today's technology, is approximately \$400–450 million. No plant of this size has been constructed yet, and there is still no desalting plant to receive thermal energy from an atomic complex. The largest dual purpose plant in operation at present is located in Kuwait, and is designed to desalt 20 million gal./day and to receive its thermal energy from power plants generated by gas gratuitously. The price of the water is high, and it is not earmarked for agriculture.

However, the thinking in this proposition has been in terms of a larger desalting project than in Kuwait (where fuel is free), and even if the price of fuel is as low as ¼ mill/kwh of electricity, the price of water will be high with respect to what the farmer can pay. The issue involved in the cost of desalinated water is not so much that of producing huge quantities of heat cheaply but that processes such as the utilization of the multi-stage of desalting technology make the cost of the water high.

At the time when desalinated water will be taken from the sea economically, the value of the Sea of Galilee as a long-term means of water storage will decline. The oceans, which serve as reservoirs of water for the desalting plants, are capacious sources which are

capable of supplying any quantity of water to the largest water desalting plant anywhere and stored most probably by aquifers. This method is preferable to the storage of water in the Sea of Galilee with its high rate of evaporation and relatively high salt content. It is expected that the level of the Sea of Galilee will decline and its salt content will rise considerably.

On the other hand, for the same amount of money, it is possible to excavate a deep water navigational canal from the Gulf of Aqaba to the Dead Sea to cause sea water to flow into the Jordan Valley both to produce a vast quantity of electricity (approximately 120 billion kwh), a commodity sorely needed to develop the chemical and metallurgical industries based on the minerals of the Dead Sea, and to provide an outlet to the ocean. Moreover, these products can be most efficiently transported by means of an inland canal. The reclaimed 200 million m.³ of water previously mentioned are a gift which could be utilized.

With these things in mind, the possibilities for, and even the continued existence of, the Sea of Galilee can be weighed. Either the Sea of Galilee will continue to fill its role of long-term storage reservoir — in this case, it will be necessary to sacrifice sizable quantities of fresh water to guard the level and to prevent a rise in saline content; or the Sea of Galilee can be preserved for nature lovers and maintain its existence by achieving a balance by means of natural sources which are difficult for men to restrain. The waters of the underground saline springs would proceed to flow into the Sea of Galilee; the rain water would continue to fall directly on its surface; and the flood waters would not be prevented from use as irrigation. The high rate of evaporation would diminish the area of the lake until a new equilibrium would be achieved between the quantities of water which flow into the Sea of Galilee and the quantities of water which evaporate from its surface. The saline content would gradually rise, and the lake itself would become more and more saline.

Lisan Lake be recreated, which would flood the saline area the length of the Jordan Rift and then unite the Dead Sea and the Sea of Galilee into one large lake. The flooding process will undoubtedly encompass the span of one generation, if not longer. (The rate of flooding will depend upon the quantities of water

which will flow to the hydroelectric power plant and the quantities of electricity which will be demanded by the region.)

The next generation will undoubtedly possess more facts to decide whether to join the two lakes or to permit the Sea of Galilee to remain as it is. The Sea of Galilee basin is an independent depression whose form is that of a huge bowl closed on all sides. Natural cliffs close off and barricade the Sea of Galilee from the south in the direction of the Jordan Rift. In this case, New Lisan Lake would proceed and extend up to the natural barrier which would separate it from the Sea of Galilee. If the two lakes are separated, it will be possible to determine the level of the surface of New Lisan Lake by a difference of two meters lower than the Sea of Galilee. However, both lakes will be connected by a canal and locks which will extend from New Lisan Lake to the Sea of Galilee in the original bed of the Jordan to permit navigation between the two lakes; but, at the same time, this will prevent the flow of saline water from New Lisan Lake into the Sea of Galilee. There will be two lakes at various levels with definite characteristics of their own. However, if the proposition is accepted that the Sea of Galilee will lose its importance as a long-term storage reservoir, and the tendency to salinity increases, there is no reason to prevent the flow of water from the Bay of Acre to generate a hydroelectric power plant in addition to the hydroelectric power center on the shore of the Dead Sea. Before the flooding of the Sea of Galilee by the water of the Mediterranean, it will be best to pump considerable quantities of water, when it is not yet too saline, to the national water system and through mixing with the fresh water of the carrier to flow to enrich groundwater which has been notably depleted.

Along this same line it is possible to cut a canal by conventional means across the Bay of Acre along 16 kilometers in an easterly direction to the mountains of the lower Galilee. This project is compatible with the topography. Then, from this point a tunnel can be dug along another 17 kilometers under the mountains of the lower Galilee to carry the waters of the Mediterranean Sea to the western bank of the Sea of Galilee. The difference in the height of the eastern exit of the tunnel (10 meters bsl) and the level of the Sea of Galilee (210 m. bsl) will make it possible to

THE JORDAN RIFT SEA LANE

Extending from the Gulf of Aqaba, which is the geographical entity in conformance with the Gulf of Suez, natural conditions are to be found which are eminently suited to excavating an additional sea level canal between the Red Sea and the Mediterranean Sea, along the Jordan Rift through the Valley of Jezreel to Haifa. There is nothing new in this idea. Approximately three million years ago, sea waters flowed through the Valley of Jezreel, and inundated the entire Jordan Rift from the Sea of Galilee on the north to the Dead Sea in the south. Back in 1855, an Englishman, William Allen, proposed to the British government the idea of excavating a navigational canal along this route. This proposal, however, was shunted aside. The British, during this period, controlled the land route to India by way of the Isthmus of Suez, and, shortsightedly, were not interested in any alternative. They were preoccupied with political stratagems to checkmate the French, engaging in all manner of means to interfere with De Lesseps in his Suez Canal project. However, in the end, the British entered the picture much earlier than might have been anticipated, and controlled the Suez Canal during most of its functioning years until 1956.

If the problem of flooding historic landmarks in the Jordan Valley is not taken into consideration (and such a situation has already occurred as a result of the construction of the Aswan High Dam on the River Nile where historical monuments were inundated, necessitating the relocation of the famed temple of Abu Simbel), then such a plan becomes feasible.

With the exception of this problem, the route from the Bay of Aqaba through the Jordan Rift is ideal for the construction of a sea level canal especially if the fact is taken into account that the Jordan Valley and the Dead Sea are depressions below sea level. There are only 110 kilometers along the Arava Valley from the Gulf of Aqaba to the depression of the Dead Sea. The Arava Valley is a desert region, almost entirely unpopulated. The land here rises gradually from the Gulf to its topographical high point, 220 meters above sea level. From this point northward, there is a

The Jordan Rift Valley: A Challenge for Development

produce a waterfall with a head of 200 meters and a flow of 160 cubic meters of water per second to generate the hydroelectric power station at this site.

The Bay of Acre-Haifa possesses a concentration of chemical and petro-chemical concerns. The cheap source of electricity (approximately 2 mills per kilowatt hour) from the hydroelectric plant of the Sea of Galilee only some 45 kilometers away, will encourage a concentration of those industries dependent upon cheap electricity. Here, also, will be an inland canal as in the Arava, and on its banks will rise the industrial complexes with sea transportation services in both directions.

decline sloping to the Dead Sea. This region lends itself very conveniently to the use of nuclear devices to excavate the canal excluding the section which is in the vicinity of the two neighboring cities of Eilat and Aqaba which lie on the Gulf of Aqaba. In this section, there will be a need to use the most modern mechanical tools but the digging area here is relatively flat. Through the use of nuclear explosives, it is possible to produce the desired result of a wide, deep canal, and, moreover, the construction period will be relatively brief.

As for the western canal in the Jezreel Vally which enters the Mediterranean Sea, land must be excavated by modern conventional means since this is a densely populated region.

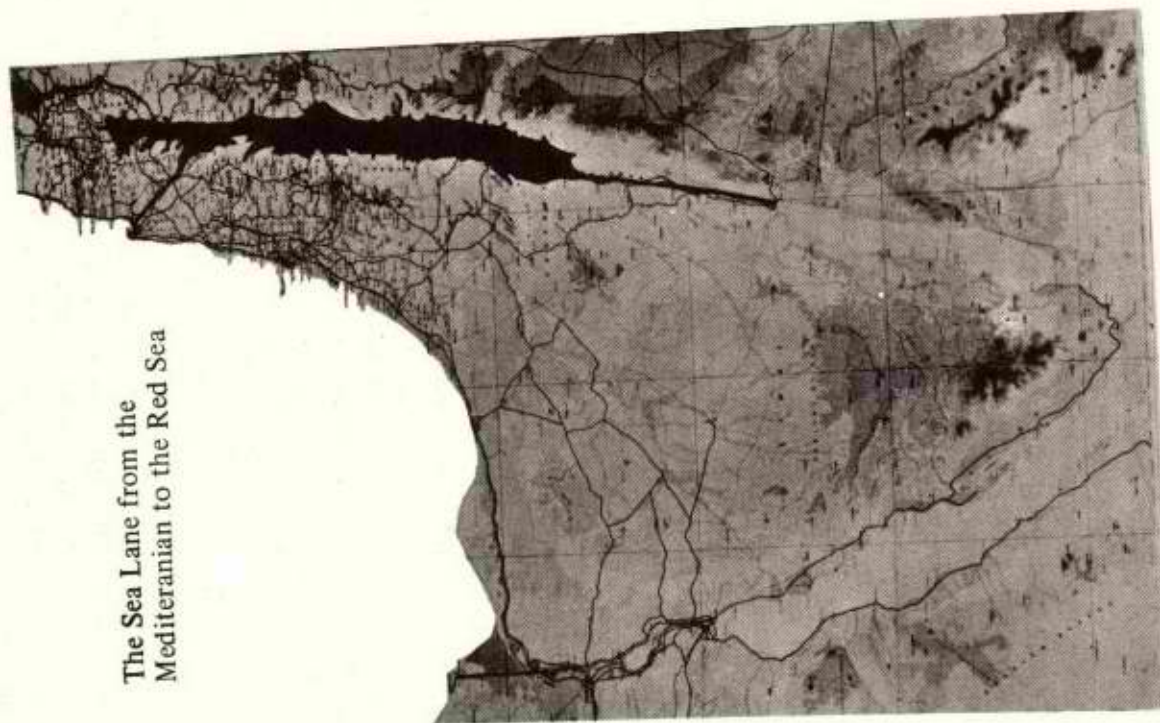
As a result of the two sea level canals, the Jordan Valley will be inundated by sea water and converted into a large lake with an area of some four thousand square kilometers, from the Sea of Galilee in the north to the Dead Sea in the South, for a length of 280 milometers (175 miles).

The boats which will use this route will sail across the large, wide, and deep lake and through two canals whose total length will be 150 kilometers (93 miles) compared with the 172 kilometers (107 miles) of the Suez Canal. This is a convenient sea route which will permit supertankers of 300,000 tons to make passage. The two bays, Aqaba and Haifa, are natural configurations and sufficiently deep to accomodate supertankers without difficulty. The cities of Aqaba, Eilat, and Haifa will become international ports, crowded with vessels and services for boats in transit. These cities will develop into comprehensive industrial centers with expanding populations.

In the generation which it will take to flood the required area gradually, the surface of the Dead Sea will rise 400 meters, and the depth of the sea will increase to 800 meters. This additional water will not disrupt the rich mineral deposits of the Dead Sea, and the high concentration of minerals in the deepest layers will not be disturbed. For industrial purposes, it will be necessary to pump the minerals from the deepest layers, but the abundance of cheap electricity will permit the production of a much greater and more unusual selection of minerals, and the establishment of a variegated chemical and metallurgical industry.

MAP TWO

The Sea Lane from the
Mediterranean to the Red Sea



The land to be flooded is largely salty, or desert in composition with little capacity for the establishment of flourishing agricultural settlements. When peace comes, there will be a need to relocate these agricultural settlers, and it will be possible to build them villages on higher lying land above the flood line and to reconstruct their irrigation installations. Now is the time to plan all the settlement and rehabilitation measures, to site the villages on the slopes of the mountains, and to settle farmers, not in areas of saline earth which formerly lay beneath the old Lisan Lake, which dried up over the milleniums. Furthermore, there will be a need to relocate approximately 30,000 farmers from the flooded regions of the Sea of Galilee valley and the Beisan Valley, which are distinguished by thriving agriculture to which the most modern scientific knowledge and methods have been applied.

Three historic cities will be flooded: Jericho, Tiberias, and Beisan. Jericho is a half-abandoned city. It will be possible to rehabilitate it gradually on the mountains above the flood line under more comfortable climatic conditions. In the new situation, it would continue to be a winter resort because of the warm climate, and as a tourist center follow in the footsteps of not far distant Jerusalem. Its proximity to the great Lake would result in its becoming a port city on the international sealand.

In Tiberias, the lower city will be flooded, and will have to be rebuilt gradually at the top of the mountain. It will be on the banks of a great lake, and its climatic conditions will be more moderate and comfortable. Tiberias will be converted into an industrial port city, with an outlet to the Mediterranean and Red Seas, and will also continue to be a winter resort and water sports center. Both Jericho and Tiberias will awaken from their historic slumber and, in the flooding process, Beisan (Beit Shean) will disappear.

The expected date of operation of the Jordan Rift Canal would be at the end of the present century or at the beginning of the next one. The Arava Canal, however, from the Bay of Aqaba to the southern Dead Sea should be in operation in coordination with the industrial exploitation of the Dead Sea mineral deposits and the erection of chemical and petrochemical complexes in the region.

2

THE INDUSTRIAL COMPLEX

While the Jordan Valley north of the Dead Sea is appropriate for agricultural settlement and tourist industries, the Arava Valley, south of the Dead Sea to the Bay of Aqaba, is suitable for the establishment of a chemical industrial complex. Such a complex could include fertilizer and light metal industries, utilizing the minerals found in the Dead Sea as raw materials, and a petrochemical industry, based on crude oil obtainable in abundance just around the corner. To supply the large amount of electrical energy to operate such variegated industries, an ample supply of cheap electricity is needed.

Since the entire chemical complex is dedicated to producing for export, it should be granted the favorable condition of being able to ship by sea through the construction of an inland canal from the Bay of Aqaba along the entire length of the Arava Valley to the Dead Sea. Then it will be possible to transport the minerals from the source by means of the most modern shipping facilities, bulk-carrier container ships (which carry the finished chemicals directly from the factory to the ship) or by means of tankers which would transport liquified chemicals. As a result of the employment of bulk carriers, it will also be possible to bring raw materials such as alumina or bauxite as well as heavy industrial equipment directly to the factory, while the mammoth tankers can convey crude oil.

As was stated earlier, it will be necessary to cause sea water to flow to the Jordan Valley to replace the fresh water (which has been diverted for irrigation) to provide the proper water balance of the two lakes: the Dead Sea with a high salt content and the Sea of Galilee. Otherwise it is quite possible that these two lakes will disappear in generations to come as a result of evaporation.

Maintenance of this water balance can be achieved by excavating a canal from the Bay of Aqaba along the Arava. Such a canal will perform three necessary functions: (1) it will allow water to flow into the Jordan Valley; (2) the water it carries will operate a hydroelectric power station along the banks of the Dead Sea which will produce vast quantities of cheap electricity (at a cost of less than 2 mills/kwh); and (3) the canal itself will serve as an inland navigational waterway for large ocean-going vessels.

As for the excavation of the canal, there is nothing to prevent the digging of a canal wide enough and deep enough to make the crossing of 300,000 ton tankers possible if the excavation work includes the use of atomic power.

As for the industrial complex, it must also be noted that in the establishment of such a large and varied chemical complex, additional knowledge, capital, and markets will be required. Thus, these essentials must be secured through such industries as will attract both capital and scientific knowledge, along with ensuring dominance over world markets.

It is natural that the type of industry which will develop along the inland canal on the east and west banks will originate at the Dead Sea. On the southern end of the canal will be found the hydroelectric power station (1000 mw) which will be fed sea water by the canal to power its generators. Moreover, the industry based upon the Dead Sea minerals — bromide, chlorine and fertilizer derivatives — will be located here. South of this area will be found a light metals industry such as magnesium and aluminum. The petrochemical industry will most likely find its site along the banks of the canal, in the center of the Arava. An industry devoted to repairing ships and building sailing vessels will find its locus near the Gulf of Aqaba as will the industries based upon the commodities produced by the metal and petrochemical industries, and the small and medium-sized industries which produce finished goods.

The Bay of Aqaba is one of the most beautiful in the world, being also rich in marine life. The latter must be protected from pollution. Aquatic sports and a broadly based tourist program must be encouraged. In fact, this characteristic of the Bay is to be preferred over its importance as a deep water port. Therefore, the

terminals and crude oil storage depots for the minerals and chemicals should be sited along the canal as far as possible from the Bay. Since the water will flow in the canal in the direction of the Dead Sea, all the polluting agents associated with the boats will be carried to the Dead Sea, and the Bay of Aqaba will be preserved. Eilat and Aqaba will become port cities, centers of management, education research, and trade for a rich, varied internal industry.

The production of cheap electricity will permit the exploitation of magnesium salts found in abundance in the Dead Sea to establish a magnesium metals industry. In each liter of Dead Sea Water, 36–42 grams of magnesium salts are to be found as compared with 1.3 grams of magnesium salts in each liter of ocean water. Moreover, the existence of cheap electricity will justify the establishment of an aluminum industry here in proximity to the magnesium industry. It will be possible to bring the alimuna or bauxite via the sea in bulk carriers from every place where they are found, along the shores of the Red Sea from African shores, from Greece, Yugoslavia, and even from Australia which supplies alumina and bauxite to Scotland and Norway.

The presence of this industry will permit the establishment of a light metal alloys industry to produce a very broad selection of light metals possessed of very unusual properties. The proximity of the petrochemical industry producing polymers (what we are accustomed to calling synthetic plastic materials) combined with the above mentioned light metals, will permit the production of materials which are distinguished by properties which withstand high temperatures, rust and corrosion, and are stronger and lighter than the toughest steel.

It is possible to erect a varied industry to produce basic metals. Through the synthesis of light metals with polymer fibers, new materials can be produced possessing exceptional properties. Traditional metals are suffering from competition with materials such as plastics, which can be molded into shape more easily and cheaply. Such alloys as aluminum combined with zinc under certain special conditions become super-plastic. They recover the mechanical properties of a normal metal and can be used for car bodies and casings of consumer durables. Plastics are now being

reinforced with carbon and boron to produce ultra-strong composites for compressor blades, rotors and fans as well as rocket cases.

All the conditions are present at the Dead Sea to produce a broad range of fertilizers, both basic and compound. Fertilizers in the form of potash are found in bountiful quantities in the Dead Sea; nitrogen fertilizer is derived from the source materials of the petrochemical industry, and phosphate fertilizer is obtained from the relatively rich mines located east and west of the Arava Vally. Moreover, it appears that the demand for fertilizer will continue to increase in the same proportion as the increase in population in Africa and Asia which are the natural markets for these products.

A varied and integrated organizational structure for the production of fertilizers will permit application and adaptation to the needs of developing countries. It will be possible to supply fertilizers of all types, from organic to the most sophisticated compounds. These fertilizers could be shipped via sea directly from the plants to the bulk carriers or the tankers, which could transport the fertilizer to the consumer nation. It is extremely important to possess the know-how required to produce these fertilizers in an economical manner and to market them successfully.

The range of products in the chemical industry is truly enormous - from plastics to synthetic fibers, fertilizers to pharmaceuticals, from detergents and dyestuffs to explosives. Raw materials include oil, natural gas, coal, salt, potash, and sulphur. The chemical industry is international in scope, and as we have seen, large companies have extensive interests and operations in countries other than their own. Moreover, chemical companies are distinguished by varying operations. Thus, the largest indigenous French chemical company, Rhone-Poulenc, is also a huge fibers group. The second largest French chemical company, Ugine-Kuhlmann, too, has extensive aluminum and steel interests. The Japanese chemical industry is dominated by the powerful, traditional trading companies. In fact, Mitsubishi even possesses two separate, distinct, and competitive outfits: Mitsubishi Chemical and Mitsubishi Petrochemical.

Another part of the industrial complex is the petrochemical group which is capable of supplying basic materials to the wide, diversified chemical complex, and of producing a wide range of industrial products including nitrogen fertilizers, the varied assortments from the polymer industry with its products so evident in the world of plastics, and even proteins for animal and human consumption.

Thus the construction of an inland canal from the Gulf of Aqaba to the Dead Sea will provide the initial impetus for a large and diversified industrial complex utilizing the electricity produced by water flowing down to the Dead Sea. The remainder of this chapter examines the current status of the industries that are involved here, keeping in mind how they bear on the development of an industrial complex centered around the proposed canal. The discussion has been divided into three sections: (1) Chemicals and Petrochemicals, (2) Light Metals, and (3) Fertilizers.

CHEMICALS AND PETROCHEMICALS

The petrochemical industry is witnessing a phenomenal growth rate both in North America and Western Europe. Petroleum is basically a mixture of hydrocarbons, and the organic chemical emphasis has thus been upon carbon and hydrogen with such end products as plastics and resins, synthetic detergents, rubber and fibers, fertilizers, and solvents. In the inorganic chemical areas, hydrogen is extracted from petroleum for ammonia products; sulphur can be recovered as an impurity in some crude oils; and carbon black and hydrogen cyanide may be petroleum-based. It has been estimated that by 1985, the production of petroleum-based organic chemicals in the non-Communist world would reach 200 million tons, with oil and natural gas by then having become the source of virtually all organic chemicals. By the year 2000, production is estimated at 600 million tons. Of this total, approximately two-thirds would be plastics, and the remainder would be synthetic fibers, rubber, agricultural

chemicals, industrial chemicals, and new chemical products as yet unknown. Still being investigated for example, are such petroleum-based products as protein. These and others will certainly emerge to take their place as major products of the petrochemical industry.

While petrochemical production began in the United States and spread to Western Europe after World War II, Japan and Australia are now developing their own complexes. The oil producing countries of the Middle East and the Caribbean area furthermore are interested in similar development.

The central part of the petrochemical industry is the ethylene plant which produces ethylene and propylene by means of thermal cracking of hydrocarbon feedstocks (usually naphtha in Europe, and ethan, propane, and butane in the United States). Olefin plants specialize in production recovery of such byproducts as butadiene and aromatics fractions. In the past 10 or 15 years, the size of the plants have grown from the production of 30,000 tons of ethylene per year to 300,000–500,000 tons, which greatly encourages the recovery of by-products. The petrochemical producer must think in terms of a petrochemical complex constituting perhaps a dozen plants, thus involving investment in by-products.

Aromatics. The by-product known as aromatics refers to the base hydrocarbons: benzene, toluene, and the three xylenes. Since World War II, the demand for aromatics for chemical purposes has increased tremendously. While aromatics were previously a product of the carbonization of coal, they are today a by-product of the steam cracking of petroleum fractions. Benzene is used in the production of detergents, plastics, pharmaceutical products, synthetic rubber, synthetic fibers, explosives, agricultural chemicals, and dyestuffs. Toluene is primarily employed as a solvent, and especially in certain types of surface-coating material; as a basic material in the production of polyurethane foams; and in dyestuffs, pharmaceuticals and explosives. The demand for aromatics has become so enormous that its production has risen from that of its former state as a by-product to a place where special plants are now designed for its production alone. Such plants are being constructed in every important industrial country.

To supply the growing demand for polymers used in the production of synthetic rubber and fibers as well as plastics, activity has expanded in the heavy organic chemical industry. Ethylene, propylene, and butadiene, are derived from naphtha cracking and styrene, an intermediate material, which is produced at a further stage of manufacture from ethylene and benzene. Approximately 10 percent of propylene in Europe is used for the manufacture of polypropylene, and 12 percent for the production of acrylonitrile which is developed into acrylic fiber. Approximately 65 percent of styrene-based butadiene rubber is used to manufacture tires.

To meet the demand for these materials American chemical and petrochemical companies have increasingly participated in the European industrial scene throughout the past decade. There has been a massive concentration of capital in a few selected sites, containing highly integrated plants, located in proximity to petroleum refining centers and such deep water ports as Antwerp, Rotterdam, and Teesside. The huge American chemical companies, Dow, Monsanto, Union Carbide, and DuPont, have expanded their bases in Europe at the same time as the oil companies, Gulf, Esso, Phillips, Texaco, Conoco, Mobil, Standard Oil of Indiana, and Occidental, have been diversifying into petrochemicals. Production of petroleum-based chemicals is expected to reach 88 million tons in 1985 and 240 million tons in the year 2000. In 1965, the world wide proportion of organic chemicals from petroleum was 80 percent, and it is expected to rise to 98 percent in 1985 and 99 percent in 2000. During the last 25 years, the ability to synthesize organic polymers has had a tremendous impact on everyday life and on technology. The synthetic polymer industry is now one of the fastest growing areas of the world economy, production has added a wide range of plastics and fibers to the range of traditional materials.

Plastics. The petrochemical industry utilizing organic chemical produced from oil and natural gas and based upon carbon and hydrogen is responsible for the production of such daily mainstays as detergents, synthetic rubber, all the myriad members of the plastics family, and synthetic fibers such as terylene, dacron, acrilan, and nylon. Today, plastics are usurping the traditional

position of glass and metals in many areas of the building industry with adequate reason to believe that there is considerable scope for much more innovation. Indeed, John Loudon, the former chief of Royal Dutch Shell, has been cited as espousing the prefabrication of houses by sections in the factory, to be assembled on the site with plastic washing machines, refrigerators, dishwashers, and vacuum cleaners.

One of the most significant characteristics of organic molecules is their ability to link up to form large structures. These structures are polymers. The nature of the polymer produced depends primarily upon the components from which it is made, the appropriate choice of these components, and the reaction conditions. These factors control the properties of the polymer. Polymers may be softened by heating to create thermoplastics; they may be decomposed without softening to emerge as thermosetting resins; they can be glassy, amorphous, and brittle as in the case of polystyrene or polymethyl methacrylate; or they may be opaque, crystalline and tough as is nylon or polyacetal. Their properties can be influenced by the incorporation of other materials, and while normally white or colorless, they can be pigmented at will. While plastics are basically organic chemical compounds, their value as materials depends almost entirely upon their physical properties. They can exhibit the low melting or softening points characteristic of organic materials and thus be readily molded under moderate conditions of temperature or pressure. The molding techniques of injection and extrusion furnish a convenient and efficient method of large scale production of complex products. These processes are relatively economical since the method of conversion requires modest amounts of power. While further economies arise from the reduction in finishing operations, the molded component is frequently available for service without further treatment.

Plastics are distinguished by their resistance to many environments that are deleterious to metals. This characteristic accounts for their extensive use in such areas as surgical implants and chemical plants. Since the density of plastics is much less than that of metals and glass, fiber reinforced resins possess high strength to weight ratios. They are thus much in demand in the

transportation and construction fields. Plastics, in addition, are efficient thermal and electrical insulators, have considerable friction and wear characteristics, and transmit light. An example of the rapidity with which plastics are over-taking metals as the basis of various products is indicated by the composition of that household staple, the vacuum cleaner. In 1958, a well known model contained twice as many aluminum as plastic components but, by 1960, in the short span of two years, the similar model contained two plastic parts to every aluminum part. Moreover, polypropylene, polyformaldehyde, glass-filled nylon, and polycarbonate all possess properties which encourage their use in place of metal. Metal coated with plastic, or plastic coated with metal, is expected to have an increasing demand; the former used as reinforced plastic for aircraft parts, automobile accessories, or common water faucets. To prevent and/or resist corrosion, steel pipes lined with plastic are being produced in great quantities, and plastic-coated steel is being developed for construction purposes.

While no polymers of new chemical structure have appeared at the moment, polyphenylenes are now marketed in England, and are being evaluated for use with carbon fiber reinforcement in the hotter parts of Rolls Royce engines. Some very complex polymers, containing such elements as phosphorus, titanium, silicon, and boron in combination with other elements, are beginning to be synthesized in the laboratory; they may bear fruit in the future.

The plastics industry is now counted as big business. In 1966, the United States produced 5,900,000 tons of synthetic resins and cellulosics; West Germany 2,200,000 tons, Japan 2,100,000 tons, the United Kingdom 1,035,000 tons, the U.S.S.R. 940,000 tons, Italy 930,000 tons, France 780,000 tons. Adding in the smaller countries, a world total is estimated at 16,309,000 or more than 40 percent greater than the production of aluminum. The number is rising rapidly so that almost every great chemical company in the world is now engaged in manufacturing plastics. Polyolefins, PVC, and polystyrene with its copolymers account for 63 percent of total U.S. production and 57 percent of total United Kingdom production.

These three plastics are very versatile: they are tough; they have high temperature resistance; and they are easy to manipulate.

They are cheap because they are made from relatively simple molecules — ethylene gas playing a vital part in their production. This accounts for the expected rise of ethylene production from 7 million tons in 1966 to 16 million tons in 1970. The largest producers are the United States, Japan, West Germany, and the United Kingdom.

The oil needed for plastics production is a very cheap material to move, either by tanker on a sea route or by pipeline overland. Indeed, with the ease of production, it has been predicted that in the year 2000, 1,700 metric tons of plastic will be produced as opposed to 2,250 metric tons of iron, 250 metric tons of aluminum, 2,535 metric tons of all metals including copper and zinc, and 44 metric tons of rubber. This output must be contrasted with the 1966 production of 16 metric tons of plastics as opposed to 464 metric tons of iron, 7.7 metric tons of aluminum, 486 metric tons of all metals including copper and zinc, and 3.9 metric tons of rubber.

Plastics are now accepted in their own right and not just as substitutes for other products.

Man-made fibers. Man-made fibers which are produced from such diverse elements as polymers and ceramics have unusual qualities of strength, high energy absorption, and temperature resistance. Until World War II, the field of fibers was limited to natural fibers such as cotton, jute, wool, flax, asbestos and silk, or rayons, which were the first synthetic fibers developed in the late 19th century. Viscose rayon, the first chemically produced commercial fiber is composed mainly of regenerated cellulose obtained from wood pulp or the waste product, cotton linters. As a result, the chemical composition of rayon is still somewhat similar to the natural fiber, cotton.

Today, there are many varieties of polyamide and polymeric fibers based on polyesters, acrylics, modified acrylics (modacrylics) and olefins such as polypropylene. Fibers can be made from most materials and have been successfully produced from glass, quartz, metals, graphite, and ceramics. In 1967, of a total of 9 billion pounds of fibers consumed in the United States, 4 billion pounds were man-made. The gross retail value of apparel alone produced from these products amounted to 34 billion

dollars, approximately 5 percent of the Gross National Product, and larger by 4 billion dollars than the total retail sales of the automotive industry.

As a result of its interests in polymers, the fiber-producing industry is now an extension of the chemical industry. Previously, the textile industry was largely a fabricating industry which purchased natural fibers and acetates to be processed on looms and knitting machines. However, man-made fibers are utilized in other ways than in the textile industry. The composition of cordage-rope has now been extensively replaced by nylon and polypropylene, since polymeric fibers do not mildew, rot, or absorb moisture. Nylon is especially adaptable for tow rope, mountain-climbing rope, and parachute harnesses. Polypropylene, less dense than water, floats, which is extremely useful in marine applications. Polyester has been used for sailcloth since it resists growth under tension and thus may be buffeted by wind without becoming floppy or saggy. Acrylics resist the elements, and thus, in highly humid regions, have replaced cotton for sandbags, and have been attractive as awnings and tents. Coated nylon and polyester fabrics have been used for constructing storage buildings. About \$150 million a year are now spent on fiber research. It is expected that by 1970 the consumption of synthetic fibers will rise to about 75 percent of the total fiber production.

Strong, stiff fibers which may be used as reinforcing agents are produced either from light elements or compounds of two light elements including beryllium, beryllium oxide, boron, boron carbide, silicon carbide, silicon nitride, and carbon and aluminum oxide. All these materials possess high melting points, indicating strong interatomic bonding and high stiffness. Carbon and boron fibers are the best known because of their attractive properties and availability. However, aluminum oxide is gaining in popularity. Carbon fibers are jet black, silky and finer than most human hairs. Their importance lies in the fact that they can be made stronger and stiffer than any other synthetic or natural material of the same weight except for single crystal "whiskers" which can be produced only on a microscopic scale. These fibers promise a new order of stiffer yet lighter construction for a vast range of man-made objects. In the four years they have been available,

much has been done to put them to practical and economic use. Most new technical accomplishments ultimately prove useful in fields outside that for which they were developed, and a new material will probably affect every field of man's endeavor. Like so many accomplishments, carbon fibers were created for the world of aerospace. Already the first production hardware designed to incorporate them, the Rolls-Royce RB. 211 turbofan engine, is running on the test bed and coming into production. Some of its most important components are made of a composite material, having a density half that of aluminum and consisting of a resin matrix reinforced with about 600,000 carbon fibers per square centimeter of cross section. Later, hotter parts of engines may be made of other composites in which the fibers are used to reinforce a matrix of ceramic or metal. The fibers themselves retain strength at very high temperatures for they are born in a furnace at a temperature far above that of molten steel.

Today's carbon fibers are sold at the high prices characteristic of anything just emerging from the laboratory. After a decade of mass production, starting in the United States this year, resin composites will be cheaper than a number of metals and other special materials.

The future of carbon fibers, nevertheless, seems very large indeed. The world market should reach the level of thousands of tons a year within the next decade, although the inevitable large price advantage of glass fiber will restrict carbon to true engineering structures and other hard-worked parts. A conservative estimate for 1978 is that carbon fibers will have a market 15 percent as large as that of glass fiber.

Synthetic Food. Synthetic food must contain all the indispensable salts and vitamins. These must be produced on a large scale through chemical and microbiological processes. The production of proteins on an industrial scale is being undertaken in several countries including France, England, and the Soviet Union. These countries are engaged in the production of fodder yeasts, whose raw material is paraffin. Hydrocarbon yeast has a 40 percent protein content as compared with the 30 percent of soya beans, the most nourishing agricultural product.

Alfred Champagnat, director of a Marseilles laboratory, has noted that the annual world shortage of animal protein amounts to 3 million tons or 15 million tons of beef cattle. In an annual production of a billion tons of petroleum, approximately 700 million tons will be paraffin-based. It is estimated that to produce 7 million tons of protein-vitamin concentrate, equivalent to 3 million tons of protein, only one percent of the above mentioned 700 million tons of petroleum would be consumed. Moreover, 6 million tons of synthetic protein are required annually to meet the needs of 250 million persons, whereas to nourish the same number with protein produced by stock farming, would require the production of from 50-100 million tons of dehydrated protein to feed the animals themselves.

A British petroleum plant has developed a process at its French refinery (Lavera) which will produce protein from crude oil. The final produce, a yellowish, odorless powder comparable to fishmeal in composition and not yet suitable for direct human consumption, is available as feed for animals and poultry which ultimately is converted to meat, milk, and eggs.

Although it may be ten years before food for human consumption is derived directly from protein produced from petroleum or natural gas, several oil and chemical companies have already begun development programs. For example, India is producing protein from petroleum hydrocarbons.

From this brief overview of the diversity of products available from petrochemicals, it is evident that the development of petrochemical industrial complexes along the canal from Aqaba to the Dead Sea will be nothing but beneficial for the area.

LIGHT METALS

Magnesium. Magnesium is the lightweight champion among metals. Even aluminum is more than one and one-half times heavier. Its low density, combined with a relatively high strength for its weight, has made magnesium important in industry. While the raw materials containing magnesium are widely distributed throughout the earth, the metal itself, is so difficult to extract that it may be exploited only by highly industrialized communities.

While pure magnesium is not particularly strong, suitably blended (alloyed with one or more elements) and worked, its strength can be doubled and even trebled. The most widely used alloying elements are aluminum, zinc, manganese, and zirconium. Aluminum and zinc are added as hardeners to raise the mechanical properties of magnesium, manganese is added to improve corrosion resistance, and zirconium is added to reduce the size of the individual grains out of which the alloy is composed, making the metal stronger and giving it ductility, creep-resistance, and strength at elevated temperatures. Magnesium-zirconium alloys are important in the transportation industry, especially in aeronautical production.

Magnesium is found as a chloride in sea water and in certain deepwell brines, including those of Michigan. Magnesite ($MgCO_3$) which is the most important solid source of magnesium, is widely distributed throughout the world, the largest deposits occurring in Australia, the U.S.S.R., Greece, Czechoslovakia, Manchuria, and the Pacific Coast of North America. Leading producers of primary magnesium in the second half of the 20th century include the U.S., the U.S.S.R., Norway, Canada, Italy, the United Kingdom, France and Japan; while magnesite is produced in quantities by the U.S.S.R., Austria, China, Czechoslovakia, the U.S., and Yugoslavia. The world production of magnesium in 1966 was 160,000 tons, of which 72,000 tons were produced by the U.S.A.

Two principal methods for the commercial production of magnesium are in use in the second half of the twentieth century. One is electrolytic, accounting for the bulk of industrial production, and the other, thermal. In Germany, where the magnesium industry first developed on a large scale, the process is based on the electrolysis of molten magnesium chloride, a by-product from the potash and carnallite operations at Stassfurt. Magnesium chloride may also be produced from brines, sea water, processed dolomite or by chlorinating magnesite. During World War II, the sea water electrolytic process, which in 1941 was the newest method of producing magnesium, accounted for the bulk of production in the U.S. In this process, sea water, which contains about 0.13 percent magnesium, is pumped into huge settling tanks where it is mixed with lime. The calcium from the lime is exchanged with the magnesium in the sea water which

precipitates as insoluble magnesium hydroxide. This settles to the bottom of the tank and is filtered off. The magnesium hydroxide is then converted to magnesium chloride by reaction with hydrochloric acid prepared from natural gas and chlorine. After thorough drying, which may be accomplished by means of spray or shelf driers or a combination of the two, the magnesium chloride or cell feed is fed to the electrolytic cells where electricity breaks it down into magnesium metal and chlorine gas.

After World War II, intensive research and development work produced strong light alloys which aided in world-wide and rapid development of the aircraft industry. These magnesium alloys were used especially for structural purposes. Perfection of alloys fabricated successfully by casting, extrusion, rolling and forging, opened up many new fields of use. Magnesium possesses special properties which make it particularly desirable for certain types of applications, including exceptional machining qualities, good fatigue resistance and damping capacity under impact stress. The attainment of high standards in the pressure die-casting technique has opened up new spheres of application in the instrument, tool, optical, and other industries where designers are often able to substitute a single casting for parts formerly built up from sheets and sections; die casting is stronger and more rigid but not heavier.

Because of their low specific gravity, magnesium alloys are widely used in the aircraft industry, as was illustrated during and after World War II. Some typical applications include housings for camshafts, timing gears, superchargers, oil filters and pumps, landing wheels, forged radial engine crankcases and propeller blades for small planes, floor beams, frames for seats, and many small parts such as die-cast instrument housings. Increased use has been made of magnesium sheet in the monocoque or stressed skin type of wing construction and it has been used on a considerable scale for fairings, cowlings and tanks. Magnesium missile sheet has been produced in volume, and various alloys have been applied in spacecrafts and in guidance systems. Magnesium tooling plate has also been used for making memory disks in electronic computer systems.

Although in the transportation area magnesium has found its greatest use in aircraft, there is a growing interest in applying its

advantages to other types of equipment, especially in automotive equipment. In Europe, particularly Germany, magnesium alloys are used in bodies and frames for motor buses and trucks, cast wheels for tramways and buses, and in a variety of small parts. In the U.S., magnesium has also been used in the construction of truck bodies and auto-transport trailers. Its use in railroad equipment includes frames for seating, partitions in Pullman cars, and instrument panels and housings.

Magnesium is increasingly being used for various types of portable goods such as the housings and handles of tools. Portable platforms and conveyor systems, dockboards, hand trucks, milk crates, office equipment, such as typewriter and adding machine frames, and various types of instrument housings are also being made from magnesium.

Because of their light weight and their ability to absorb dynamic energy, magnesium alloys are being used in parts of high-speed and reciprocating machinery such as warp beams, bobbins, spools and knitting bars, so necessary to textile plants. Cast magnesium foundry flasks and molding and core boxes are used in foundries, and it is also utilized for industrial gratings and pedestrian bridges.

The use of magnesium in consumer goods of various types is constantly expanding, now including such items as domestic vacuum cleaners, griddles, wheel toys, luggage, lawn mowers, step ladders, and photographic and motion-picture cameras.

Magnesium functions as an important element in aluminum alloys. Its chief function involves increasing the mechanical and corrosion-resisting properties. It also facilitates heat treatment. A growing use of magnesium is as an expendable galvanic anode for the cathodic protection of buried metal structures such as pipelines, as well as for ship hulls and tanker compartments.

With its high affinity for oxygen, magnesium is used as a deoxidizer in the manufacture of metals. The increasing production and use of zirconium hafnium, uranium and beryllium has resulted in an increased demand for magnesium as a reducing agent.

Because of the increase in use of magnesium, markets exist. Exploitation of larger amounts of magnesium found in the Dead Sea needs to be considered. Cheaper outlets to markets for Dead Sea magnesium along with cheaper sources of electricity for the

extraction of magnesium from magnesium chloride can be considered if the canal from Aqaba to the Dead Sea becomes a reality.

Aluminum. In 1967, the Western nations used approximately 7.5 million tons of aluminum, and it is expected that demand will double in the next 10 years. Aluminum is replacing many metals, such as steel and copper, since it is light, weather-resistant and a good conductor of heat and electricity. It is a good reflector of light and radiant heat as well. Six big producers (Aluminum Company of America, Alcan Aluminum Ltd., Reynolds, Kaiser, Pechiney, and Alusuisse) account for approximately three-quarters of western smelting capacity, and the top four possess more than one-third of the western world's semi-manufacturing capacity.

The production of aluminum in the United States is a major industry, second only to iron and steel in the metallic sector. The industry received its primary impetus during World War II when there was an insatiable demand for the product of its light, strong qualities. Since that period, new uses have increased the demand, as its qualities were revealed as an ideal building material. Furthermore, its use in automobile production has increased ten-fold since 1946; railroad and marine enterprises have increased their consumption annually. It is a popular material in the manufacture of consumer durables, machine parts, tools, and equipment. The net result has been that the local supply in the United States, is now inadequate to meet the demand, and over 85 percent of the bauxite (the raw material for aluminum) currently in use is imported.

In 1966, the United States produced over 37 percent (3 million tons) of the world's supply of aluminum which was 8 million tons; the U.S.S.R. almost 18 percent; the Eastern European countries less than 6 percent; the continent of Asia approximately 5 percent. Today, the United States consumes about 53 pounds per capita of primary metals; Europe — 6 pounds; and Asia and Africa less than one pound.

Smelters have been concentrated in countries with abundant hydroelectric or thermal power resources, such as the United States, Canada, and Norway, since power utilized in the smelting process accounts for approximately 15 percent of costs and a

power price difference of 0.1 U.S. cent per unit adds 3 percent in costs. In high-cost energy countries, such as France, Germany, and Italy, smelting is undertaken by means of special pricing. Since 1954, North America has been the major producer of aluminum and the main supplier to European semi-manufacturers. However, North American capacity now provides only 48 percent of the total as compared with 85 percent in 1945. Location of smelters is now determined more by transportation costs and semi-manufacturing is carried on in proximity to the ultimate consumer.

Although, at present, North America produces 450,000–500,000 tons per year more than it consumes, by 1972 this export surplus will have declined to zero. Europe, on the other hand, now imports approximately 300,000 tons per year. Thus, new operations are in order, and the demand is growing.

Many factors have combined to promote the desirability of locating smelters in metal-consuming countries. Power costs, of course, have a significant influence since, in the smelting process, the aluminum is separated from the oxygen by massive doses of electricity. It takes approximately 18,000 kwh to make a ton of aluminum which is roughly the equivalent of a two-bar electric fire which has been switched on for more than a year. The most influential considerations include: the prospect of nuclear power costs falling to 4 or 5 U.S. mills a unit within the next 10 years; shorter haulage and lower handling costs if the aluminum is shipped directly to Europe (and not to a North American smelter first); and high tariffs, particularly the 9 percent external tariff of the Common Market. In addition, some governments are providing financial incentives to encourage the erection of smelters within their borders. Eventually, when nuclear power is universally available, and the demand for aluminum in the raw material producing countries represents a more notable share of the market, it is probable that new smelters will be located near the bauxite and aluminum plants. Such a process would certainly cut transportation costs, but, for the foreseeable future, it appears that semi-manufacturing will continue to be carried on in proximity to the ultimate consumer. Transportation is a decisive factor in this area, too. The processes of rolling and extruding add value but also result in much more awkward shapes, which in turn,

result in approximately doubling the transportation charges. And, too, tariffs are higher on semi-manufactured goods.

An investment of approximately 3,000 dollars is required to produce one ton per year of semi-manufactured aluminum. The economies of scale which can be gained by combining all operations in one plant from mining the bauxite to rolling have tended to greatly increase the size of new plants.

In dealing with this situation, producers have moved into the semi-manufacturing stage thus increasing integration. Approximately 80 percent of the entire semi-manufacturing capacity in the United States and Canada is owned by aluminum producers. The Aluminum Corporation of America processes virtually all of its own aluminum. While, at one time, Alcan Aluminum Limited only processed approximately one-quarter of its aluminum, it now processes 50 percent, and is moving toward 60 percent. In Europe, forward integration increases.

In Norway, Alnor (51 percent Norwegian and 49 percent American) has opened a new smelter with an initial capacity of 80,000 tons and an envisaged expansion to 240,000 tons. It is located on the island of Karmoy, approximately 50 kilometers north of Stavanger. The plant is integrated to produce not only raw aluminum but also semi-manufactured goods. This plant has the advantage of cheap hydroelectric power (3 U.S. mills/kwh. plus delivery) and a modern production process. The oxide is reduced to metal which is semi-manufactured in the same building without being cast into ingots. Besides the raw aluminum, such semi-manufactured goods as "sheet," "strip," "tubes," and "wire rod" will be produced. When the extrusion plant is in operation, the company expects that approximately one-third of the total output will be in the form of semi-manufactured goods, while the remainder will be in the form of straightforward ingots, billets, and slabs. However, the ultimate goal is a fifty-fifty division of the two types of product. Elimination of the intermediate stage of production is expected to reduce costs by 50 percent. The Norwegian partner in the enterprise, Norsk Hydro, is the world's largest exporter of nitrogen fertilizer, and the world's second largest producer of magnesium. It believes that it is beneficial to have an interest in all industries connected with water

power. The electricity which powers this smelter is hydro-generated. The American partner, Harvey Aluminum, will supply the Alnor smelter with alumina produced by bauxite deposits in the Virgin Islands. The Harvey Company will receive 25 percent of the smelter's output free of charge to sell in the United States.

In England, British Aluminum (partly owned by Reynolds Metals of the United States) and the British Mining concern, Rio Tinto Zinc Corporation, are building two smelting plants to produce 224,000 tons of ingots by 1971. Rio Tinto will build its 112,000 ton smelter on the island of Anglesey at Holyhead in Wales and obtain cheap power from the Dungeness "B" nuclear power station in Kent. British Aluminum is building its 112,000 ton smelter at Invergordon in Scotland, the last undeveloped deepwater port in the United Kingdom. Electricity for these two smelters will cost 0.6d per unit because of government subsidy. The Invergordon plant will receive its power from the Hunterston "B" station of the South of Scotland Electricity Board.

If New Zealand agrees to grant tax concessions, a consortium of British, Australian, and Japanese companies will build a major aluminum smelter in that country. The basic attraction is New Zealand's cheap water power. The proposed British investors of this vertically integrated plant have already begun working the world's largest bauxite deposits at Weipa in northeastern Australia. Processing of this ore takes place at the world's largest single-stream alumina plant at Port Gladston, in Queensland, Australia, and this alumina is now being smelted in North America. The proposed smelter would be built at the deep-sea port of Bluff, near Invercargill in the southern part of New Zealand's South Island. The power would be obtained from Lake Manapouri in South Island. Manapouri power is expected to be operating by April 1970, with an eventual output of 620 mw on a continuous basis and 700 mw at peak load. The smelter would be built with an initial capacity of 105,000 tons to be increased to 290,000 tons by the early 1980's. Manapouri power will cost less than 2 mills/kwh., (0.2 United States cents), as compared with hydro-electric kwh., (0.2 United States cents), as compared with hydro-electric power costs of nearly 4 mills in Australia, and

approximately 3 mills in the United States, where much of Australia's alumina is now being smelted. (The cheapest power until now has been at Bonneville in the United States — 2½ mills/kwh.) The Japanese users of this aluminum would gain an even greater advantage since Japanese power costs 7 — 7½ mills/kwh.

At the present time, West Germany is on the verge of increasing its aluminum production capacity which, until now, has averaged 60 percent of the amount used by German industry. The price of electric power has, until recently, hampered German development since this cost is an important factor in aluminum production. In the production of aluminum, 18,000 kwh are required to make one ton. The interest in increased production of aluminum all over the world is apparent when one realizes that none of the three proposed entrepreneurs represent German companies but rather the American Kaiser Company; the Swiss Alusuisse (in association with Metallgesellschaft of Frankfurt); and Pechiney of France. The three sites are all in the Ruhr.

With the proposed hydroelectric power plant on the shore of the Dead Sea, sources of cheap electrical power will be available. Aluminum extraction from bauxite can thus be integrated into the industrial complex, the canal being the means of transporting raw and refined materials.

Titanium. In recent years, titanium has become important in alloy forms. Principal employment of titanium metal is in structural parts in high-speed military aircraft where high strength and low density are important. Titanium and titanium alloys can be used at temperatures up to 800 F., several hundred degrees higher than the useful temperature range for aluminum. It is used in the compressor section of jet engines, in airframe construction, aircraft skins, fire walls, and as fasteners. In other military applications, it may prove useful for armor plate because of its toughness, and for structural components of atmosphere makes it suitable for special applications, such as heat exchanger tubes, superstructure parts, valves, and propeller blades.

In corrosion-resistant applications, titanium is used in valves and pumps for corrosive chemicals, in wire cloth for filtering

equipment, and screens. It is employed to line pulp bleaching equipment in chlorine dioxide environments. It has been used in centrifuges, condensers, filter presses and heat exchangers where corrosion is a problem. In the electroplating industry, titanium has been found to be excellent for anodizing racks. It is used in prosthetic devices because there is no reaction between titanium and fleshy tissues or bones.

A list of the potential applications for titanium is lengthy because the combination of its high strength, low density and excellent corrosion resistance creates a multitude of uses. However, the high cost of titanium (\$20/pound for mill products) has precluded its use in many applications. Continued decrease in price to a competitive level with other metals would ensure that large quantities of titanium would be used in transportation equipment other than aircrafts, such as automobiles, trucks, buses, railroads and ships.

Titanium is the ninth most abundant mineral, exceeded only by oxygen, silicon, aluminum, iron, calcium, magnesium, sodium and potassium. It is known to exist in approximately 98% of all rocks and occurs in practically all sand, clay, and other soils. It has also been found in oil, coal, natural waters, vegetation, animal flesh and bones, volcanic ash, deep-sea dredgings, meteorites and stars. However, despite this widespread distribution there are numerous deposits of highly concentrated titanium minerals readily accessible and easily mined. Of the many minerals which contain titanium, only two are of prime commercial importance: ilmenite and rutile. Ilmenite, the more abundant of the two minerals, is a combined iron-titanium oxide usually expressed as iron titanate ($\text{FeO} \cdot \text{TiO}_2$) although its composition varies considerably. Ilmenite contains about 32 percent titanium and 37 percent iron. Ilmenite occurs frequently with hematite and magnetite (iron bearing ores) in rock formations and in sand in beaches and rivers. Rutile, which in pure form is titanium dioxide (TiO_2), is richer in titanium content than ilmenite but is generally diluted with other minerals either in rock formations or beach and river sand. Known deposits of rutile are not so extensive as ilmenite.

Important sources of titanium ore in North America are the Allard lake district of eastern Quebec; Sanford lake, N.Y.; Iron

Mountain, Wyoming; and Pablo Beach, Florida. Of these, the Allard lake district contains the largest known ore reserve. There, two large high-grade deposits are estimated to contain many hundreds of millions of tons of ore.

Titanium ores are also abundant in Australia, Brazil, India, the Malay States, Norway, Russia, Sweden, Finland, Portugal as well as in various places in Africa. Travancore, India, is one of the major sources of titanium ores because of its high TiO_2 content, and much of the titanium ores imported by the United States for production of titanium dioxide pigments comes from India.

The most important compound of titanium from the point of view of consumption is TiO_2 , which is used extensively in the pigments industry because of its excellent hiding power or opacity. Titanium dioxide, a pure white compound having high reflectivity, is ideal for use in white paints, enamels and lacquers and can be used in conjunction with other pigment compounds in colored paints. It is also used in pigments for rubber, paper, oilcloth, leather, textiles, inks, and cosmetics. Titanium dioxide is produced from rutile or ilmenite by dissolving the ore in a sulfuric acid solution and precipitating the iron compounds. The solution is then hydrolyzed, producing a hydrous titanium oxide, which is washed and calcined.

Titanium tetrachloride, the raw material for producing titanium metal, is the next important compound. It is produced by chlorinating TiO_2 or titanium ores in the presence of carbon. The minor amounts of iron, silicon oxygen and other impurities present after chlorination are removed by fractional distillation. Other important uses for titanium tetrachloride are as a catalyst in many chemical reactions and as a smoke-producing compound for sky-writing or smoke screens. Titanium carbide, a compound produced by reacting carbon with a titanium compound, is used in conjunction with tungsten carbide in cutting tools and dies.

FERTILIZERS

How to accelerate the economic growth of the developing countries is one of today's most urgent problems. One of the

obstacles is the failure of food production to keep pace with the population explosion. Indeed, preliminary estimates for 1965/1966 indicated that the per capita food production in the developing regions had declined to the 1957/1958 level which was equivalent to the inadequate pre-World War II level. Food output can be increased by at least 50 percent (under the conditions prevailing in many developing countries) through the application of fertilizers even without the use of other inputs. Thus greater and more and more careful use of fertilizers comprises the best prospect for a country with a rapidly growing population which cannot increase the amount of land available for agriculture.

The population increase in the period 1960-2000 will be as great as the total growth throughout previous recorded history. This is true because of the success of current measures to improve man's health and well-being, and also the failure of present population control measures to retard the birth rate sufficiently to reduce the growth rate of world population. Population growth rates are, on the whole, higher in the world's developing areas.

Future world food needs will be affected by two salient factors: population growth and rate of economic development. Among the various estimates which have been developed pertaining to future food requirements F.A.O. has concluded that the world's food supply would have to be doubled between 1960 and 1980 to meet reasonably adequate levels of nutrition. This will require an annual rate of increase in food production of 3.5 percent throughout the period. But if the population of the world's developing areas expands to the predicted three billion persons by the year 2000, these areas would, of necessity, have to develop an additional food production capacity equal to current production throughout the world.

The main hope in achieving rapid growth in food production lies in increasing crop yields on land already under cultivation. Existing levels of crop production are generally low in the developing countries where there is the greatest urgency to increase the food supply. In 1960-1962, wheat yields reported in Algeria, Pakistan, and Argentina averaged 6.0, 8.1, and 11.2 hundred kilograms per hectare compared with 16.1, 35.6, and 43.0 in the

United States, the United Kingdom, and the Netherlands respectively. At the same time rice yields in the Philippines and India averaged 11.8 and 15.2 hundred kilograms per hectare, while those in the United States and Japan were 38.3 and 47.8, respectively.

The increase in crop yields in the technologically advanced countries has been accomplished by the increased use of fertilizers. Almost one-half of the yield increase in the United States between 1940 and 1955 has been attributed to the increased use of fertilizers.

The decision to produce or import fertilizers will be affected by the availability of local and external sources of low cost raw materials and other inputs required by the fertilizer industry. While the potash and phosphorus manufacturing processes entail raw materials, nitrogen fertilizers are generally based upon the complex and costly production of ammonia. Modern methods encompass fixing nitrogen from the air and combining it with hydrogen to form ammonia, which required a sizable electric power supply or other energy sources.

It has been suggested that regional cooperation among countries be projected as an efficient means of promoting economic development in those regions of the world whose national markets are so small that the cost of domestic manufacture of fertilizers becomes burdensome. Countries adopting a plan of joint development of fertilizer projects would experience the economic problems typical of the construction and operation of a large-scale venture. There would, though, be a reduction not only in unit cost but also in total capital investment.

Importance of Fertilizers. In considering the importance of fertilizers in production and consumption in the developing countries, emphasis is placed upon three plant nutrients: nitrogen, phosphorous, and potassium.

The present outlook for the world food situation implies that food demand will rise faster than food supply in the developing countries for a substantial period into the future. If the F.A.O. nutritional targets are considered (which are based upon present medical knowledge of physiological needs), meeting its minimum would require an increase of 26 percent in total food supply per

capita over the average 1962-64 level in the developing countries as a whole, which, disregarding future possible changes in population growth, would not be possible until 1996.

Since developing countries have, in the period of the last twenty years or so, considerably reduced the margin between the cultivated area and the total area of suitable land that could be brought under cultivation without injections of heavy capital investment, future progress in production will occur only by more frequent crops and by increasing yield per acre or hectare. Whichever method is employed, fertilizers will have to perform a leading role in increasing agricultural production. Except where very high quality soils and limited time periods prevail, more frequent cropping, reducing the time that land is permitted to lie fallow, and sustained increases in yield per hectare of crop, demand increasing applications of fertilizer. Water as well as fertilizers is important during the growing period. Experiments have shown that where water and fertilizers are combined, the yield response of the crops may be much higher than in cases where additives are applied alone.

Consumption of fertilizers by developing countries has grown at a rate of 12-13 percent per year and reached almost 15 percent in 1965-66. Estimates indicate that by 1980 the developing countries' share will reach one-third. However, even this demand will be insufficient when compared with need. Moreover, farmers will have to be allowed to purchase fertilizers on credit, if necessary, and they will have to find a market with the assurance of a fair price for their increased population.

Developing countries will continue to be sizable fertilizer users in the future. While net imports of nitrogenous fertilizers will increase less than the average, potash imports will rise rapidly. More than half of the 40 million tons of fertilizer nutrients consumed in 1980 by the developing world will be covered by imports. At the same time, the high proportion of imports to satisfy fertilizer consumption in developing countries and also the considerable proportion of imported raw materials in local fertilizer production by 1980 could require foreign exchange expenditures of 7 billion dollars per year. While fertilizer production in developing countries is generally more expensive

than the import of fertilizers, local production makes less demand upon international finance. However, in terms of foreign exchange, fertilizer imports are much more desirable than grain imports.

By 1965-66, world production of fertilizer had more than doubled over its 1956-57 level, up to 48.4 million tons. However, consumption was a bit below this figure because of losses in fertilizer transport. In 1955-56, developing countries produced 6.0 percent of the world fertilizer total and consumed 10.6 percent. By 1965-66, production had risen to 8.1 percent and consumption to 14.6 percent respectively. World production of commercial fertilizers in the 1967-68 crop year is estimated at 57.7 million tons, up 8.1 percent over the previous year, and according to F.A.O., consumption rose an estimated 8.3 percent to 55 million tons for the same period. The output of nitrogen was estimated at 25 million tons: an increase of 12.1 percent over 1966-67. Production of phosphoric acid, estimated at 17.5 million tons, was up 5.4 percent, while potash production rose by 4.8 percent to an estimated 15.2 million tons. Europe continued to be the heaviest user of fertilizers, with a consumption of some 137 kilograms of all fertilizer nutrients per hectare of arable land.

Asia's fertilizer production in the developing world has risen sharply in the last ten years. Eight countries in Asia produce nitrogen, two of which, India and Taiwan, produce more than 60 percent of the total. (Three of the seven countries in Latin America which produce nitrogen, produce the bulk, and similarly one of the four European producers, produces more than half.) The same concentration may be observed in phosphate and potash production. The total of Asian potash production comes from Israel. Today, there is no production of potash in Africa.

Developing countries which produce an excess of fertilizers, export their surpluses almost completely to developed countries; there is thus little trade between developing countries. Net imports of phosphate and potash fertilizers are three and four times greater than in 1955-56. While the share of nitrogenous fertilizer imports in total consumption declined from more than 76 percent in 1955-56 to 54 percent in 1965-66, the share of trade in covering

total consumption of phosphates and potash fertilizers has increased. Moreover, the development of bulk shipping appears to have affected the consumption increase. While in Asia, the growth rate for phosphates was higher than that for potash, in the world as a whole, there has been a faster rate of growth in potash demand. However, nitrogen predominates in fertilizer consumption in many developing countries.

It is estimated that by 1970 total world consumption of fertilizer will range between 53.3 – 65.5 million tons, and in 1980 between 89.7 – 108 million tons. These estimates are, of course, heavily influenced by population projections, political stability, availability of foreign exchange, and government policies. Naturally, an overall yield relationship is assumed between fertilizer use and additional food production. Estimates of future fertilizer consumption by developing countries excluding less developed Europe, include a figure of between 9.2 – 11.2 million tons in 1970 and 27 – 38 million tons in 1980.

Rated capacity in developing countries for the production of fertilizers amounted to 5.5 million tons of nutrient in 1965 or approximately 9.8 percent of the world total. The world production capacity by 1970 may reach approximately 90 million tons of nutrients of which 14.3 million tons would be located in developing countries (15.9 percent). With respect to the components of this figure, nitrogen capacity would roughly treble, phosphate capacity would increase two and a half times, and potash capacity nearly three and a half times.

Rated capacity possesses two defects as an indication of practical production possibilities. Plants which are located in the developing world cannot expect to have a sustained rate of operation compared with plants in the developed world since it is more difficult to manage these plants efficiently, the sources of spare parts are remote, engineering ability may vary in quality, and greater organizational and transportation problems are present. Moreover, approximately three years are required to bring a new plant up to its sustained level of operation.

Nitrogen Fertilizer. Ammonia is the basic intermediate product required in the production of nitrogenous fertilizers. It is synthetically produced from a hydrogen source and the nitrogen

in the air. Hydrogen sources are easily available all over the world since they are found locally either as natural gas or produced as a by-product from such processing fuels as naphtha or refinery gases at refinery sites. Production of ammonia is very capital-intensive and subject to important economies of scale, even at such large unit sizes as 1,000 or more tons per day. Seaborne transportation of ammonia is on the rise and expected to increase rapidly in the coming years as trade increases and the size of ammonia tankers increases. Thus new ammonia plants will tend to be very large in size, located at close proximity to cheap sources of natural gas, the cheapest hydrogen source of ammonia.

Considerable sources of natural gas are to be found in the developing

Considerable sources of natural gas are to be found in the developing countries, particularly in the Caribbean, the Middle East, southern Latin America, Nigeria, and the Far East. Refined techniques of transporting liquefied natural gas are tending to challenge the present advantage of producing ammonia at the source of natural gas. Naphta supplies are more limited since other consumers compete for its use. Its availability is affected by the breakdown of consumption between heavy and light products, the nature of the crude oil input, and the existence of a petrochemical industry. Furthermore, refineries in developing countries seldom produce enough naphtha to feed very large ammonia plants. The fact that the ammonia plants are subject to very significant economies of scale, has led to the establishment of a number of plants of very large size. However, technical problems in running these very large ammonia plants have still not been fully overcome. Their operation is extremely complex, and these large plants have experienced serious difficulties in working up to capacity.

Phosphate Fertilizer. While basic slag, a by-product of steel production, is used as a phosphate fertilizer, the only source of phosphorus for fertilizer production is phosphate rock. While deposits of phosphate rock are found in many parts of the world, economical mining requires an output of approximately 500,000 tons per year. Thus mineable phosphate deposits in developing countries are operated only in North Africa, West Africa (Senegal

and Togo), in the Pacific Islands, and the Middle East – producing one-thirds of the total world output.

Phosphate Rock Mining Capacity in 1970

	(in millions of tons)
U.S.A.	38.0
U.S.S.R.	25.0
North Africa	24.5
Others (mainly Oceania and West Africa)	9.5
Total	97.0

Source: Supply and Demand: Prospects for Fertilizers in Developing Countries, OECD, 1968.

World seaborne trade in phosphate rock is sizable, amounting to 26.2 million tons in 1965 as compared with 70.3 million tons for grain shipments. While single-super-phosphate contains approximately 18 – 21 percent of the active ingredient, making it more economical to ship enriched rock, triple-super-phosphate which contains 46 percent of the active ingredient is coming more into use, creating an advantage for producing the fertilizer at or near the mine. World reserves of phosphate rock deposits are reported to be close to 72 billion tons, of which one to two-thirds is considered to be economically mineable. In 1966, production reached 72 million tons (U.S.A. – 31 million tons). On the export side, Morocco is the world's biggest single exporter of phosphate rock. An outstanding new development is the report of large reserves of phosphate rock in the Spanish Sahara (the second largest in the world). Plans are already underway to produce 3 million tons a year, rising to 10 million tons in seven years.

The other principal raw material essential in the treatment of phosphate rock is sulphur, in the form of sulphuric acid. Nearly half of the world's total sulphur production is used by the fertilizer industry. Restricted sources of cheap sulphur should tend to keep prices up which, in turn, should hasten the trend towards elemental phosphorus production by means of the electric furnace

process (relying upon cheap electric power) and also the treatment of phosphate rock by means of nitric acid. The latter process may be more economical in the production of complex fertilizers as it requires much less sulphur. When a cheaper process is perfected for purifying heating oils, an enormous source of sulphur will become available.

Potash Fertilizer. Potash fertilizer is an adjunct of potash salt deposits which are even more narrowly restricted in locale than phosphate rock mines. Spain and Israel, alone of the developing countries, produce this element with small quantities coming from Chile and Peru. While by 1970, Jordan, Congo (Brazzaville), Ethiopia, Morocco, and West Pakistan are likely to have some potash capacity, the total for all of these countries will not amount to much over 10 percent of total world capacity. As potash fertilizers require only a relatively minor amount of processing at the mine, they will continue to occupy a prominent place in international trade. The main suppliers, at the moment, are France, Germany, the U.S.S.R. and the U.S.A. Low-cost mines in Canada, now in production, affect trade patterns.

Estimated World Reserves of Soluble Potash Materials

Countries	(in millions of tons of K ₂ O)	Reported Reserves
U.S.S.R.		15,800 – 18,300
Canada		15,800
East Germany		12,700
German Fed. Rep.		18,000
France		280 – 360
Israel and Jordan (Dead Sea)		1,800
Spain		250 – 460
United States		380
United Kingdom		130

Source: United States Bureau of Mines

Apart from the Dead Sea area, potash deposits exist in developing countries including the Congo (Brassavill), which ought to be going into production at the end of 1968, Ethiopia, which is likely to develop a potash industry in the very near future, and West Pakistan, where a mineable deposit has just been discovered. The size of the reserves in Pakistan and Ethiopia has not yet been assessed but is reported to be higher than 30 million tons of ore in each case. In the Congo, production is based on a mining concession which contains 50 million tons of mineable sylvinite ore. Further research is being done at the moment, and the Congo reserves are supposed to be considerably larger. Production will start at 500,000 tons of potash per year.

While the production of salt from sea water and inland salt lakes by means of solar evaporation in shallow pans made of consolidated clay is an ancient practice in the arid and semi-arid regions of the world, it is only since 1932 that potash has been so manufactured from the brine of the Dead Sea. The current cost of this production in Israel is approximately 20 dollars per ton containing 60 percent potash. It is expected that when anticipated production reaches one million tons per year, the cost will be lowered to approximately 14 dollars per ton.

In Jordan, the Arab Potash Company has a concession covering one half of the southern end of the Dead Sea — 100 km.² in area, capable of producing 420,000 to 600,000 tons of potash annually. The process is similar to that utilized by the Dead Sea Works in Israel, and the cost of production will, according to estimates, be the same.

Chile and the United States also employ the solar evaporation method of producing potash. However, where potash occurs as a solid deposit below the surface of the earth, the process utilized is that of mining these underground deposits. This system is used in Canada, Germany, France, and New Mexico (U.S.A.). There, coal mining methods are employed. While it is usual to recover approximately 60 percent of the deposit, ultimate recovery can be increased to 90 percent by removing the pillars at the final stage of mine operation. The cost of these mining operations mainly depends upon the following: the depth of the deposit beneath the surface; the nature of underground formations to be traversed; the

thickness of the potash deposits; the location and remoteness of the site.

Since mining development costs can be written off as a percentage of the ore mined over a period of years, large development costs reflect only a small portion of the cost of the ore. Use of modern machinery also serves to minimize labor costs. In Carlsbad, New Mexico, where the average ore analysis is 18 percent potash and ore cost at the mine mouth including tax, royalties, and other costs, bring the totals in approximately \$2.20 per ton of ore, the cost of ore required for one ton of product (60 percent potash) amounts to approximately \$8.10. In Saskatchewan, Canada, where the ore analysis indicates 26 percent potash, the ore cost amounts to \$6.80 per ton of product.

Solution mining is also utilized in Canada for the recovery of potash at depths which are impractical for mining by conventional shaft methods. Here water is pumped into the solid potash deposit by means of drilled holes. This water dissolves the potash, and the solution is forced to the surface from which the potash may be recovered by means of concentration and crystallization. Recently, it has been deemed fortuitous to inject a blanket of natural gas over the potassium chloride deposit to prevent excessive dissolution of the covering sodium chloride layer to maintain the relative purity of the potash solution.

The investment for the crystallization process is approximately 30 percent larger than for the flotation process. The significant difference in the cost of production (\$17.37 per ton as compared with \$15.61 per ton) is caused by high utilities requirements for the crystallization process and great fixed costs. In Canada, the cost of production by the flotation process is lower (\$14.26 per ton) because the potash content of the ore is greater, although the Canadian investment is larger. The cost of production of muriate of potash by solar evaporation assuming no cost for raw materials, is \$10.50, and adding fixed costs, the total cost amounts to \$20.04 per ton which is \$4 to \$6 per ton higher than potash produced in Saskatchewan, Canada, or Carlsbad, New Mexico.

To fully exploit potash production in developing countries, costs must be kept low and competitive particularly in those areas such as Israel and Jordan where potential internal consumption is

not very large. In exporting to the Middle and Far East, these nations must base their cost computations upon the necessity to compete with the vast resources and low prices of the Canadian product. If royalties, profits, and freight costs to the Middle East are added to the estimated production cost of \$15 per ton for Saskatchewan potash, the price at a Middle Eastern point can be anticipated at not more than \$25 to \$28 per ton. Thus competitors in developing countries would be well advised to hold their cost of production to the lowest possible level and to immediately initiate steps leading to the progressive reduction of all costs. Such measure should include:

- a. reducing capital requirements for potash products as much as possible by reducing infrastructure and other costs or allocating them to some other account
- b. increasing the capacity for production to the maximum extent possible
- c. utilizing by-products and co-products
- d. developing bulk handling facilities for moving raw materials as well as finished products
- e. designing processing plants in an integrated manner and providing facilities for future expansion with minimum costs
- f. taking all essential steps to attain full capacity rapidly; keeping production at full capacity by employing competent personnel, providing adequate exchange funds, and assuring sufficient raw materials, adequate utilities, and product sales

Location of Fertilizer Plants. The fertilizer is worldwide in scope and is becoming increasingly complex. The increase in world fertilizer needs by 1980 (70 million tons) will entail an estimated future outlay of approximately \$7 billion for new fertilizer plants. The location of these plants is, of course, extremely important to the developing countries both as producers and consumers.

The transportation factor is usually dominant in the location of primary fertilizer plants, particularly with respect to raw material supplies, and to a lesser extent delivered costs of products to secondary producers, lenders, and/or distributors. The effect of

transportation costs plus loading, unloading, and port charges can be seen from the fact that the ex-mine costs of phosphate rock can be less than one-half the delivered cost to producers located overseas. Therefore, it must be stressed that it is no less important to secure the lowest cost transportation and improvements in bulk shipping and cargo handling them to press for greater skill in production and new developments in process technology.

Transportation factors, with respect to finished goods, are also of considerable significance in determining the optimum location of a primary fertilizer producer. The impact of lower delivery costs to consumers, on the part of competitors, renders it imperative that the selection of a location be made which allows minimum cost deliveries, emphasizing also reliability and efficiency. Bulk shipments and deliveries are thus assuming increasing importance.

Power costs are also a factor in location. In those areas of the world where ample hydroelectric energy is available, power costs may be reckoned as low as three mills per kwh; whereas in countries dependent upon imported fossil fuels, the local power rate may be between 10-20 mills/kwh. For example, an ammonia plant might require about 700 kwh/ton of product. Thus, the availability of low cost power is definitely a positive factor in plant location of processes with appreciable net energy requirements.

Water availability is also a salient factor in plant location. Adequate supplies are required for process needs, cooling, power and other purposes. Where fresh water supplies are insufficient, sea water is frequently utilized for cooling purposes. Water for process requirements, boiler feed, and human consumption necessitates relatively high purity standards which, if fresh water supplies are inadequate, can be obtained through ion exchange, condensate recover, or steam distillation. Skilled process design frequently permits considerable economies to be achieved in process water requirements which often amount to a fraction of cooling water needs. In ammonia manufacture, approximately 50,000 gallons of water per ton of ammonia could be specified for cooling purposes as compared with 10,000 gallons of condensation for re-use in the boiler or other parts of the plant.

This year, on the one hundredth anniversary of the gala opening of the Suez Canal, one finds the venerable waterway in the third year of its second closing engendered by military activities. The history of the building of the Canal was accompanied by a constant refrain consisting of conflict and intrigue on the part of England and France. The English were, at the same time, masters of an overland route, and had built a railroad from Alexandria to Suez to assist them in their communications network with India. The French decision to finance a canal across the Isthmus of Suez appeared to pose a direct threat to England's unshared hegemony over India.

Ferdinand de Lesseps' original approaches to the Egyptian government of Mohammed Ali were doomed to failure as the Khedive refused to grant him a concession for the excavation of a canal across the Isthmus on the grounds that the creation of such an international waterway would perpetually endanger Egyptian independence. Later, when the Canal had been constructed and opened to international shipping through the initiative and financial backing of the French, the English came to realize just how essential such a Canal could be for guarding their imperial interests in India and East Africa. In 1875, England eagerly seized an opportunity to purchase 44 percent of the stock in the Suez Canal which the Khedive Ismail Pasha was interested in selling. England achieved status and standing on the Board of Directors of the French Suez Canal. England gradually widened her control over Egypt and the Canal District, eventually forging a protectorate, and, in 1914 with the outbreak of the First World War, virtually became the government, basing her decision for this act on the

need to protect the interests of her allies and the precious route to India.

In 1952 the revolt of the "Young Officers" occurred, and Egypt was declared a republic. The influence of England over Egypt was brought to an end in 1954, and by 1956 the last British soldiers left the Suez Zone. In that same year, Egypt nationalized the Suez Canal, terminating the conditions of the concession twelve years before the expiration date.

In October 1956, in an attempt to reassert control over the Canal, the armed forces of England and France entered the Sinai Zone while, at the same time, Israeli units penetrated the Sinai Desert. This military episode failed. Counter-diplomatic measures by other interested powers in the United Nations served to arouse great anxiety on the part of President Eisenhower and his advisers informing him that the conflagration would become uncontrollable. Pressures were thus brought upon the British, French and Israelis to withdraw from the Canal Zone. While this end was being implemented, the Canal, itself, was closed to shipping for six months.

From this time on, the Egyptians became the undisputed rulers of the Canal's destiny. They proceeded to put into operation the development plans of the former Canal company, deepening and widening the canal to meet the demands of modern commerce. (The Company had executed seven development plans from the inception of the Canal, and had just begun to implement the eighth plan, before the 1956 closing.)

It is interesting to note here that the width of the Canal on its opening day one hundred years ago was 22 meters; its depth — 8 meters. It was capable of accommodating boats up to 1700 tons (dwt) but in the pending "Nasser Plan" for the Canal's development, an attempt was to be made to provide for the accommodation of oil tankers larger than 70,000 tons, and according to the needs of the times to continue to deepen and widen the path which, in 1967, had a length of 107 miles, a maximum depth of 50 feet, and a maximum width of 660 feet, with a minimum width of 600 feet. Approximately 21,000 vessels crossed the Canal in 1966, carrying a total load of approximately 247 million tons. The Egyptian Canal management carried out their

tasks efficiently, and repaired and maintained services to the ultimate satisfaction of the users, so that international shipping operated smoothly, without interruptions and disturbances. The single exception was that all vessels flying the Israeli flag were prohibited from using what had hitherto been an international waterway.

The income of the Canal grew from year to year and was the most important source of foreign currency for Egypt except for the proceeds from cotton exports which are the greatest single Egyptian source of funds. Indeed, in 1966, receipts from Canal crossings totalled approximately \$227 million, with another \$80-\$90 million being received as income from auxiliary Canal services.

A consequence of the 1954 Egyptian "Young Officers" revolt was that eventually Nasser gained control and established a nationalized economic system. Large scaled projects were initiated such as the construction of the Aswan High Dam which supplies great quantities of electricity at cheap prices, allowing for an increase in acreage of irrigation areas to promote successful agricultural settlement; the construction of a great steel complex; the erection of fertilizer factories; the granting of permits to search for oil in the Sinai Desert, the Bay of Suez, and the Western Desert; and many other development enterprises. In addition, Egypt aspired to leadership of the Arab world. In the process, she created the largest and most thoroughly equipped and drilled army among her sister states. The almost limitless quantities of the newest and most modern equipment at her disposal were provided through the generosity and goodwill of the Soviet Union, which at least enabled her to bring to fruition a centuries-long dream.

President Nasser himself was at the height of his influence both in Egypt and in the entire Arab world, and was a prominent leader of the Third World camp of unaffiliated nations. He succeeded in maintaining his independence through political maneuvering between the Eastern Bloc and the Western Nations, leaning sometimes to the right and sometimes to the left, but always actually pledging little. Although his many stratagems were flexible over a broad range, he was a prisoner of his "anointed mission" continuously waged against the existence of the state of Israel, his northern neighbor.

On May 23, 1967, President Nasser ordered the closing of the Straits of Tiran to Israeli-bound vessels, thus declaring a sea blockade of the Bay of Eilat. At the same time, he continued to deploy his armed forces into the Sinai Desert on a vast scale and up to the border of Israel.

On the sixth of June, the Israelis reacted sharply to this Egyptian show of force, overrunning the Sinai Desert and occupying the vantage points along the Straits of Tiran. On 10 June, they reached the Eastern shore of the Suez Canal and established themselves along its length. Since that time, a matter of some three years, the Canal has been closed to navigation. International shipping has been forced to resort to rerouting around the Cape of Good Hope, the ancient sealane in use before the Suez Canal was constructed.

On the hundredth anniversary of the Canal, the political struggle of the great Powers over influence and control of the Canal has once more been renewed, and Egypt's fate is indissolubly linked to its ultimate decision. During her twelve-year reign over the Canal, Egypt gained sufficient experience, it would appear, to enable her to succeed in reopening the Canal to international shipping. If the destiny of the Canal, however, is decided by an agreement between the Great Powers, it is almost impossible to avoid the conclusion that the net result would be some sort of Foreign Protectorate. The Canal has not ceased to be the most important international sea passage between Europe and East Africa and the Far East, and the users, both from the west and the east, prefer and wish her to be free.

To appreciate this fact, one need only examine the effects which ensued after each closing of the Canal. The 1956 closing occasioned serious repercussions in England which was at that time entirely dependent for her oil supply on sources east of Suez. Consequently, she hastened to expedite her program to develop atomic energy centers to produce electricity in order to reduce dependence upon non-domestic sources of energy. The remainder of the Western European countries followed in her footsteps. The closing also hastened the development of the American Plowshare program to exploit atomic energy to execute civil engineering projects. One of its intentions was to propose the excavation of a

canal parallel to the Suez Canal through Israeli territory, constructed with the assistance of nuclear energy. The Plowshare experts considered that construction of such a canal would be cheaper and more time-saving.

The second and continued closing of the Suez Canal greatly accelerated the building of supertankers (200,000 – 300,000 tons) to carry oil, and even larger tankers are now in the offering for the purpose of conveying oil from the Persian Gulf around the Cape of Good Hope to Western Europe and the Mediterranean Sea. In addition, the demand for Libyan oil, found west of Suez, is continually increasing, and there is no reason to prevent Libya from becoming one of Europe's principal suppliers.

Thus, voices are heard who claim that the importance of the Suez Canal to international shipping is declining, and apparently the day is drawing near when minerals and raw materials will be transported by huge bulk carriers whose size will prevent passage through the Suez Canal, and manufactured products will be carried by faster container ships which will allow for considerable economies even in the long journey around the Cape of Good Hope. Other voices have been heard who maintain that it is possible to ship to Africa and the Far East without any canal, and that the Suez Canal is destined to the fate of the ancient canals of Ptolemy II, Darius I, and Senusret III, which were eventually buried under the shifting sands. One must anticipate that when many and varying voices express a multitude of diverse opinions, such a radical view will also make itself heard.

The fact must not be avoided that the Canal was closed because of political complications and an act of war, and not as a result of a reduction in shipping cargoes carried or as a natural conclusion to fall in volume because of the discovery of a new, more convenient shipping route. Without a shadow of doubt, if the Canal reopens and shipping is resumed, the world will breathe more easily.

All the nations who need the Canal have suffered serious losses, according to the amount of business that they conducted either to the east or west. The trade of the East African nations was seriously affected, as was that of India, Pakistan, Italy, and the other Mediterranean nations. England and Northern Europe, more-

over, are also paying a price, but these countries are compensated by the full employment of their shipyards, having at one time been presented with a golden opportunity to develop and/or rehabilitate a previously languishing industry. Everyone is paying more for gasoline since the number of supertankers that carry oil cheaply around the Cape of Good Hope is still too small. Of the thousands of tankers in use carrying oil all over the world, approximately 300 are over the 70,000 ton size, thus making the long haul around the Cape to East Africa economical.

Approximately 85 percent of the tankers are too small to make a profitable trip around the Cape, and transportation is generally costly. Fertilizers are still not being carried by giant bulk carriers, and neither are minerals nor much wheat, rice, and manufactured goods. While there is a tendency to increase the volume of bulk carriers, the planned size will still be capable of passing through the Suez Canal. Containers, moreover, are constructed on the principle of loading and unloading at maximum speed on a speedy voyage. Their efficiency will rise if they sail via the shortest route, and that includes the Canal crossing.

It is interesting to note the history of the plans to deepen and widen the Canal. It has always been obvious to the Egyptian Suez Canal Authority that they must develop plans to change the physical structure of the Canal to keep pace with the ever increasing size of those ships which might utilize the Canal facilities. When it became apparent that super-tankers were no longer an engineer's drawing-board dream but a reality, the Canal Authority accepted plans before the 1967 war to deepen and widen the Canal. The plans suggested that the Canal be renovated in two stages: the first stage was scheduled to give a draft of 48 feet allowing tankers of 125,000 tons to pass through loaded, and 200,000 to 250,000 ton tankers to pass through in ballast. The second stage, which was scheduled to be completed in 1976, aimed at a 60 foot draft, would significantly change the Canal to allow 250,000 tankers to pass through loaded and in ballast, based on the assumption that the size of tankers has reached a plateau in the 175 – 200,000 dwt. range.

During 1967 it became obvious that the two-stage project should be telescoped into a single project which would take five

years to complete. It was first estimated that this five year project would cost 400 million dollars. However Stephen Longrigg in *Oil in the Middle East* estimates that the cost to deepen the Canal only one foot along its length would be 10 million pounds sterling. The over-all cost then must be re-estimated. Whatever the cost might be, it is all too obvious to the Egyptians that outside funds must be solicited to begin any project.

Any funds will be further moving. First, the World Bank has accepted the project and is willing to loan the Egyptians forty to fifty percent of the foreign exchange capital needed to begin the renovation process. Second, the oil companies might be encouraged to foot part of the bill, even though these same oil companies encourage the construction of the super-tankers. Third, the oil states in the Persian Gulf can be counted on to provide part of the capital outlay. Thus there is a need to reshape the Canal. It is in the interest of both Egypt and the users of the Canal to reshape the waterway, and because of these motivations, there will be funds available to realize the plans.

The expected load of the Suez Canal is not conditioned by the size of oil tankers or by finding an energy alternative to oil such as nuclear energy or by the discovery of new sources of oil west of Suez. The truth of the matter is that the Mediterranean Basin demands a natural outlet to the Red Sea and the Indian Ocean. What is required is not a shallow waterway but a broad, deep crossing capable of accommodating the most modern vessels. West of Suez are found the industrial nations of western Europe including the Soviet Union. In contrast, east of Suez are found the densely populated nations of Asia whose trade with the Western World is constantly growing, and whose economic ties are becoming more and more interdependent. The industrial nations require vast quantities of energy, and their requirements grow annually both for oil *per se* and for oil as a raw material of chemical industries. In 1966, 180 million tons of oil passed through the Suez Canal in route to the West. In the year 2000, it is expected that Europe will require one billion eight hundred million tons of oil from the Persian Gulf out of a total demand for four billion tons of oil. It may be presumed that the transportation of oil by pipeline to the Mediterranean coast will increase to 200 million

tons per year as compared to 50 million tons today. The tanker fleet will have to transport some one billion six hundred million tons of oil. Most of this oil will pass through the Suez Canal and a part will travel around Africa. Thus, it is expected that the cargo load of the Suez Canal will continue to increase. It is logical to conclude that the Suez Canal Authority will do its utmost to prepare the Canal for the crossing of supertankers with a 200,000 – 250,000 dwt capacity. Estimates indicate that widening and deepening the Canal to the above-mentioned measurements would necessitate a financial investment of approximately one billion dollars.

If one could find a suitable topographical path to excavate a canal parallel to the Suez Canal on the east bank, in the Sinai Desert, but yet at a distance of some tens of kilometers in order to facilitate the operation by employing atomic energy explosives and to accomplish all this without disturbing orderly navigational operations in the present Canal, then it would be possible to excavate a wider and deeper canal for the crossing of larger vessels at the same financial investment required for improving the Suez Canal. But as luck would have it, the alternative route in Sinai is too close to the present canal, and using nuclear energy is likely to have a limited value in cutting only those short sections which are at a safe distance from the present Canal and the settlements along its banks. It is, therefore, apparent that this alternative is neither practical nor economical.

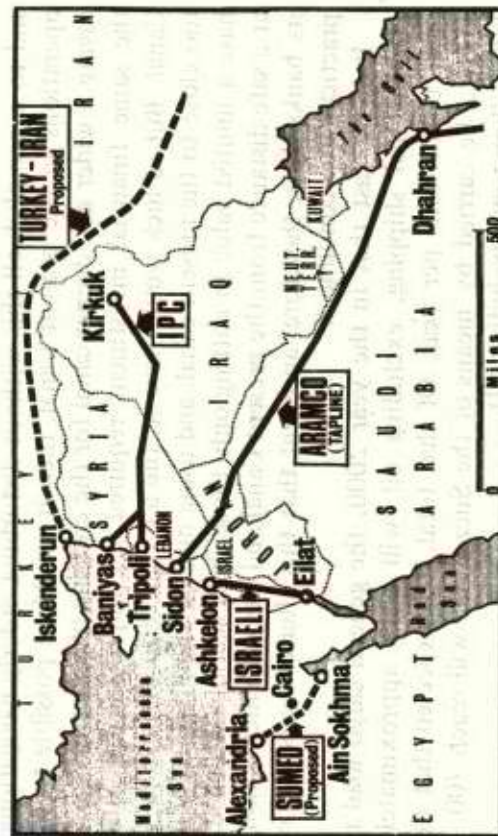
It is forecast that in the year 2000, the general cargo load in international shipping, excluding oil, will reach approximately eight billion tons per year. Of that total, it is expected that the load to be carried by means of the Suez Canal will reach 700 – 800 million tons (excluding oil).

The pressures for transporting cargo via sea routes will thus exceed the permitted capacity of the Canal even if it can receive 250,000 ton ships. In the twenty-first century, there will then be a need to evacuate a parallel canal to relieve the burden of the tremendous cargo load to be transported by sea in an exchange of trade between the post industrial societies of the West and the teeming population of over four billion persons east of Suez, in the Asian countries and East Africa, all of whose economies are in

a constant process of increasing production and consumption by fantastic proportions. If energy consumption is adopted as a standard of measuring economic activity, it has been estimated that, at the beginning of the third millennium, the world will require 21 billion tons (oe).

The proposed new sealane, it is expected, will principally transport required energy to the western industrial nations, in addition to vast quantities of fertilizers, raw materials, and finished industrial products. It is not visionary to foresee that this sealane will be one of the primary international shipping routes.

Middle East Oil Pipelines



PIPELINES

All the previous proposals are excellent when peace comes; however, in reality, this time is still shrouded in mist since wartime activity continues, and the Suez Canal is not yet open to international shipping. Oil continues to flow to Europe via the long

route around the Cape of Good Hope which extends over some eleven or twelve thousand sea miles as compared with the 4,500 sea mile route which encompasses the Suez crossing. This oil is still carried by the presently available tanker fleet which includes relatively few of the giant supertankers.

The pipeline from Eilat to Ashkelon however is now a *fait accompli*, and its installations are operating. Oil flows through this pipeline along the short and busy traditional route in a combined operation of huge super-tankers on the sea which are connected with a system of pipelines and pumping stations crossing the continental isthmus which separates the Bay of Aqaba from the Mediterranean Sea.

Egypt currently has secured a contract for a pipeline from the Bay of Suez to the Mediterranean Sea, west of Alexandria transverse 207 miles and utilizing 42 inch diameter pipes which will transport 50 million tons of oil per year at a financial investment of 175 million dollars. It has been planned to put such a pipeline into operation by 1972. The Israeli pipeline has a 42 inch gauge; a length of 160 miles; and includes a financial investment of \$113 million. In the first stage, the pipeline will carry 20 million tons of oil per year, and, with the completion of the pumping stations, will reach a full capacity of 60 million tons of oil per year.

Since the Bay of Aqaba is a natural deep water configuration, it is ideally suited to the anchorage of supertankers which are even larger than the present 300,000 tons. Storage will be provided on shore for the vast quantities of oil carried by the tankers. It will be possible through the use of an underground nuclear explosion to provide underground reserve tanks to store huge quantities of oil along the deserted shore of the Bay of Aqaba, prior to transshipment. The oil will flow from Eilat by means of pumping to the sea terminal at Ashkelon, and then will be loaded aboard tankers of varying capacities according to the facility of the ports of delivery. Very few European ports are currently able to accommodate 100,000 and 200,000 ton tankers. This scheme is roughly the process in use by the Gulf Oil Company at Bantry Bay in Ireland. Oil is transported in 300,000 ton tankers from the Persian Gulf to Bantry Bay where it is pumped to storage tanks and then back to smaller tankers to be distributed to the various

increased use of supertankers. Also consider that it is not economically advantageous to deepen and widen the Canal. Now: Is it *a fortiori* wise to develop a sea route around the Arabian peninsula for supertankers and connect this route to a system of pipelines across the Isthmus of Sinai to the Mediterranean Sea? To answer this question, cognizance must be taken of the relative advantages of this new shipping system with that of (a) the Suez Canal alone (whether it is renovated or not) and (b) the exclusive use (for supertankers) of the sea route around the Cape of Good Hope. In the ensuing paragraphs, the conclusion is reached that indeed the Suez Canal will be able to compete for cargo traffic (oil included) against the use of the long sea route and even against the combination of a sea route and pipeline system. That is to say, the Suez Canal will continue to remain an integral part of the world's major shipping routes.

It is to be expected that by 1980, oil exported from the Shickdoms of the Persian Gulf to Europe will reach a volume of 500 million tons per year. To transport this quantity, there will be a need to invest some one billion dollars in a system of pipelines and pumping stations (according to 1968 estimates). By 1990, oil exports to Europe will grow and there will again be a need to invest large sums for additional pipelines and pumping stations. By the year 2000, it will be necessary to transport some one billion eight hundred million tons of oil from the Persian Gulf to Europe. This quantity will require a further financial investment in the neighborhood of four and one-half billion dollars, for enlarging the pumping apparatus and parallel pipelines. These new enlargements would not be the end because after their installation another financial investment is demanded to enlarge the installed capacity of pumps and pipelines all in order to keep up with the constant increase in the size of oil exports from the Persian Gulf to Europe.

As was previously mentioned, an alternative to the massive increase in pipelines is the financial investment of one billion dollars, for the improvement of the Suez Canal in order to accommodate supertankers of 250,000 tons. Such a canal would be able to grant passage to boats with a capacity of 4.5 billion tons per year, of which there would be only two billion tons of oil, and the re-

European ports. (*The Financial Times* of London featured a series of articles on the Bantry Bay operations in the spring of 1968.) The two pipelines Egyptian and Israeli, will be capable of transporting 110 million tons of oil per year after 1975. It is difficult to prophesy just when the Suez Canal will reopen to international shipping, but it is hoped that this even will occur in the near future and that great quantities of oil will be carried by way of the Suez Canal. The cargo will be transported by 70,000 ton tankers, which still predominate in the oil tanker fleet, and whose owners neither intend to put them into drydock nor to sell them for junk.

In the same stage, when one of the planned pipelines began operation, and later when the second pipeline commences activity, it is reasonable to assume that the supertankers (300,000 tons) will prefer the short route around the Arabian peninsula to the oil terminal on the Bay of Aqaba, or the terminal on the Bay of Suez. Here, they can discharge their cargo. The oil will then be pumped to the appropriate terminal on the Mediterranean Coast, and, once more, loaded on medium-sized tankers to be transported via the Mediterranean Sea to their designated ports. For each 300,000 ton tanker which will sail along the short route around the Arabian peninsula, it will be necessary to provide three similar tankers to carry the same annual quantity of oil on the voyage along the long route around the Cape of Good Hope.

Apparently this solution promises to be successful in the long run, and the combination of supertankers and a system of pipelines pumping the Persian and Arabian oil from the Red Sea straits to the Mediterranean ports will render the Suez Canal unessential in terms of transporting oil. To determine if oil should be carried via pipelines and supertankers, the cheapest route must be selected, and thorough studies should be undertaken to reveal if a system of pipelines and supertankers is indeed to be preferred over shipment via the sea. But the fact cannot be denied, however, that the Suez Canal is the most important international shipping lane for carrying dry and bulk cargo.

The concluding paragraphs of this section discuss the following speculation: Consider that using the Suez Canal alone as a means of conveying cargo will become increasingly disadvantageous, either because of the current military situation or because of the

mainder, dry cargo. (It must be noted that oil tankers sail in one direction in ballast.)

Thus, the conclusion must be reached that the Suez Canal will be able to grant passage to quantities of oil and dry cargo expected at the end of the century at less than one-quarter of the financial investment required for additional pipelines to carry the same quantity of oil (excluding dry cargo) as a system of pipelines and pumping stations across an overland continental route between the Gulf of Suez and the Gulf of Aqaba and the Mediterranean Coast. In order to carry one hundred million tons of oil per year through the Suez Canal, there will be a need for 35 supertankers (each a 200,000 tonner) on an average route of nine to thirteen thousand sea miles on a two-way journey as compared with 55 supertankers of 300,000 ton size class around the Cape of Good Hope (a two-way route of 22,000 sea miles). A fleet of 450 tankers, each in the 200,000 ton class would be able to carry a billion tons of oil per year through the Suez Canal.

Toward the end of the century, the Suez Canal will reach the limit of her freight-carrying capacity having exhausted all her slack. At the same time, there will be a demand for a Jordan Rift canal from Aqaba to the Mediterranean Sea. This canal will be capable of accommodating 300,000 ton tankers. Thirty-three tankers, each in the 300,000 ton class, will be able to cross from the Persian Gulf through the new canal to Europe, carrying one hundred million tons of oil per year as compared with 33 tankers, each in the 500,000 ton class, sailing the long route around the Cape of Good Hope. The canal will be able to accommodate three and one-half billion tons of oil and dry cargo per year. The financial investment for pipelines and pumping stations from the Bays of Aqaba and Suez to the Mediterranean Sea to convey the same quantity of oil is five times as expensive as the cost of widening and deepening the Suez Canal, and seven and one-half times as expensive as the expenditure for constructing a navigation canal through the Jordan Rift. The obvious conclusion would appear to be the expansion of the Suez Canal to permit passage of 200,000 – 250,000 ton tankers at the earliest possible opportunity, that is between 1970 – 1980. The pipelines from the Bay of Aqaba and

the Bay of Suez to the Mediterranean Sea, the first of which is in operation, and the second in the planning stage, will simplify the moving of oil during the transition period until the Suez Canal is enlarged.

1956	 Length 660ft Depth 46.2ft Draught 36ft Capacity 31,000	Approx. price per ton \$125
1957	 Length 841.8ft Depth 57ft Draught 43.4ft Capacity 66,000	\$90
1961	 Length 817.8ft Depth 57.6ft Draught 44.9ft Capacity 71,000	\$85
1966	 Length 870ft Depth 66ft Draught 50ft Capacity 119,000	\$98
1968	 Length 1076ft Depth 80ft Draught 62ft Capacity 200,000	\$70
1969	 Length 1122ft Depth 76ft Draught 57.9ft Capacity 300,000	\$67

TANKERS AND CONTAINER SHIPS

The amount of seaborne cargo is continuously increasing at stupendous proportions and will continue to do so in the future. While in 1967 such freight amounted to one billion eight hundred and sixty million tons of bulk cargo per year, of which oil comprised 1050 million tons, it is expected that by the year 2000, it will reach eighteen billion tons. Technological development in the planning and construction of sea-going vessels will resolve the shipping problem. The huge oil cargo to be transported will be handled by the building of supertankers, and less and less labor will be employed in the moving of more and more oil. All the processes involved in transporting oil have now been mechanized. Oil is pumped to the coast and loaded aboard tankers in the same manner. A fleet of tankers, aided by an electronic apparatus including computers, delivers it to the designated, specially equipped ports. Here, the cargo is unloaded by means of the most modern and rapid pumping equipment and delivered to the network of storage tanks on the coast. At this point, the redistribution process begins in order to supply the various consumption centers in the interior, by means of a system of pipes. This co-ordination of pipes, pumps, and tankers in transporting oil insures a swift, smooth run operation.

A very promising development has recently been undertaken in the area of transporting seaborne dry cargo — the employment of containerization. This method entails integration between the movement of freight on land and sea through the use of a single packaging operation, and the development of one mechanical operation to unload and reload aboard vessels, namely, the new, efficient container. While the use of containers is still in the early stage of development, its contribution to the carrying of seaborne cargo is rapidly growing. Another valuable breakthrough is being initiated in the area of bulk carriers where larger volumes are being handled through a mechanical method of unloading and reloading such commodities as iron, manganese, coal, bauxite, alumina, phosphates, and grains. The following pages examine the developments in tankers and container ships.

In 1960 a little more than half of the world's tanker capacity was composed of ships smaller in size than 24,000 deadweight tons (dwt), and few tankers were larger than 40,000 tons. By 1970, it has been estimated that over half of this capacity will be provided by ships larger than 60,000 tons. In 1965 the first 100,000 ton tanker was launched; in 1966 a 210,000 ton tanker cleared the ways; and in the summer of 1968 Japanese shipyards launched a vessel with a capacity of over 300,000 tons. Indeed, a tanker with the capacity of 372,000 dwt will float out of a Japanese yard in 1971.

In 1967 more than 130 tankers above 150,000 tons were on order at various shipyards throughout the world. According to Clarkson's estimates for *The Financial Times* (April 28, 1969) there were forty ships under construction or on firm order in the 150,000 — 200,000 dwt class, 124 in the 200,000 — 250,000 dwt range, and 48 in the 250,000 dwt and above range.

This striking change in tanker capacity was affected by the changing patterns of supply and demand for oil throughout the world. Before World War II, petroleum shipments comprised principally finished products transported primarily from Venezuela and the United States to the world markets, with Western Europe being most important. This situation changed radically as an aftermath of the Second World War. The tremendous increase in global oil consumption during the war (which continued afterwards) turned the United States from an oil exporter to an oil importer and encouraged the most thorough development of major oil fields in the Middle East. Moreover, the War served as a stimulus to the construction of large refinery centers in or near the large market areas of Europe and Japan.

These transformations in the supply and demand area changed oil shipping from the transportation of relatively small batches of a myriad of finished products to large quantities of single quality crude oil to feed the new refining centers, frequently located at long distances from major oil fields of the Persian Gulf. Thus a great demand was created for large size tankers.

At the present time, the three most widely traveled routes for oil run from the Persian Gulf to Western Europe; from the Persian Gulf to Japan; and from the Caribbean Sea to the United States.

In addition, there are a miscellany of other routes. In order to reach European refineries, Persian Gulf oil must either pass through the Suez Canal which cannot accommodate ships over approximately 70,000 tons or it must travel around the Cape of Good Hope which adds 4800 miles and four weeks to the round trip. Shipments to Japan pass through the Straits of Malacca (between the Malaysian Peninsula and the islands of Sumatra) which appear unable to accommodate ships larger than approximately 210,000 tons. Carriers, greater in size, will have to traverse deeper channels in the East Indies, such as the Lombok Strait (between the islands of Balisand Mataram in the lower Indonesian archipelago) which, of course, will add considerable length and time to the eastward voyage.

Thus, because the shipment of oil involves a large quantity of a single quality commodity requiring transportation over vast distances, ship owners and operators, seeking to maintain and raise profits, must search for economies in overall operations, undertake chartering, and simplify management through the espousal of even larger carriers.

In the economies of shipbuilding, the investment required for a ship per unit capacity, i.e., the price of the vessel per ton of payload, decreases as the ship becomes larger. (Indeed, if a value of 100 is arbitrarily assigned to a 100,000 ton tanker on a price index, it would drop to 84, 78, and 74 for similar vessels of 200,000, 300,000 and 500,000 tons respectively.) Similarly, the cost of propelling the ship to and from its destination is affected by size and in a positive manner. According to the standard formula by which the engine output for a ship of given size and speed can be roughly estimated, the power required does not rise directly with vessel size but rather at two-thirds power of size (size in this context being the weight of the whole ship fully loaded, and not simply payload or deadweight tonnage). Again using 100 as the power "index" for a standard ship of 100,000 deadweight tons, the increase in cost rises to 150 and 210 as the deadweight tonnage is doubled and tripled respectively. Therefore, since it is apparent that fuel consumption rises roughly in proportion to engine output and not ship size, the larger vessel has the advantage (assuming constant speed of 16 knots) over smaller ships with

equivalent tonnage. Consequently, a substantial reduction occurs in freight cost per ton of oil delivered. On a cost index of 100, a 100,000 ton tanker, carrying oil from the Persian Gulf 11,000 miles around the Cape of Good Hope to the United Kingdom, reaches 165; for a 300,000 ton tanker, the cost index reaches 108, approximately 35 percent less.

Since few ports have basins sufficient in depth to accommodate the mammoth tankers with their drafts of 65 feet (for 200,000 tonners) and 85 feet (for 300,000 tonners), they have to be moved either in jetties projecting from the shore or to offshore buoys in various ways and the cargo oil pumped on or off through underwater pipelines. The jetty system is particularly adaptable since ship to shore communications are much better; rapid and smooth coupling for the oil lines is easily obtainable, reducing total loading and unloading time considerably. Several ships can be berthed at once.

Moreover, as the deep-draft ships will require re-routing to avoid shallow straits, larger vessels will be required to maintain the break-even point thus encouraging the development of the central terminal station. Here the oil is carried to specially built distribution points instead of directly to the point of delivery. So, for example, oil bound for Japan from the Persian Gulf would be carried in a 300,000 ton tanker to a deep water central terminal station near the mainland of Japan, and then distributed to the mainland in smaller tankers. Possible sites for such a station in the Far East include the Ryuky Islands, Kyushu, and Shilolu.

Oil bound for England would be shipped around the Cape of Good Hope in 300,000 ton tankers to a central station on the Atlantic Coast for distribution to destinations along the coast in smaller tankers of approximately 100,000 tons. Such a station has been constructed at Bantry Bay, Ireland, and other suitable sites include Brest, Cherbourg, and Marseille in France. Of course, loading facilities in the Persian Gulf will have to be appropriately upgraded.

The Gulf Oil Company terminal at Bantry Bay is located on Whiddy Island and will accommodate six new 312,000 ton Gulf tankers which will use the terminal as a staging point for the supply of crude oil to Western European refineries. At Whiddy

Island, the oil from the enormous tankers, completing the long voyage from the Persian Gulf around the Cape of Good Hope will be piped into 12 huge storage tanks, each with a capacity of 80,000 tons. There will be no refining operations at Bantry Bay. The oil from the tanks will be re-pumped into tankers of approximately 100,000 tons, which will then transport the cargo to Gulf refineries at Europort (Rotterdam), Holland; Gulfhaven, Denmark; Milford Haven, Wales; and a partly-owned refinery at Ruelva, Spain. The use of the huge tankers will enable the Gulf Company to transport oil around the African continent at approximately half the operating cost per barrel that would be incurred in shipping the oil via the Suez Canal with 50,000 ton ships. Upon completion of the operation of all six tankers, there will be 35 sailings a year into Bantry Bay, and three sailings a week from Whiddy Island of the 100,000 ton shuttle tankers to European refineries. The terminal will require a permanent staff of 30 persons to supervise the discharge of oil and the transfer to the smaller tankers.

Experience in working with the presently existing supertankers, approximately 200,000 tons and over (of which 144 in the 200,000 ton class alone are scheduled for delivery in the next three years) has illustrated that these ships must be handled more carefully than smaller vessels. Drydocking becomes a more hazardous operation so that the procedure for drydocking must be much more precise than in the past. (This has led at least one oil company to consider carrying out repairs and surveys afloat by building a watertight cofferdam around part of the ship.) These ships must also travel more slowly in crowded waters and be careful to avoid any situation requiring a halt at full speed (since stopping requires a distance of 2.5 miles). Furthermore, tugs are needed to maneuver these ships in port or confined waters, and the possibility always exists of increased fire hazards. While the bigger tankers cost less to build, and automation makes it possible to run a 200,000 ton ship with a smaller crew than was previously required for a 100,000 ton ship, the growth in tanker size may yet be limited by the development of increasing numbers of oilfields in various parts of the world which would obviate the necessity for numerous long hauls, although the new Alaskan oil fields require

nearly as long a haul to New York as from the Persian Gulf around the Cape of Good Hope to Europe.

There are other cargoes for tankers besides oil. British shipyards are engaged in building two tankers to carry liquified petroleum gas (LPG) with a size of approximately 20,000 tons each. These shipments are fully refrigerated so that their cargoes can be carried at a temperature of approximately -40 F. The first ship especially built to transport liquified gases (methane, ethylene, LPG, ammonia, etc.) was the 17,000 ton "Bridgestone Maru" constructed in 1962. The first commercial methane tankers were built in 1964 and each transports over 12,000 tons of cargo respectively at a temperature of -162 C. At the beginning of 1968, there were already more than 200 liquified gas tankers in service, of which only 14 percent had a payload greater than 5,800 tons.

While the growth of world trade in liquified gases is a relatively recent phenomenon (indeed, October 1964 witnessed the inauguration of commercial shipments of methane), approximately 1.5 billion m.³ of methane are now being transported by ocean tankers from Algeria to the United Kingdom and France. In 1969 shipments of 3.5 billion m.³ per year of Libyan natural gas began to be shipped to markets in Italy and Spain. At the end of 1969, shipments should have begun to flow of 1.4 billion m.³ of methane per year from Alaska to Japan. Additional projects to ship methane gas include: an increase in supply from Algeria to France and, perhaps, other countries in the Mediterranean area, the shipment of Brunei natural gas in 1972 to Japan, at the rate of approximately 6 million m.³/day. Other possible markets for methane include the East and West Coasts of the United States, Eastern Canada, Brazil, and Argentina.

Shipments of liquified gases have considerable future potential: witness the growth of the tanker gas fleet from ten carriers in 1955 to a predicted 280 carriers by 1970. In the future, it is expected that the size of the ships will increase; freight charges will be reduced; ship designs will be improved; and demand for these products will rise.

It has been estimated that over the next twenty years, shipments of gas may grow to 300 million m.³/day. The prospect of American imports appears to be well founded since, in the

United States, natural gas accounts for approximately 30 percent of total primary energy consumption, and demand is rising at the rate of approximately four per cent per year. Since present reserves are sufficient only for 16 years at the current rate of consumption, there is a possibility that within the next ten years, U.S. imports may reach as much as one billion cubic feet per day. After 1985, it has been estimated that this figure could rise to between 2.8 billion ft.³ and five billion ft.³/day. While the bulk of U.S. imports would probably come from Venezuela, it is also possible to consider Nigeria, North Africa, and the Middle East as suppliers. It is further expected that Japan will soon have an import potential of approximately one billion cubic feet per day, and Western Europe, four to five billion cubic feet per day.

The world shipbuilding industry, then, is in the midst of a tremendous boom engendered by orders for mammoth oil tankers, bulk carriers, container ships, and other specialized vessels. The number of oil tankers on worldwide order stands currently at 133, of which Japan's shipyards are engaged in building 58, Sweden - 16, The Netherlands - 12, and Denmark - 11; and, according to Lloyd's Register of Shipping, at the end of September 1968, the world merchant ship order total was at a peak of 3378 ships, aggregating over 44.5 million tons. The world fleet has been growing at a rate of approximately four to five percent per year.

The British share of the total world shipping order-book at the start of 1968 amounted to approximately six percent. While other nations tend to limit themselves to specialized types of vessels, British shipyards build a wide range of ships from large oil tankers and bulk carriers to sophisticated cargo liners and other specialized vessels. Japan's share of the total shipping world order book amounts to approximately 42.7 percent, and her shipyards specialize in large oil tankers and bulk carriers. Mass production of standardized ships has aided the amazing Japanese advance in production. (Until 1955, the British were first in shipbuilding.) Increasing computerization and the opening of docks capable of producing 500,000 ton vessels will enable the yards to overcome labor shortages. By 1971, it is estimated that 59 percent of Japanese export ships will be over 100,000 tons compared with 11

percent in 1967. While the Japanese have either built or are building the six 310,000 ton tankers for the Gulf Oil Company, Mitsubishi (Heavy Industries of Japan), the world's largest shipbuilder, is contemplating a plan to construct a shipyard capable of building supertankers (tankers) of up to 750,000 tons. The shipyard would be constructed on Koyake Island in Nagasaki Harbor or a similar site in Western Japan, and until orders for 750,000 ton ships are forthcoming, two 350,000 ton tankers can be built simultaneously. This yard would be completed by the end of 1970.

Sweden stands in second place in the world shipping order book. While the construction of tankers account for approximately 60 percent (10.42 million tons) of total Japanese orders, slightly under 50 percent of West German orders, and slightly over 33 1/3 percent of British orders, in Sweden almost 90 percent (3.02 million tons out of a total of 3.80 million tons of order) of orders are for tankers. Sweden is also participating in the building of container ships.

To successfully meet modern shipping needs, a veritable transportation revolution has ensued which has been spearheaded by the innovation of the container ship. The cargo container itself is a simple aluminum or steel box with doors at one end, measuring eight feet high and eight feet wide; containers are found from ten foot lengths up to forty foot lengths. The guiding forces behind the use of containers is to effect an integration and, of course, a cost saving in motor, rail, and sea transportation by moving containers rapidly and mechanically between each form of transportation. The secret of this thorough transportation system lies in the standardization of the containers, and the fixtures and fittings which are required to carry and hold the containers during each type of transportation. The net result is a radical reduction in transit costs and time.

The use of containers originated in the United States where, in 1955, the Pan Atlantic Corporation (later the Sea-Land Corporation) transported an experimental cargo of boxes on a platform on a tanker sailing between New York and Houston, Texas. The owners of the corporation were not shippers but truckers who concluded that, if handling could be speeded up,

containers carried on ships would offer a viable alternative to railroads and trucks along American Coastal routes. In the first container shipment, the boxes were loaded and discharged by a big shore crane, and, in a matter of three months, cargo handling costs had been reduced from \$5.83/ton to \$0.50/ton. A route between New York and Puerto Rico was then inaugurated in which port handlings worked out at twenty times less than those of a conventional ship, and port turnaround times were cut from seven days to fifteen hours. Following this experience, the Matson Line established container ship service between Hawaii and the West Coast of the United States. Two years ago, Sea-Land started container ship service across the Atlantic. European shipping companies organized together in several groups and consortia in order to build and operate container ships. By the end of 1967, a number of shipping lines were operating container services across the Atlantic although the majority of them were only carrying containers on their conventional ships. The building of special international container ship services on the world's main trade routes, however, had begun.

By the end of 1968, nine shipping companies or groups are reported to have been operating ships designed to carry full or part container cargoes across the Atlantic and several more are to have expected to follow suit. The vast increase in the number of containers handled by the big European ports since the Atlantic service started illustrates the rapidity of growth of the medium. After one year of operation, Rotterdam, in 1967, was handling 1,600 containers per week; by July 1968, the weekly volume had reached 2,500 containers per week while Antwerp moved 43,820 containers in 1966, and 57,020 in 1967; the British Transport Docks Board moved 55,244 containers in 1967, and increase of 31,991 over 1966; and the Port of London handled 48,805 containers in 1967, an increase of 32,205 over 1966.

Moreover, two British groups are building nine ships to operate a joint weekly container service between England and Australia starting in February 1969. A United Kingdom to New Zealand container service is now being scheduled for the early 1970's. The first Japanese container ship sailed for the U.S. West Coast in a joint service with Matson Lines in September 1968. Sea-Land,

which has been delivering military cargoes to Vietnam in containers, is now loading its ships in Japan on the return journey. In the near future the Japanese are contemplating the establishment of a container ship service to Australia; in the early 1970's the British expect to switch to containers for the Japan and Hong Kong to Europe trade.

While some 145 container ships now ply the seas, by 1970 there will be at least 300 in service, and it is estimated that by 1980, at least 630 million tons of cargo on the world's deep sea trade routes will be carried by container ships. Although the container ship of 1969 displaces 27,000 gross tons (and carries 1300 containers), and the next generation will be larger and faster, it is considered to be some time into the future before such vessels will carry 100,000 tons of cargo, a humble figure by present day tanker standards.

The new British container service to Australia (carrying 1,300 containers in each of nine ships) will replace approximately 80 conventional cargo liners presently engaged in the England-Australia trade. One container ship of similar size will adequately provide for all of France's trade with Australia while only two German ships are required to take care of their share of the trade; the Italians can manage with one ship; and the Dutch will barely fill three-quarters of such a vessel. It is thus calculated that that container service to Australia will reduce by twenty days the present round trip voyage, meaning that less capital will be tied up in goods en route; there will be a considerable savings in interest charges; stock levels will be reduced thus creating further savings in overhead. Damage to goods carried by purpose-built container ships has been reduced to a fraction of those shipped by conventional means. If containers are employed as the key element in the distribution system, full loads move more regularly from factory to distributor to wholesaler thus cutting warehousing and stock costs in both home and overseas markets.

As a result of a study recently completed for the British Port Council by Arthur D. Little, Inc., it is estimated that the potential container traffic on the North Atlantic is now equivalent to approximately 4,500 twenty-foot containers that can be carried across the ocean by special purpose ships each way each week, and

that this traffic is expected to grow to accommodate the transportation of 5,000 containers abroad ship weekly by 1970. While container space now amounts to less than half the maximum cargo, by 1970 it will be approximately equal to or slightly more than the maximum cargo available.

Mr. G. Beyer predicts that it will be possible in 1970 to transport all the "containerizable" North Atlantic cargo in twenty-five very large container ships of 60,000 dwt. The cost savings to be realized (compared with the cost of conventional transport) is estimated to be about 12 percent for a container transport from the factory to the port of destination, and about 28 percent in the case of a complete door-to-door service.

McKinsey's study on containerization forecasts savings of up to 50 percent in the cost of transport, a reduction of 70 percent in the number of cargo ships on the North Atlantic run, and a twenty-fold rise in the productivity of port-workers handling general cargo.

Further developments include: container rail-land bridge across the United States or Canada to carry containers in unit trains between container ships in the Pacific Ocean and the Atlantic Ocean. It has been claimed that by means of shipping containers across the United States or Canada, travel time from Japan to Europe will be reduced by at least three weeks, and the cost would be cheaper than shipping through the Panama Canal. The Russians are interested in container service across the country to Japan, and this Trans-Siberian route could be a reality by the 1970's. The Sea-Land provides road trailers for all its containers.

Another means of container transport is air freight which presently carries only one percent of world freight and estimates spanning 1980 do not raise this figure. Giant freight airplanes of the future could perhaps carry as many as twelve 20 foot long containers carrying light, bulky cargo. However, even if such a development were to take place, air freight could not compete cost-wise with sea freight. The types of goods carried by air do not lend themselves to the filling of a large container by one seller. Although container ships require fewer ports of call they do require more feeder services. Containerization changes shipping and port operation from an intensely high-labor operation to a high

capital affair. While few employees are needed, there is a considerable capital investment required for the containers, ships, and cranes. Thus a high rate of utilization of equipment is essential.

To offset the capital investment, it must be borne in mind that one of the principal advantages of container shipping is its efficient adaptability of transfer between various modes of transportation. Containers can be hauled just as readily either to railroad freight terminals or airports where they can be transferred to flatcars or to airplanes. It is just as easy to transfer containers to a railroad freight terminal from a ship or to a marine terminal or an airport from a railroad freight terminal. Wherever the container is transferred, machinery performs the job with an absolute minimum of manual labor.

Containerization has also encouraged the construction and operation of ever larger and faster general cargo vessels since by drastically reducing the amount of time a ship must spend in port, it has become economically feasible to make the required capital investment for specialized container ships. As an alternative prospect heavy capital investment in large broad-bulk ships which have to spend approximately half of their time in port is decidedly unattractive.

The utilization of container ships and supertankers is one bit of evidence for the observation that the great advantage of water transportation through the ages has always been that it is the cheapest method of carrying commodities. To maintain this advantage in the present era, stress must be placed on the size of the ship, the speed in constructing it and the means of accommodation. Thus eight massive building docks are in the planning, execution and/or operating stage at the present time in Great Britain, France, Portugal, Italy, Germany, and Scandinavia, and it appears that approximately the same number will go on the drawing boards in the near future.

A few years ago, the shipbuilding industry was still operated much as in the days of cottage industries, particularly in England where great emphasis was placed upon shape and detail. It was the Japanese who realized that size and speed are important. They began to apply assembly line techniques to the building of giant

vessels. Since big sub-assemblies involve more work under cover, better planning and control, along with higher accuracy, faster building speeds and lower building costs resulted.

The advantages were immediately recognized. The faster rate of building results in the lowering of overhead for the shipbuilder, along with higher profit and lower price per ship. (The appropriate measure of shipyard efficiency is gauged by the number of man-hours involved in each ton of steel that leaves the yard in the form of a ship. Man-hours vary with the types of ship built. They are highest for a complicated passenger ship and lowest at the end of a series of standard giant tankers or bulk carriers, and include a minimum of 33 hours in the best yard in Sweden, an average of 40 hours in Japan, and 45 hours for simple ships or bulk carriers in England.) In 1956 the price of a 31,000 ton tanker was estimated at \$125 per ton while in 1961, the price of a 300,000 ton tanker is expected to be estimated at \$67 per ton.

Japan's new building docks are laid out to be built up to 500,000 ton sub-assemblies, using conveyors to move plate and prefabricated sections. Sweden's newest building dock is equipped with a crane capable of lifting 800 ton blocks with a new 1,329 foot dockyard large enough to construct 750,000 ton ships. In 1970 Harland and Wolff in Belfast will be handling similar size sub-assemblies but with a crane of greater span using a dock able to build one-million-ton ships. Expensive automated cutting equipment is only justified if the steel output is sufficiently great to bring a return on capital investment. This, in turn, is affected by the price of labor.

In the desire to speed up and rationalize those phases of shipbuilding between the rolling of plate and its fabrication, new machinery of all kinds has been developed. At present a method widely used in European shipyards to mark up ship's plate for cutting is to employ an automatic plate-cutting machine in which the cutting heads are controlled by a photo-electric cell moving over a one-tenth scale photographic plate showing the necessary lines. This method requires at least three men on the job. In Sweden, however, one girl sits and waits for two completely automated plate-cutting machines to finish their rolls, and then she simply changes the punched paper tape.

Japan's shipbuilding industry began its present phenomenal growth phase in 1963 when the first of the present series of completely new shipyards began operation. Among its assets were ample space alongside deep water and large pools of available labor from relatively impoverished farming districts in the vicinity. Thus the Japanese could easily construct new docks with sufficient space for new machinery capable of high productivity.

The British shipbuilding industry is now rising from the doldrums of the past ten years, aided and abetted by devaluation and government subsidy. The latter is providing the wherewithal to rationalize and regroup during the breathing space which has been provided by devaluation. An independent Shipbuilding Industry Board has been created to buy shipyards, increase group working capital, and provide loans for plant modernization. Job flexibility is increasing, and labor peace has been achieved. Mammouth building docks are being projected (among them the previously mentioned Harland and Wolff dock in Belfast), and orders for supertankers are on the drawing boards.

Swedish shipyards are the most modern in terms of automation, and there may be a correlation between this fact and the fact that Swedish wages are 40 percent higher than the rest of Europe. In Sweden, automated machinery welds the seams of large slabs of steel, and carries out the initial stage of the prefabrication process by attaching angle bar. Other machines weld T-bars automatically. The intensive use of automated machinery has made Sweden the leading shipbuilding country in Europe, and second in the world only to Japan.

Many emerging nations attempting to broaden their industrial base have looked upon expansion into the shipbuilding industry with favor, particularly on a medium scale. Accordingly, Taiwan is constructing repair docks and building berths for ships up to 100,000 dwt. Greece is building a shipbuilding and repair yard including an associated steel plant: upon completion the entire project will employ between 2,000 - 4,000 people. Singapore is expanding its shipyard facilities; India is building a shipyard; Indonesia already has shipyard facilities; as do Brazil and Peru. Turkey is building four new shipyards, each capable of building

ships over 25,000 tons and is completing a marine diesel factory; while in South Africa shipyards are being built to accommodate 30,000 ton ships with export potential. All this activity is most encouraging in terms of the maritime resources to be required in the future.

With the concurrent increase in automated shipbuilding and ship size, it is important to compare the relative values of transporting oil solely by sea with the transporting of oil using pipelines. On the surface this comparison might be easily accomplished; however, when it is realized that the basis of comparison is efficiency, the task becomes more difficult. It is just not easy to compare the efficiency of pipelines with that of tankers since the cost per ton-mile of transport by pipeline is, in broad terms, affected by quantity while in the case of all other methods of transportation of oil, the criterion of cost is distance. In the latter case, cost decreases with distance while in the former case it decreases as the quantity carried increases. While flexibility is a definite advantage in ocean tanker transportation, pipelines lack this attribute. Tankers may be switched to any trade route according to need; they can carry any type of oil; are able to cope with the varying seasonal demands for its transportation. Pipelines on the other hand, are permanent fixtures. When a large diameter trunk pipeline system has been constructed, it cannot be rerouted if conditions should change indicating the desirability of another pattern of transportation. Thus planning for the construction of a pipeline involves at the outset a determination of the ultimate capacity with respect both to the flow of oil over a particular route and over a long period of time. Moreover, there is a definite relationship between the oil-carrying capacity of a pipeline and the size of its diameter. (An increase in diameter leads to a rather greater increase in capacity.)

Construction costs of pipeline have risen considerably since 1957, whereas costs of tankers have not increased over the period. Thus the investment capital required for pipelines is much greater than that required for tankers. In the operation of pipelines, both high capital costs per tonnage mile of transportation capacity are the norm and low labor requirements. Thus fixed costs

predominate and account for 65 - 80 percent of total costs. In such a situation, the economies of a larger diameter line may be achieved only if it is used at full or almost full capacity.

Pipelines even when used to maximum capacity are, in general, at a disadvantage when compared with ocean-going tankers for transportation over equal distances. A small tanker (30,000 dwt) can be operated at a considerably lower overall cost per mile than a large diameter pipeline even when allowance is made for the loss involved in the ballast voyage of the tanker. With relation to the cost per ton/mile only comparatively, short pipelines of large capacity can compete with tankers, and then only with small vessels. It is maintained that the output of the pipeline must be large enough, and the pipeline itself used to full capacity in order that its high capital cost will not outweigh its low operating cost. Indeed, even when the pipeline route is substantially shorter than the alternative sea route (such as in the case of the TAP line route *vis-a-vis* tanker transportation via the Suez Canal), pipelines have been unable to compete with supertankers.

Presently existing or planned crude oil pipeline systems serve two purposes. The majority of them complement ocean-going transportation of oil by tankers and are not competitive with them but rather create tanker employment by bringing oil from inland regions to the loading seaports or by transporting oil from the discharging seaports to the inland refinery in the consumption area; a small number of pipelines compete with tanker transport by substantially shortening the alternative sea route only when very large quantities of oil are to be transported over a fixed route for a long period. Even the latter occasionally suffer from the competition of low tanker rates, rendering an under-capacity utilizing of the pipeline.

The current popularity of inland refineries located in proximity to the consumer indicates that the total initial capacity of pipelines as a means of supply in Western Europe will approach 70 million tons per year, and their ultimate combined capacity will be more than 150 million tons annually to meet future demands estimated over a 15 to 20 year period.

Chief among large pipelines presently being constructed in Europe is the 34-inch 480 mile Southern European pipeline to be

laid from Lavera (Marseille) to Strasbourg and Karlsruhe with an initial capacity of ten million tons and a maximum capacity of thirty million tons with an extension to Ingolstadt, Bavaria, South Germany (a 24-inch pipeline with an initial capacity of eight million tons per year). This new artery will be created to carry the northward flow of crude oil from the French Mediterranean Coast to the new refining center along the Upper Rhine, and through the linking of several new inland refineries in France and Germany directly with a Mediterranean port will considerably shorten the supply route carrying Middle Eastern and North African crude oil to these new plants. It is estimated that the distance to be saved by an ocean tanker carrying oil from the Persian Gulf via Suez to Lavera will be approximately 5,500 nautical miles per round trip as compared with the Voyage to a North Sea port.

Moreover, the 625-mile, 28-inch pipeline from Genoa via North Italy, Switzerland, and Austria (Vorarlberg) to South Germany (Stuttgart and Ingolstadt) will have an impact upon the existing transport routes to Switzerland and South Germany which could lead to a decrease in imports of crude oil for these destinations via North Sea ports.

In the Middle East, the inland oilfields of Northern Iran, Kirkuk, and Mosul demand pipelines to bring the product to the Mediterranean Sea. The oilfields of Kirkuk are connected by pipelines to the Mediterranean ports of Banias and Tripoli (532 and 555 miles respectively). As a crude oil trunk line, the TAP line, Trans-Arabian 30-31 inch in diameter pipeline, carries Saudi Arabian crude oil from the Persian Gulf to the Mediterranean port of Sidon, a distance of 754 miles, traversing four Middle Eastern countries while avoiding an alternative double voyage by tanker of approximately 3,300 nautical miles each way around the Arabian peninsula, and also saving Suez Canal fees.

The Turkey-Iran pipeline, stretching from Iran's south-west oilfields to Iskenderun on Turkey's Mediterranean coast, is the most ambitious to date. It will consist of 1000 miles of 42 inch diameter pipes conveying a maximum of 60 million tons of oil a year. The proposed cost is 1.2 billion dollars.

If, as indicated, a new sea level canal needs to be constructed to alleviate the future congestion of the Suez Canal, then the use of nuclear explosives as compared to chemical explosives to build such a canal needs to be examined.

The United States Congress and Atomic Energy Commission are encouraging and supporting the Plowshare Program which seeks to adapt nuclear explosions to peaceful purposes. The Plowshare Program received its impetus from the interest engendered in the construction of a sea level canal when the Suez Canal was blockaded by Egypt in 1956. A small group of scientists convened at the Lawrence Radiation Laboratory in Livermore, California, to discuss the feasibility of cutting another canal through "friendly" territory using nuclear explosives. If nuclear excavation of a sea level canal is to be undertaken, it is a matter of concern to many nations, either directly or indirectly. Indeed, international agreements or treaties designed to limit the development of nuclear weapons may, unfortunately, apply to peaceful uses of nuclear explosives as well.

While it was believed that such earth-moving projects could be accomplished with nuclear explosives, still insufficient information existed to provide a suitable basis for engineering design, and the question of the control or reduction of the unacceptably high levels of radiation had not been answered. Such problems must be resolved because there is no less expensive source of large quantities of energy nor less expensive means of moving large quantities of earth than with nuclear explosives. Answers must be found to the questions of controlling such enormous amounts of energy and of predicting precisely the effects of such an energy release. There is also the problem of the radioactivity produced by nuclear devices. The levels of radioactivity expected must be determined; and after this, it must be determined if they can be reduced at the explosion source or at least attenuated at the site. Only after these factors are at hand can the profits be calculated for all the economic consequences predicted, along with the assurance of complete safety.

The Plowshare Program research has increased the general understanding of the use of nuclear explosives as an engineering tool. A nuclear explosive varies from a chemical explosive in that the energy is released much more rapidly, thus producing a sharper shock wave, and making it more effective in shattering rock although somewhat less effective as an earth mover. The nuclear charge is much more compact which leads to a much higher initial-energy density and, thus, to a much higher temperature and pressure after detonation. Since the nuclear explosive is compact, transportation and emplacement costs are reduced.

Nuclear and chemical explosives are not competitive. They do not serve the same engineering purpose. It is not economically feasible to set off very large quantities of chemical explosives, for their usual function is to break up rock which is to be removed by other means. Nuclear explosives, however, are so inexpensive per unit of energy released that they can not only break rock but also provide surplus energy to move it as well. Although nuclear explosives are usually several orders of magnitude larger in size than customary chemical blasts. Over a wide range of explosive yields, it has been learned that it is possible to ascertain rather accurately the size of a crater formed if the depth of burial and the size of the charge are known. Present data available is considered adequate for making preliminary estimates of the size and cost of excavation projects. At approximately the same time that the Plowshare Program was initiated, President Eisenhower inaugurated a study of steps required to improve the present Panama Canal. The study included the possibility of excavating a sea level canal using nuclear explosives. The feasibility of digging an inter-ocean sea level canal across the American Isthmus is influenced by several factors: the ability to make stable excavations of adequate size, utilizing large explosions; the successful control of potential safety hazards; the successful planning and coordination of time, effort, equipment, and materials required for the nuclear excavation, along with the major conventional construction required to complete an operating interoceanic waterway.

It is certainly feasible to contemplate digging a sea level Isthmian Canal with nuclear explosions. Nuclear explosions have

already occurred which would have made craters large enough for the canal had they taken place at the proper depth underground. The Sedan crater, created by a 100-kiloton nuclear explosion in alluvium, illustrated that the general concept is scientifically sound.

Thus, the actual questions with respect to feasibility of the Isthmian project pertain to cost, safety, and politics. (The latter has no place in an engineering study.) The engineering concept involved here is to blast the sea level channel with a row of buried nuclear explosive charges. These explosions would be designed to blow enough rubble out of the channel so that it will be sufficiently wide and deep for navigation without the necessity of any excavation by machinery. The cost saving occurs because of the low unit cost of nuclear energy compared with chemical energy, machinery, and labor utilized in conventional excavation. As for the safety question, radioactivity would be limited by utilizing thermo-nuclear explosives developed with the main objective of minimizing the initial production of radioactivity. In addition, deep burial of the explosives would trap a sizable percentage of the radioactivity underground. In the case of the Isthmian Canal, the prevailing winds from the north and northeast are essentially across the Isthmus and along the canal axis, and thus the land area subject to fallout would be minimized. The projected levels of radioactivity in the fallout are low and dilution and decay, both on land and in the ocean, can be expected to reduce concentrations to a harmless condition in a short time interval. People would be evacuated from the detonation area at a point of maximum yearly gamma ray exposure of 0.5 roentgen. Return of the evacuees to most of the canal area would be permissible within a year after completion of the nuclear excavation.

The deeply buried nuclear explosions for a sea level canal would cause much less air blast than the same yields occurring on the surface. However, because of the large yields required, it is necessary to consider close-in damage from the direct blast wave and minor, longer-range damage from focusing of refracted waves, as far away as 300 miles. Focusing can take place if there is a layer up to 200,000 feet in altitude where wind or temperature causes a

higher sound velocity than at the surface. While tests indicate that direct blast waves would fall to insignificant levels within the evacuated area, some direct blast damage would be expected beyond this area. At longer ranges, weather is a determining factor. Focusing from refraction in the ozonosphere, between 100,000 - 200,000 feet in altitude would depend upon regional high altitude wind patterns not yet measured. To avoid window damage in more heavily populated areas, it might be necessary to restrict firing to certain seasons of the year or to limit the maximum yield.

The range of possible ground shock hazard from an underground nuclear explosion is affected by the size of the explosion; coupling of explosive energy into the earth; propagation characteristics of the regional geology; local geology beneath structures at the range of concern; and structural response. Experience with underground testing in Nevada indicates that significant damage should be confined to the evacuated area. However, some minor damage might occur beyond the evacuated area.

Thus the safety evaluations of the canal project for radioactivity, air-blast, and ground shock indicate that a close-in region exists where the hazards are severe and must be handled by evacuation. The other problems appear to be manageable provided that the necessary development of nuclear excavation technology and surveys of site conditions take place. Indeed, it may be said that this excavating project is, at present, the ideal example of one where nuclear means are clearly economically superior to every other method.

Overall cost of accomplishing the desired task is the most useful standard for evaluating nuclear explosives in engineering applications. Included are the cost of assessing safety; the cost of employment and firing; the cost of the explosive itself; and the cost involved in acquiring land and controlling it for the necessary length of time.

There are varying sizes and shapes of nuclear explosives. In the Plowshare Program, the diameter of the explosives is of particular interest since it determines the size of the emplacement required. The amount of desired neutron shielding affects the diameter of a

given explosive. The Atomic Energy Commission has provided figures on charges for nuclear explosions to assist in making engineering estimates for excavation projects. From this it can be learned that increasing the energy release by a factor of 200, for example from 10 kt to 2 mt only doubles the projected cost. Thus the largest explosive will lead to the lowest unit cost. Four values of the diameter of canisters containing nuclear explosives of different yield have been provided by the AEC. Explosive yields of 10 kt can be accommodated in 12-inch canisters, 25 kt in 16-inch canisters, 100 kt in 18-inch canisters and 1 mt in 24-inch canisters, of a cylindrical form, with a height-diameter ratio of approximately 5:1.

It is possible to transport nuclear explosives by any convenient means to the projected point of detonation. Nuclear explosions, similar to chemical explosions, are started by a detonator. While both require the same types of electrical connectors, nuclear explosions require more precautions to assume positive control. Multiple electric firing circuits and coded firing signals may be used to eliminate dangers of premature firing and/or misfire.

It is considered that the thermonuclear device is well suited to the Plowshare concept since, for a given energy yield, it is less costly than the fission explosives, and when used properly will produce much less radioactive residue.

If the nuclear explosion is buried sufficiently deep, it will be completely contained and produce a cavity around the emplacement site. In the Sedan shot in 1962, it was shown that a 1-kt explosion buried at a depth of 30 - 60 m. underground will produce a crater approximately 90 m. in diameter. Larger explosives at greater depths will produce larger craters, and with careful engineering, most of the residual radioactivity will be buried harmlessly far beneath the bottom of the crater. Thus a single shot on an appropriate shoreline could form a crude but usable harbor adapted to the nature of the terrain. A similar channel cut completely through an isthmus will produce a sea level canal.

Lower comparative costs of explosive energy available from nuclear sources make this method attractive. A wide variety of chemical explosive substances have been developed over the

Type of explosive	cost/ton TNT equivalent (10 ⁹ cal)
Chemical:	
TNT	\$460.00
Dynamite	400.00
Ammonium nitrate-fuel oil	120.00
Nuclear:	
10-kt nuclear explosive	35.00
100-kt nuclear explosive	4.50
1-Mt nuclear explosive	0.60
2-Mt nuclear explosive	0.30

Source: E. Teller, W.K. Talley, G.H. Higgins, G.W. Johnson, *The Construction Uses of Nuclear Power*, (McGraw-Hill, 1968).

centuries. Ammonium nitrate and liquid petroleum are most commonly used in bench blasting in open-pit mines and quarries while a form of dynamite (nitroglycerine in an inert binder) is used in underground mining; black powder is utilized in most fuse trains and pyrotechnic applications; and guncotton (nitrocellulose) or TNT in weapons. Nuclear explosives can also be designed to fill specific requirements.

In terms of cost per unit of energy release, nuclear explosions are about the same as chemical explosions at the few-kiloton level, but become much less costly as the total energy release is increased.

Another important advantage of nuclear explosions that would reduce the cost of most operations is that of compactness. For example, a nuclear charge of a few kilotons would weigh a few thousand pounds and could be emplaced down a 30-in-diameter hole, while a chemical explosive of the same energy release, would weigh a few thousand tons and would occupy a volume of several thousand cubic meters. The logistic advantage of still larger

explosives is even more dramatic: a 2mt nuclear charge can be placed down a 40-inch-diameter drilled hole, while a 2mt chemical charge would require a cube 100 m on a side. (Incidentally, such a quantity of high explosives would represent 4 years' production of the United States chemical industry at the present rate of consumption of explosives for engineering purposes.) In fact, the charges for nuclear explosions in the 10 kt to 2 mt range are almost independent of yield, while the energy release increases 200 times, the cost does not quite double. Furthermore, the diameter of the required emplacement bore hole is quite insensitive to yield, varying only from 12 to 40 inches. Thus, as a rough estimate, the cost of a nuclear explosion of 10 kt to 2 mt would be \$500,000 and the charge could be emplaced down a 40-inch hole.

Engineers in the Soviet Union often do use large quantities of high explosives for excavation, in precisely the fashion being considered by Plowshare. Their largest work is an irrigation project started in 1964 near Bukara, in Uzbek province, aimed at connecting the Amu-darya and Zervashan rivers. By October, 1964, seven large detonations, using a total of 27,000 tons of high explosives, had been set off. The largest one, perhaps the world's record, was set off on July 23, 1964. According to Soviet publications, 9,352 tons of explosive were placed in 1,936 holes (from .9 - 15 m deep) and fired simultaneously, excavating a 15 kilometer long cut in one step. High explosives were used because excavators and bulldozers have proved utterly helpless there.

A proper evaluation of the engineering properties of the site, however, must be undertaken to determine the most economical set of conditions for the type of excavation under consideration. To properly evaluate the use of nuclear explosives for large-scale excavation, the engineer must have a thorough understanding of the medium, the depth of burst, and the explosive. Each site must also be individually studied as to proposed use and properties after completion of the excavation.

While taking account of this necessary knowledge, the Plowshare Program concerned itself with crater development in canal digging. Thus, in 1959 the Sandia Corporation in New Mexico conducted a series of low-charge experiments in clay and

coarse alluvium, and in 1963, the U.S. Army Corps of Engineers Nuclear Cratering Group and the Lawrence Radiation Laboratory conducted an additional series of high-explosive low-charge tests in alluvium, and in 1964 did the same in basalt.

These experiments were initiated to determine the effect upon crater dimensions of variations in the spacing between charges; the effect of spacing upon the irregularity, or cusping, in the crater; the shape of the lip relative to the lip obtained with point charges on both sides of the crater and the ends of the crater; and the effects of the medium upon the data.

One major conclusion was the following: To produce a crater when a nuclear device is exploded, the ground beneath the zero point is crushed and compacted, and the overburden blown away. As the depth of the burial increases, the depth of the crater increases. Other conclusions indicated that a spacing equal to approximately one crater radius results in a smooth-sided crater with apparent dimensions approximately 10 – 20 percent larger than those of a single-charge crater; spacing approximately 1.25 times the crater radius produces a ditch with dimensions similar to those expected from single charges; a spacing of 1.5 times the crater radius gives a crater smaller than a single-charge crater, irregular in cross-section; if four or more charges in a row are fired simultaneously under conditions that result in a uniform ditch, the lips on the side of the crater are 50 – 100 percent higher than that anticipated from a single charge but at the extremities of the crater the lips are virtually nonexistent in alluvium. Data for basalt indicates that for optimum charge spacing, there is 30 percent enhancement in width and depth over single-charge results. It would appear that even in hard rock, a straight channel can be produced with no cusps.

It should be noted that at the depth of the burst at which maximum crater dimensions occur, approximately half of the material is thrown out of the crater, and the rest is fallback material, which is that part of the medium which has been put into trajectory by the explosion and has fallen back into and around the crater. Ejecta or throwout material are deposited upon the lip of the crater out to a distance of approximately three crater radii. While the properties of throwout and fallback material

are similar, consideration should be given as to whether the medium is relatively compressible, such as soil, or incompressible, such as rock. It is significant that, in a rock medium, the throwout and fallback material will occupy a greater volume after the explosion than before the explosion.

Engineering properties depend upon the medium, depth of burst, and the yield of the explosive, and these parameters must be properly evaluated in order to yield the most economic set of conditions for the type of excavation at hand. This entails a necessity for full awareness of the effects of these parameters in the design of any nuclear excavation. The stability of large masses of material that might be involved in a slide of an excavation 120 or 150 m deep is a subject of much present research. There is an urgent need for the quantitative characterization of the behavior of fissured and fractured rock material. The effects of nuclear explosions upon the engineering properties of such other formations as saturated, fine grained media, and stratified media including sandstones and shales must be evaluated. It is also desirable to provide a solution to the problem of nuclear explosions on non-level surfaces.

Another property to be taken into account is that of slope stability which is the most critical area of concern in engineering in connection with nuclear excavation. The methodology of the analysis is as pertinent in the present situation as in conventional excavations. Such factors as foliation and groundwater must be thoroughly scrutinized before nuclear excavation is considered. Since utilization of nuclear explosive tools permits great depths of excavation more economically, the need for a thorough stability analysis becomes essential as even small slides could fill the bottom which is the most useful portion of the excavation.

Where an excavation is to be utilized as a thoroughfare, for example, the question of foundation stability assumes a pertinent place in design. Since the bottom of the apparent crater consists of several hundred feet of fallback material, the latter should attain a density similar to preshot conditions whereas rock should be well compacted. Excess moisture, poor density, and excessive fines should be corrected. If a foundation has a low-bearing capacity, it would require a properly designed flexible pavement.

Because of the more difficult problems of stability to be encountered in a soil excavation, it becomes apparent that a rock medium lends itself much more appropriately to nuclear explosion techniques than soil. This is a beneficial situation since the greatest economic benefit will also be realized from the application of nuclear excavation techniques to rock.

In conclusion, to adequately evaluate the use of nuclear explosives for large-scale excavation, cognizance must be given in designing the medium, the depth of burst and yield of the explosive. Adequate evaluation of these parameters will yield the most economic set of conditions for the excavation desired.

In the particular operation of a nuclear cratering explosion, the device itself and the material surrounding it are vaporized. In the process, gas expands, pushes the surface aside, and is released to the atmosphere as fallout. It is important to examine this factor in detail.

While radionuclide released from underground nuclear explosions in the Plowshare Program will be initially distributed in the medium by direct explosive action, it is possible that long-lived and biologically significant radionuclides could later enter into and move with groundwater flow. Present experimentation with adequate precautions at the Nevada Test Site and Plowshare Project Gnome have not revealed any significant post-explosion movement of radionuclides, but radioactive waste disposal operations however demonstrate clearly that radionuclides can be transported considerable distances by means of groundwater flow. There is no single, simple formula which can be applied to indicate the character and extent of possible radionuclide contamination of groundwater since the complex inter-relationship and variability of the environment factors serve as a deterrent. It thus becomes necessary to probe each proposed site of a Plowshare nuclear explosive application for unique geologic and hydrologic conditions which could indicate continued migration of radionuclides.

The story of groundwater contamination begins with the distribution of radionuclides from a fully contained nuclear explosion. That is to say that the underground explosion is so deeply buried that the fireball and the direct neutron flux will not

reach the atmosphere and that no massive venting of radioactivity occurs. To use as an illustration: a 1 mt explosion which derives 99 percent of its energy from thermonuclear reactions, the radioactivities initially released are distributed by direct explosive action. With the passage of time, the gaseous elements and compounds may diffuse through natural and explosion-induced cracks to the surface, and the radionuclides may come into contact with groundwater. Of interest in this exposition are only the longer-lived radioactivities (half-lives of one year or longer) which are involved in postexplosion groundwater distribution. If underground rivers are not involved, groundwater travels slowly, and the material, borne by it, moves even more slowly. It is possible for years to elapse in order for the radionuclides to travel one mile. Thus the short-lived species will decay into inconsequential amounts with short distances from the initial source. The most significant long-lived radionuclides are tritium (T or H^3) and strontium (Sr^{90}) which is biologically the more dangerous. Tritium is the predominant long-lived nuclide (12-year half-life) from the fusion reaction and strontium is the predominant long-lived (28-year half-life) from fission.

One of the most important safety problems relating to large-scale construction problems involving nuclear explosions is that of radiological safety. In the process of firing a nuclear cratering explosive, a large quantity of earth is thrown upward along with a certain quantity of vaporized material and radioactive debris from the thermonuclear explosive. (In a nuclear cratering explosion, the device itself and the material which surrounds it are vaporized.) As the violent agitation caused by the explosion subsides, the material starts to fall back to earth but the solid particles are already undergoing the process of contamination by means of condensation of the vaporized fission products and other radioactive materials upon them. Most of this contaminated material falls to earth within a few hours and is called local fallout. To insure that the amount of radioactivity produced during an explosion of a nuclear excavation project is not of an amount sufficient to endanger the human populace, the amount and kind of radioactivity to be produced during the explosion and distributed after the explosion must be planned, and the estimated

content, the main cloud becomes well-developed, separated from the base surge or low-lying dust cloud which surrounds the main cloud.

Radiological safety, fallout predictions and calculations, however, are primarily concerned with local fallout. Fallout prediction has, as yet, not been perfected to an exact science and thus has its limitation.

Many onlookers have distinguished themselves by their disenchantment with nuclear earth-movers. They have claimed that the devices, after allowing for past and present experimentation, are still "unclean." Up to now, no one has yet found a method of replacing the fission trigger which detonates the hydrogen device, and it is the fission explosion, although it may contribute only 20 percent of the total yield, which is responsible for radioactive fallout. However, of late, a significant breakthrough appears to have taken place in this sensitive area. Two nuclear excavation tests held in January and March, 1968, at the Nevada Test Site as part of the Plowshare Program seem to point the way to the virtually complete elimination of fallout. In both of the cases at hand, fallout was limited to an area of approximately a few hundred yards from the craters, and radiation could not be detected a scant three days after the explosion. Such results were produced by a new, very small thermonuclear explosive which is triggered by a tiny fission device, thus radically reducing the radiation engendered by the nuclear explosion.

Tests have shown that in a nuclear-cratering explosion, approximately 70 to 90 percent of the local fallout is deposited within a relatively short distance, less than ten miles from ground zero. In planning an actual construction project, pre-shot calculations would establish boundaries with which blast, seismic shock, or radiation might be hazardous. Here, prior to detonation, it would be necessary to evacuate. Blast or seismic shock will be characteristic of the zone of maximum radius. In the case of the planned Transisthmian Canal, it is expected that workers can resume drilling on the lip approximately three weeks after the detonation. The entire population could be expected to return to the area approximately two years after the last detonation.

exposures must be compared with health standards to determine whether there are any areas requiring control and monitoring.

In discussing the dangers of fallout, there are two types of radiation doses to be taken into consideration: the external dose and the internal dose. The external dose from whole-body irradiation by gamma-emitting radionuclides can be estimated in terms of the quantity of fission products and gamma-emitting induced radionuclides which escaped from the crater and the distribution of this escaped activity. The internal dose is obtained from radionuclides which may be assimilated or ingested and concentrated and/or retained by vital body organs, and perhaps, cause damage.

Three sources of radioactivity may be found in a nuclear excavation explosion: fission-product activity induced by the nuclear explosive; activity from induced radionuclides produced by neutrons from the thermonuclear processes that interact with device materials; and also with soil and rock surrounding the device; and activity from radionuclides which are actually produced in the thermonuclear processes. In any given excavation explosion, the amount of fission-product activity produced is related to the fission yield of the device. Thus accurate estimates of performance may be obtained from previous efforts. Soil-induced activity can in large measure be prevented by utilizing neutron-absorbing materials in and around the device to reduce the number of neutrons available for soil activation.

There are three types of distribution on the fallout which is generated by a deeply buried nuclear cratering explosion. The first is a large segment of the activity produced which is trapped by particles of debris and ejecta falling back either into the crater or on the lip and finally being entombed in the rubble. The second is a much smaller portion of the activity produced which escapes from the crater; it is injected into the dust cloud in the form of particulates, and, at the end in a matter of hours deposited on the earth as local fallout. The dust cloud is affected by meteorological conditions, depth of burst, total yield, and type of material being excavated. In a dry non-gas-generating material, such as basalt, the main cloud fails to be perceptible, but in the case of a gas-generating medium, such as alluvium with ten percent or more moisture

As has been mentioned, radioactivity presents a potential threat to man's well-being, either directly to man or indirectly via biospheric members involved in the human food cycle. It may perhaps be easier to resolve many of the technical engineering problems than the biological questions! Radioactivities are inevitable by-products of the utilization of nuclear explosives, and while the presence of chemical elements, and development work may reduce these results to some extent, it seems hardly likely that sizable reductions will be achieved overnight. Thus guidelines concerning the potential biological hazards must be established to properly evaluate the engineering problem.

The potential hazards of radiation to man can be subdivided into three parts: those arising from high radiation doses which are delivered at a rapid rate; those arising from high radiation doses which are delivered at a slow rate; and those arising either from low doses of radiation which are delivered rapidly or from low doses of radiation which are delivered over a very long period of time (years).

Two potential types of radiation exposure directly concern the Plowshare Program: namely, low doses of radiation delivered rapidly, and low doses of radiation delivered in small increments over a protracted period. The serious problem involves delayed effects, either genetic (inheritable) or somatic (produced directly in individuals exposed to radiation). The absence of definite information relating to low-dose radiation effects upon man does not mean that there was no effect. A limit may be placed upon hazard potential since the size of the dose does not appear to increase the effect.

In contemplating increase in radioactivity from such an excavation project such as that of a canal, recourse should be made to a comparison between conventional and nuclear central station power plants. An important point was cited in an article appearing in *Science*, April 17, 1964. Eisenbud and Petrow analyzed the fly ash produced by combustion of pulverized Appalachian coal for radioactivities from naturally occurring radium. As a result (and combined with other data on the released fission products from nuclear-power-generating stations), they

concluded that, when the physical and biological properties of the various radionuclides are taken into consideration, the conventional fossil-fueled plants discharge larger quantities of radioactive materials into the atmosphere than nuclear power plants of comparable size.

Another hazard which can be a concomitant factor in large nuclear excavation projects is air blast which may occasionally propagate great distances with damaging intensity. Even fairly weak blasts can alarm people, break windows, crack plaster, and create other nuisances without destroying any building, or killing, or seriously injuring any people.

These occurrences have their source in the after-effects of cratering bursts where a modified source wave is proposed with a strong wave shot upward and a reduced wave emitted horizontally along the ground. Some energy initially directed upward is diffracted into horizontal propagation; thus, at long distances, there appears to be less relative amplitude attenuation than is observed closely. Amplitude attenuation increases with scaled depth of burst, varying with certain material characteristics around a burst, and appearing to decrease with increasing yield. Atmospheric temperature and winds can cause refraction focusing of blast waves and considerably extend the normal range of minor damages to windows, plaster, etc. Surface temperature inversions can enhance blast pressures for 20 to 30 miles; jet-stream winds can focus waves up to 100 miles; and ozonosphere conditions at 100 - 150,000-foot altitudes can cause minor damage at a distance of several hundred miles from megaton class cratering explosions. Thus, if possible, it is advisable to conduct major excavation projects during a season when high altitude winds are blowing away from any populated areas.

The effect of nuclear-explosion-induced ground motion upon various types of facilities has already been mentioned. Using response spectrum techniques, evaluation of potential damage to engineered structures can be ascertained. The most common damage to residential type buildings which may be expected is cracks in the walls. It seems that peak surface velocities of approximately 10 cm/sec represent the threshold of damage in older homes having plastered interiors while 20 cm/sec peak

velocities seem to be nondamaging for properly built new homes with plastered walls or stuccoed interiors. Moreover, building and equipment of the types found at most large construction projects are able to survive severe ground motion.

PART TWO

Energy and Power Centers

INTRODUCTION

The remainder of this book constitutes, in a sense, an appendix dealing with primary energy, power centers, and water desalination. The purpose of these introductory remarks is to relate the contents of the concluding two sections of this book to the overall proposal presented in the first three sections.

In general, the Jordan Rift Scheme is a proposal for the development of an industrial complex, utilizing the unique physiography and climatic conditions of the Jordan Rift. By diverting the waters of the Gulf of Eilat-Aqaba into the depression of the Dead Sea, a water-fall will be created generating hydro-electric power. The low cost of this energy will be the necessary stimulus for industrial development which should include exploitation of both the minerals abundantly available in the Dead Sea and oil for petro-chemical products. It is estimated that for a period of the first 20 – 25 years there will be sufficient quantities of low-cost electricity and ample quantities of fresh water for industrial development. Abundant low-cost electricity is obviously the most important factor for the further industrial development of the region. But in the not too distant future with the natural growth of the industrial complex, there will be a demand for more energy, for more fresh water, and for more people. By that time, however, it is conceivable that a dual-purpose power complex, economically producing both a great amount of fresh water and power will be obtainable. The shortage of manpower can be overcome through technological sophistication which will allow for greater industrial control.

By that time the Middle East will be more involved in the mainstream of the world-wide need for greater energy sources. It is expected that by the year 2000 the demand for primary energy will rise from approximately five billion tons of oil equivalent (toe) in 1970 to 21 billion toe – an enormous quantity by current standards.

Oil, then, has and will continue to conquer the world markets. It seems to flow in endless quantities, illustrated by the fact that more than one-half of all seagoing transport is engaged in carrying

oil. Since 60 percent of all proven oil reserves are located in the Middle East, it is estimated that toward the end of the century the Suez Canal will reach the saturation point of her freight passage capacity. At the same time there will be a demand for the Jordan Rift Canal, a parallel sea lane to the Suez Canal, as discussed in Section Three of this book.

Oil is needed to generate power, but the increasing world demand for greater amounts of low-cost energy has provided the initial impetus for the construction of thermo-nuclear power plants. From the projection rates of construction of nuclear power stations in the world, it is estimated that by 1985, they will generate 20 to 25 percent of the world's electricity. Philip Sporn has estimated that by the year 2000 half of the electricity of the USA will come from nuclear stations. For the world as a whole, considering the high cost of capital expenditure involved, and the local need for sophisticated engineering skills, about 40 percent of its electricity will come from nuclear reactors. Assuming that nuclear power and hydroelectric power will together supply half of the electricity, this would leave the rest of the primary energy input to be supplied by fossil fuels — oil, gas, and coal.

The industrial countries, where there is a major nuclear development, are concentrating on the perfection of the fast breeder reactor which will efficiently utilize the uranium. Because of its ability to convert U^{238} to plutonium producing more plutonium than it consumes, the fast breeder is receiving priority in the US, USSR, and Western Europe. Successful performance of these facilities and the demonstration plans extant in the 1970's should lead to commercial development and use of the fast breeders in the 1980's. Dr. Glenn T. Seaborg expresses the hopes and the demands of the scientific community in his article "Need We Fear Our Nuclear Future," *Bulletin of the Atomic Scientist* (January 1968), pg. 37.

I am thinking here primarily of breeder reactors and the ways in which they could enhance the efficiency and economy of nuclear power. In fact, if we are truly to make use of nuclear energy as a major source of power for the future, it is essential that we develop reliable breeder reactor systems within the next few decades. It

is only through breeder reactors that we will be able to achieve the most efficient and economic use of our nuclear fuel resources — the World's supply of uranium and thorium. If we are successful we could make available to mankind, in the form of abundant very low-cost energy, a force for progress unparalleled in history. These then are the incentives — or I should say the imperatives — for what might be called the most important technical challenge of the next decades — the development of efficient and reliable breeder reactors.

The final pages of this book are directly concerned with water desalination. Here recent developments in the various techniques proposed for this process are reviewed. As the discussion will show, the methods currently available make the process simply too cumbersome and thus economically disadvantageous to be immediately incorporated into any overall industrial scheme for the Middle East. With this in mind, the section on desalination includes an appraisal of the Oakridge, Tennessee proposal for agro-industrial complexes composed of nuclear power plants providing the energy needed for both water desalination and electricity for industrialization. The Oakridge concept that agro-industrial complexes be developed on an integrated basis is given support in the Jordan Rift Scheme. The Scheme, however, is based upon the premise that regional planning and development should utilize the natural resources and physiography to their utmost: thus hydroelectric power; thus 1000 million gallons per day of fresh water are currently available from natural resources, water for farming and industry; thus chemical and petro-chemical industries for immediate development. Then, in a generation when all natural water supplies are fully utilized and when the demand for power overtakes the hydroelectric supply, integrated nuclear power stations and water-desalination plants can be incorporated into the scheme.

The development scheme outlined in this study, in effect, utilizes the technological sophistication of the 1970's. The implementation of the major parts of the Scheme will be effected in the 1980's, but the guidelines in the proposal are focused on the societies existing in the year 2000. With this in mind it is not

fanciful to speculate about some basic trends in the nature of the world during the next thirty years. By so doing, we can achieve a better understanding of the challenges that confront engineers and scientists during the next generation. For example: we can talk, with relative certainty, about the world population and its distribution between the highly industrialized societies and the developing societies; about the ever increasing demand for energy in both societies; about the increasing use of the seas to transport the fuel for that energy; about the possibilities of producing low-cost energy by nuclear fission; and about the heavy pressure on scientists and engineers to improve the techniques for water desalination.

The concluding two sections of this book, then, help to put into perspective the various aspects of the Jordan Rift Valley Development Scheme.

4

ENERGY

The future development of the world economy will depend to a very great extent on the availability of suitable sources of energy. The great western industrial nations – the United States, Canada, the Western European nations, and Japan – require vast quantities of energy to maintain their high technological level. While it is possible for the industrial nations of North America (the United States and Canada) to supply their energy needs from indigenous sources of oil, coal, gas, uranium, and water power, the countries of Western Europe, in contrast, in 1964 imported 47 percent of their total energy supply, and Japan imported approximately 67 percent. In fact, Western Europe imported approximately 79 percent of its total oil requirements, and Japan 99 percent of its oil requirements.

As the great coal reserves for Western Europe and Japan are found in the United States, the Middle East and Africa are the loci of the oil reserves for these nations. Western Europe obtains approximately 55 percent of its oil from the Middle East, and approximately 20 percent from Africa. Japan imports 82 percent of its oil from the Persian Gulf.

Oil has conquered the world markets and continues to flow steadily in endless quantities. The magnitude of the task of supplying the world's fuel needs can be illustrated by the fact that more than one-half of all seagoing transport is engaged in carrying oil. Supply is greater than demand, and the price is more or less stable. Production is a relatively uncomplicated process – mainly by means of automatic pumping – and transportation of the product is easily handled by the use of large tankers. Unloading is

simple, as is storage in large tanks, and piping through a network stretching all over the European continent. Oil is well able to compete price-wise with other fuels. Similarly it is well-adapted to fuel power stations and is the only fuel (at the present time) which can successfully power automobiles, trucks, and planes. It is an important raw material for the chemical industry as well.

Thus oil from the Middle East and Africa is of particular interest to the nations of Western Europe and Japan.

In spite of the fact that there is a surplus of oil on the market today, serious concern exists over future supply. Will new sources of oil in addition to the currently known and proved reserves be discovered? The abovementioned reserves amounted in 1967 to some 56,800 million tons, of which approximately 60 percent was located in the Middle East; approximately nine percent in the Soviet Bloc (including China); approximately ten percent in Africa; and approximately 18 percent in the Western Hemisphere (including the United States and Canada).

However, the discovery of oil is an uncertain affair at best, and, at the present time, the largest oil field ever to be exploited in the United States has just been uncovered on the northern coast of Alaska. (It is possible that it will yield some five to ten billion barrels of oil which would make it the world's largest oil field.) Moreover, every year new sources of oil yield at least a sufficient supply to meet yearly requirements. But today's energy needs are vast, and principal primary energy demands may be expressed as reaching approximately five billion tons (mtoe).

It is expected that by the year 2000 the demands for primary energy will rise to approximately 21 billion (toe), which is an enormous quantity by present concepts, with respect to known reserves of principal primary resources in the world.

There are those who worry whether sufficient reserves of oil will be discovered to satisfy industrial demands for providing for efficient operations in the developed nations in the period after the year 2000. It is estimated that, up to now, geologic surveys have been undertaken in only approximately five percent of the total area of the earth's surface, and prospecting is continuing in Northern Canada, the Middle East, and Africa, and on the continental shelves.

On the other hand, coal reserves are found in great abundance. It is estimated that known quantities of hitherto unexploited coal in the United States will be sufficient for 250 years; in Russia and China for 200 years; and in Western Europe for 80 years. If oil reserves diminished, it would be possible to convert coal to liquid fuel for transportation, and to provide raw materials for the chemical industry. Many areas of the earth have not yet been explored, and undoubtedly, concealed within their folds are rich veins of coal. It will be possible to construct huge thermal power stations in the vicinity of coal mines, and to produce cheap power to be carried long distances on the national or regional grid by means of 800 kv - 1500 kv high voltage transmission lines which are now going into operation in the United States and Russia. Thus the location of the mine and its distance from the ultimate consumption of the electricity becomes a matter of no importance.

Prophets and fervent proponents of nuclear energy are convinced that the place of oil will decline gradually in the human energy balance, and its importance will be impaired in the same process, as the use of fast breeder reactors for producing electricity will become commercially feasible and widespread. Continental implements of transportation such as the automobile and the train will be powered by electricity while ships will be operated by nuclear power.

According to OECD (Organization for Economic Co-operation and Development) statistics, by 1985 nuclear reactor power plants will produce approximately 350,000 mw. Uranium requirements will rise from approximately 10,000 tons in 1970 to approximately 60 - 70,000 tons in 1985, and the total quantity of uranium needed in the entire period will amount to some 500,000 to 600,000 tons. It is estimated that by the year 2000, the production capacity of nuclear reactors in the United States alone will reach a potential of approximately 734,000 mw, with a yearly requirement of 1,000,000 to 1,200,000 tons of uranium. Known reserves of uranium in the world in December 1967 amounted to approximately 700,000 tons at a price of up to \$10/pound, and another 1,200,000 tons at a price of up to \$30/pound according to E.N.E.A.I.A.E.A. (European Nuclear

Energy Agency – And the International Atomic Energy). With the appearance of the fast breeder reactor, the converting factor in the exploitation of uranium will be greater. By 1970, it is anticipated that production at nuclear reactor plants will reach 70 Twh (converted to oil terms, 18 million tons of oil equivalent); by 1970, 280 Twh (70 mtoe); by 1980, 630 twh (145 mtoe) as compared with estimates of total energy requirements amounting to 1440 mtoe.

But a more serious question has been raised regarding the contribution of nuclear energy to world fuel requirements. The European Atomic Energy Community (Euratom) report on "The Problem of Uranium Resources and the Long-term Supply Position," casts doubt on the adequacy of the supply of uranium to meet all the demands that would be made by a great extension in the use of nuclear energy for the production of electricity. This report shows that the supply situation is not assured and in the absence of substantial new discoveries, the reserves of uranium would be reduced to three or four years consumption by 1980. The Euratom study does not regard the large reserves of lowgrade ore as a feasible source of supply. Furthermore, it takes about ten years from the discovery of new mines to the start of production. It is, therefore, far from certain that unlimited expansion of nuclear energy is possible so long as nuclear reactors depend on the fissionable material found in Uranium²³⁵.

A really massive contribution from nuclear energy to meet the world's fuel requirements will depend upon the development of economical reactors. This may very well take place by the 1980's but even then the time required for a reactor to produce enough excess material for a second reactor will probably be at least fifteen to twenty years.

The search for fusion power has received substantial support. For over 15 years the U.S. Atomic Energy Commission has funded Project Sherwood, which searches for ways to control a fusion reaction. The major Sherwood research centers are located at Los Alamos, N.M., the E.O. Lawrence Radiation Laboratory at Livermore, and at Princeton University. Even the most optimistic forecasts envisage that several decades may pass before fusion power plants are a reality.

The major part of the world's fuel requirements in the 1980's will, therefore, still be met by fossil fuels – coal, oil, and gas.

PRIMARY ENERGY

An Overview: We are fortunate that a number of primary energy resources are known to be at our disposal, including oil, gas, and coal. While solid fuels are still the largest source of energy in the world, and their consumption has steadily increased in absolute terms, their relative importance is diminishing. At the same time, the consumption of oil has greatly increased everywhere, particularly because of its utilization in the transportation industry and as the most important source of chemicals. Utilization of natural gas has begun to create an impact in many parts of the world.

World Consumption of Primary Energy – 1966

	Percentage of world population	Percentage of world energy consumption	Per capita energy consumption (mtoe)
North America	6.5	37	7
West Europe	10.3	20	2.2
Communist countries	32.3	30	1.05
Sub-total	49.1	87	2
Rest of the world	50.9	13	0.31

Source: Sir Harold Hartley, *New Scientist*, 13 November, 1969.

Between 1929 and 1962, total world consumption of solid fuels increased over two and one-half times. Oil and natural gas, however, have attained even higher rates of growth. Indeed, in

some areas, they have overtaken solid fuels, and in others, replaced them. Concomitant with this growth in the utilization of oil and natural gas has been the trend in the industrialized areas towards energy transformation into secondary forms with the emphasis upon electricity, for which there is a fast-growing demand.

It is obvious that both the climate and the degree of industrialization play considerable roles in determining the average energy consumption per capita from one country to another.

Unfortunately, neither coal, oil, natural gas, nor water power are conveniently located where they are required, and energy must be transported in continuously increasing quantities both within countries and within regions as well as between the principal geographic areas of the world. For example, there is little coal to be found in Japan, and limited quantities of oil have been discovered to date in Asia and Australia. While Western Europe possesses coal and gas, it, too, has restricted amounts of oil. On the other hand, North America and the USSR are bountifully endowed with coal, oil, and gas which they consume in abundance. The major producers and exporters of oil include the Middle East, North Africa, and the Caribbean Region.

An overall rate of increase in primary energy requirements of approximately 4.3 percent/year is expected between 1964 and 1980, with the proportion between the three main sectors varying only slightly. On the other hand, the increase in all other regions of the world combined will average about 6 percent. In the latter areas, commercial energy consumption will be substituted for noncommercial forms (wood or peat), and sizable industrial expansion is to be expected. It is estimated that per capita consumption will more than double in those parts of the world not included in the OECD area (0.5 toe to 1.1 toe) and in the OECD area consumption will rise approximately 65 percent to over 5 toe. Except for the OECD area (not only in Eastern Europe, the USSR, and Oceania), per capita consumption would range over 2 toe, and the average for the remaining regions of the world would be 0.5 toe. (These areas include nearly three-quarters of the world's population.)

If we assume a similar growth relationship of 4.3 percent/year from 1980 to 2000 in the OECD areas, and 6 percent/year in the

Eastern Bloc and the rest of the world, we achieve a picture of world energy requirements as described in the following table:

World Requirements For Primary Energy

(mtoe)

Year	OECD	Eastern Europe USSR Communist Asia	Rest of the World	World Total
1950	1,309	390	168	1,867
1960	1,843	950	312	3,105
1980	4,300	2,800	1,100	8,200
2000	9,419 *	8,487 *	3,528 *	21,434 *

* extrapolated

Source: OECD, Energy Policy.

It is inevitable that as the coal industry continues to decline, the share of oil and natural gas in primary energy requirements will increase to meet total demand. It is predicted that between 1967 and 1986, the share of the non-Communist world's energy market held by oil and natural gas will increase from 63 to 73 percent.

Proved World Oil Reserves: The largest deposits of proved oil resources are located in the following areas: the Middle East - approximately 34 billion tons; Central and South America - approximately 4 billion tons; North Africa - approximately 5.6 billion tons; the Far East (especially Indonesia and Malaysia) - approximately 1.6 billion tons; and now Alaska. The reserves, excluding Alaska, represent approximately 54 years of production at present rates. Other sizable reserves are to be found in the Soviet Bloc and China. Total reserves in the Soviet Bloc in 1967 comprised 5 billion tons, representing approximately 20 years of production, and U.S. proved oil reserves average about 12 to 15 year's supply at current production rates.

At the moment, the total of proved world reserves, excluding the vast new Alaska fields, is estimated at approximately 56.8 billion tons, an amount sufficient for 40 years at current rates of consumption. The present average rate of recovery is approximately 30 percent, but it could rise to 50 percent by 1980. Extensions of fields or new fields which could be discovered or exploited under present conditions would furnish North America with approximately 40 billion tons of oil, and the USSR with an additional 27 billion tons.

World Proved Oil Reserves At End 1967

(in billion tons)

Country / Area	amt.	% of total
U.S.A.	5.2	9.2
Canada	1.3	2.2
Caribbean	2.8	4.9
Other Western Hemisphere	1.1	1.9
Total Western Hemisphere	10.4	18.2
Western Europe	0.4	0.7
Africa	5.6	9.8
Middle East	33.9	59.8
U.S.S.R., E. Europe and China	4.9	8.6
Other Eastern Hemisphere	1.6	2.9
Total Eastern Hemisphere	46.4	81.8
World (excl. U.S.S.R., etc.)	51.9	91.4
World	56.8	100.0

Sources: U.S.A. - American Petroleum Institute
Canada - Canadian Petroleum Association
All other areas - Estimates published by the "Oil & Gas Journal"
(25 December 1967)

Actually, we stand at the very beginning of the road in the search for oil. First of all, production techniques are still relatively

primitive, and often only 25 percent of the oil in a specific field is recovered. With more sophisticated methods, it is considered possible to recover 50 to 60 percent of the oil available which would double existing reserves even if additional oil were not discovered. Thus far, only 5 percent of the areas of the world (on land or sea) have been thoroughly explored - underneath which it may be presumed that a supply of oil or gas could be found. In northern Canada, for example, there is an area of some 465,000 square miles where vast quantities of oil are known to exist but where conditions are too rugged to justify the expense of a thorough search while there is a world surplus.

Drilling in deep water at sea is a new phenomenon which is just beginning to be exploited. It is estimated that there are approximately 100 billion tons of oil under the continental shelves and slopes at depths of up to 1,000 feet. While total estimates of the yield of this new source can be at best simply fragmentary, it is believed that the ultimate total yield will be approximately 500 billion tons of oil excluding the output of the Communist countries which are also estimated to possess a considerable quantity.

In addition, large quantities of oil exist in tar sands such as the Athabaskan deposits of northern Alberta, Canada, and the Orinoco tar belt of Venezuela. The Athabaskan deposit is estimated at 112 billion tons from which approximately 42 billion tons of upgraded synthetic crude oil could be recovered. (This figure is similar to present total proved crude oil deposits.) Potential reserves of tar sand and shale oil represent, according to conservative estimates, at least four times the present proved crude oil reserves of the world. The first commercial plant at Athabasca came into operation within a month of the closing of the Suez Canal in June, 1967. It is located near the small town of Fort McMurray and is delivering up to 45,000 barrels (7 million liters) of synthetic crude oil per day. This deposit contains sufficient tar sands to keep the plant in operation for the next 30 years at the present rate of production. The extraction process in operation requires 90 million liters of water per day since 260 liters of water are required to process one ton of oil sand.

Natural Gas: Natural gas has relatively recently emerged as a primary source of energy. In 1962, 75 percent of world production was consumed in North America.

In the United States, natural gas supplies 30 percent of the country's energy requirements. In the North Sea enterprise of the Phillips group (the English portion of the Continental Shelf), England projects an extraction of 118 million m.³/day by 1975. Natural gas, unlike solid fuels, emits no smoke or ash; the heat of its flame is instantly controllable; and it can be turned off and on as simply as electricity. Thus it has become popular as a fuel in the domestic cooking, heating, and air-conditioning fields. In the industrial area, gas is used not only in fields where its cleanliness and controllability are particularly advantageous (such as food packaging, glass, ceramics, and metal processing), but also in such varied activities as generating electricity in a power station, crisping cereals, and tempering the nose cone of a missile. In addition, some natural gas is used as a chemical raw material. Commercial production of natural gas in the Caribbean area and South America is associated with oil.

At present, world resources of natural gas are believed to exceed 30 trillion m.³. Proved resources of natural gas in Western Europe are provisionally estimated at approximately 2.5 trillion cubic meters. The Middle East possesses reserves estimated at 6 trillion cubic meters, of which a considerable amount is to be found in Iran, Saudi Arabia, Kuwait, and Iraq. Algeria has dry (not associated with oil) gas reserves of two billion cubic meters. In addition, there are large fields in Libya. The exact extent of the reserves in countries in the Soviet Bloc is not known, but it is a fact that the Soviet Union has the second largest natural gas reserves — 4 trillion cubic meters. The majority of proved natural gas resources are found in North America, 9.5 trillion m.³, the United States having the biggest reserves, 8 trillion, and Canada possessing reserves of 1.5 trillion m.³ — the equivalent of at least 20 years supply at present production rates. Venezuela also possesses considerable reserves. Furthermore, it is estimated that there are undiscovered resources in this area five times as great. It appears that presently known world reserves could support a considerable expansion of natural gas throughout the world.

Coal: Coal is found in greater abundance and variety in North America than in any other part of the world. While the total amount of coal (in beds of a thickness of 30 meters and over, above depths of 1,200 meters for high grade coal, and above 500 meters for lignite) has not been estimated in detail, it is considered to range between 3,000 to 4,000 billion tons. Coal in the ground, which has been inventoried in detail, includes approximately 1,530 billion tons in beds of thickness of 35 meters and over (75 meters for lignite and sub-bituminous coal above a depth of 915 meters), of which approximately 50 percent is estimated to be recoverable, although a considerable amount of it at higher costs than those prevailing now. Recoverable reserves, available at present costs, from beds of a thickness less than 300 meters (1,000 feet) below the surface amount to 243 billion tons, assuming 50 percent recovery. Approximately 50 billion tons of the latter consist of high quality bituminous coal located in the Appalachian region. These recoverable reserves are equivalent to over 250 years of production at present rates. Hard coal reserves in Western Europe are estimated at approximately 400 billion tons, and measured reserves at approximately 200 billion tons. The latter, assuming 50 percent recovery, are equivalent to approximately 220 years of production at present rates.

This coal ranges in grade from high quality coking coal to steam coal. Anthracite coal is found in exportable quantities in North Vietnam and South Africa as well as in North America and the USSR. Western Europe possesses approximately 70 billion tons of lignite reserves which are equivalent to approximately 80 years of production at present rates. The Soviet Bloc (including China) is a major coal producing area. Their measured reserves are believed to approximate between 400 and 500 billion tons, representing some 200 years of production at present rates, assuming a recovery rate of 50 percent. Measured reserves in the remainder of the world are estimated at approximately 80 billion tons, which is a supply in excess of 100 years of production at present rates. Moreover, since large areas of the world are still unexplored, there are undoubtedly large potential reserves which will come to the fore in the future.

RESOURCES AND REQUIREMENTS

Since the OECD countries are the largest consumers of energy, and as such maintain the demand and production of the sources of energy, it is wise to focus attention on their energy requirements a bit more closely.

Great activity has taken place in the area of energy development and production in the OECD countries no less than in the rest of the world. Although all the OECD countries are not at the same stage of industrial development, the majority are well-advanced in this direction. The growth in their demand for energy is affected primarily by the increase in economic development within each country.

Since 1959, oil has taken the lead as the largest single source of energy in the OECD area as a whole. On the other hand, oil is found in abundance only in the North American sector of the OECD area. Thus the expansion of international trade in this commodity has been a constant one. Oil has moved out of the Middle East, the Caribbean area, and Africa to Western Europe and Japan primarily. The OECD area consumes approximately two-thirds of the world total of oil but produces only one-third. While the principal force of the impact of natural gas is only now beginning to make itself felt, it has all the earmarks of a future blockbuster. Europe has tended to lag behind the United States in natural gas development since, until recently, there were scanty reserves deriving, in no small part, from a lack of thorough exploration. Interest in the use of natural gas was stimulated by the shortage of oil during World War II. Difficulty in transportation at first impeded its development but in 1959 it became possible to transport liquified natural gas in especially constructed tankers by means of a freezing process. Freezing of natural gas had been demonstrated by the U.S. Bureau of Mines as early as 1917. Considerable basic research into the low temperature properties of metals and insulating materials was needed to properly construct tankers. Proven reserves of natural gas in the European OECD area are provisionally estimated at 2,500 billion m³. However, since more major fields have been

discovered within the past few years, and present exploration methods may cause drastic changes in the perspective at any time, a provisional estimate has even less significance than usual.

The overall rate of increase in the primary energy requirements forecast by OECD between 1964 and 1980 is, as has been mentioned, 3.7 percent annually. Specific demand for petroleum products, especially because of the expansion of the transportation sector, will increase rapidly in Europe. Energy consumption in Japan has increased sharply since 1950. (In the period between 1950 and 1964, consumption nearly quadrupled.) The industrial sector is responsible for over 50 percent of the total final energy consumption; the domestic and miscellaneous sector, approximately 19 percent; and transportation, approximately 23 percent. This compares with a figure for the industrial sector in OECD Europe of approximately 40 percent of fuel consumption, and less than 30 percent in North America, and the proportion in both these regions is expected to decline.

OECD Area Requirements For Primary Energy
(mtoe)

1950	1960	1964	1970	1980	2000
1,309	1,843	2,225	2,880	4,300	9,419*

* extrapolated

Source: OECD, *Energy Policy*

While energy demand will increase in all sectors during the period, the transportation and domestic sectors will witness the greatest increase. The requirements of the former should approximately double between 1964 and 1980. Per capita consumption will rise by approximately 65 percent in the OECD area between 1962 and 1980.

It must always be borne in mind that any estimate of future energy requirements is tentative and subject to a considerable margin of error partly because of various fluctuating elements. The

OECD has preferred to use estimates that reflect a high rate of economic growth so as not to fall prey to the dangers of underestimating future energy requirements.

Possible Import Requirements
(mtoe)

	OECD Europe	OECD North America	Japan
1970:			
Coal and lignite	(undetermined)	(net exports 145)	15
Oil			165
Total	515-560	145	180
1980:			
Coal and lignite	(undetermined)	(net exports 185)	20
Oil			370
Total	780-930	185	390

Source: OECD, *Energy Policy*

It is considered that coal reserves in the OECD area as a whole far exceed expected requirements. These reserves in each of the regions will suffice well beyond 1980, and those in North America are more than adequate to cover any shortages of particular qualities which might arise in the other two regions. In addition, countries outside the area should have supplies to export. As has been previously cited, the OECD area suffers from a deficiency of oil. Since proved reserves of oil are very unevenly distributed throughout the world, it is evident that, for each of the OECD regions, the majority of energy imports will continue to consist of oil. If we assume that total European imports are to be covered by oil, the overall import requirements of the OECD area could total approximately 870 million tons in 1970, and 1,485 million tons in 1980. Increased energy imports, however, could raise havoc with the balance of payments, or meet obstacles contingent upon assuring the security of supplies. The position of natural gas in the energy economies of the European and Japanese sectors of OECD will depend, not only upon the results of exploration currently

being undertaken, but also upon the success in cheapening the cost of transporting natural gas.

OECD - Europe. Total primary energy consumption in Western Europe expressed in terms of primary energy increased by approximately 98 percent, or at an average annual rate of approximately two percent in the period between 1929 and 1964. In periods of steady economic expansion uninterrupted by war or depression, such as in the period between 1947 and 1964, the average annual increase was 4.5 percent, and the underlying trend rate of growth above 4 percent per year. Total final consumption grew at a rate of approximately 3.9 percent between 1950 and 1964, and is expected to provide an average increase of approximately 3.7 percent per year up to 1980. Energy requirements in Western Europe are expected to increase at a slightly faster rate than in North America, almost doubling between 1964 and 1980 (from 751 mtoe to 1,400 mtoe, and 960 mtoe by 1970).

oil. Specified demand for petroleum products (demands that could not normally be satisfied by other forms of energy) is expected to increase its share from the present 17 percent to nearly 21 percent of future total primary fuel requirements. The expected expansion of the transportation sector will contribute largely to this result. The portion of the transportation sector in the total final consumption of oils is expected to increase from 20 percent in 1964 to 23 percent in 1980. At the present time, there is no alternative to oil as the fuel for air and motor transportation. A substantial decrease is expected in final energy requirements of railroads between 1960 and 1980 because of the increased efficiency occasioned by the electrification and dieselization. There is now a rapidly growing demand for non-energy products (chiefly bitumen, lubricants, and petrochemical feedstocks) which is expected to increase. Proved reserves in OECD Europe are small with respect to internal requirements - approximately 315 million tons. It is estimated that petroleum from reserves already being developed will continue up to 1980 and beyond, and exploration, partly in the North Sea, will also continue. While an increasingly large volume of oil will go into traditional fuel outlets, the proportion of crude oil destined for burning will decline.

However, the amount of oil produced each year going into chemicals will be much larger since the chemical industry is growing at the rate of 15 percent per year. (The oil industry is growing at the rate of eight percent.) Much experimentation is being undertaken by European chemical companies in the direction of new products based on oil for the petrochemical industry.

International trade in energy has expanded in countries both with and without indigenous resources. The share of the various producing regions in satisfying the total oil requirements in the European region has changed in recent years (1959 - 1964).

Share of the Various Oil Producing Regions
in Total Supply in OECD Europe

Region	1959	1964
Middle East	65.3	54.9
Caribbean	18.5	12.3
Soviet Bloc	5.6	6.3
Africa	1.2	19.4
Far East and others	1.1	1.1
Indigenous Production	8.3	6.0

Source: OECD, Energy Policy

While the Middle East remains the principal supplier, the proportion of supplies coming from Africa has risen 18-fold in the five year period between 1959 and 1964.

GAS. In OECD Europe, the exact picture with respect to reserves of natural gas is difficult to obtain. Indeed, as late as 1966, natural gas provided only two percent of Western Europe's energy. The greatest progress had been made in Austria where gas had been discovered in World War II, and the immediate postwar period of the Russian occupation. By 1955, natural gas accounted for more than 30 percent of all fuel used by power stations, and for most of the period since then, it has met more than 10 percent

of the country's total energy requirements. The French also began to develop natural gas facilities during World War II when they

World Oil Production - 1969
(million tons)

U.S.A.	510,000
Canada	63,000
Caribbean	206,000
Other Western Hemisphere	56,000
Total Western Hemisphere	835,000
Western Europe	17,000
Africa	231,000
Middle East	633,000
Soviet Union, East Europe, China	363,000
Other Eastern Hemisphere	54,000
Total Eastern Hemisphere	1,298,000
World Total	2,133,000

Source: Petroleum Press Service, 1970.

were suffering from a severe oil shortage. In addition to being sold directly to industrial consumers, French natural gas is fed into the national distribution system in place of town gas, and used as fuel for electricity generation. In south-west France, it has been responsible for the development of a local chemical industry using natural gas as a raw material for fertilizers and plastics. In 1966, natural gas accounted for 6 percent of France's overall fuel requirements. Natural gas was discovered in Italy in 1949. By 1962, it accounted for ten percent of Italian primary energy consumption. The Dutch natural gas field discovered at Groningen in 1959 is the second largest discovered in the world. It contains 1.8 trillion cubic meters. Since 1959, several more fields have been discovered in Holland. Gas sales in 1967 were estimated at more than seven billion cubic meters, of which over a billion cubic meters were exported to West Germany, Belgium, and France.

By 1975, it is estimated that natural gas will supply approximately 30 percent of Holland's primary energy requirements, and 14 percent of England's requirements, while for Western Europe as a whole, the share of natural gas will be between 10 to 15 percent.

In the North Sea enterprise, England projects an extraction of 118 million m.³/day by 1975. The French recently concluded the world's largest contract for a supply of liquid natural gas from Algeria starting in 1970-71. Under its terms, a peak 3.5 billion m.³/year will be shipped from a new plant at Skikda to Fos in the vicinity of Marseilles. Shipments in the first year will total 1.5 billion m.³ in 1975. The new Libyan plant at Marsael Brega is scheduled to produce 10 million m.³ per day and has already secured a twenty year contract with Italy with shipments to be received at La Spezia, and a fifteen year contract with Spain with shipments to be received at Barcelona. Proved reserves of natural gas in the European OECD area are provisionally estimated at approximately 2,500 billion m.³, of which reserves in the Netherlands are estimated at 1.8 billion m.³, in West Germany, 205 billion m.³; in France, 200 billion m.³; in Italy, 140 billion m.³; and in Austria, 20 billion m.³. Based upon production in 1966, current European reserves would be sufficient for more than 100 years. Since the proved reserve figure, among other things, does not include the gas discovered in the North Sea in England's portion of the Continental shelf, whose potential has been quoted above, one can see just how tentative these estimates are.

COAL. As previously noted, coal reserves in Western Europe are sizable. Total hard coal reserves are estimated at approximately 400 billion tons, and measured reserves are estimated at approximately 200 billion tons. The latter, with 50 percent recovery, would provide for approximately 220 years of production at present rates. The coal ranges in quality from high-grade coking coal to steam coal, and much of it is found in considerable quantities. Only anthracite coal is in short supply. Furthermore, Western Europe possesses considerable lignite reserves which are included among the region's cheapest energy resources. It is estimated that measured reserves are in excess of 70 billion tons, and are largely to be found in West Germany. If an

economically recoverable proportion of only 15 percent is assumed, these reserves correspond to approximately 80 years of production at present rates.

Solid fuel production in Europe varies from country to country. For example, in the United Kingdom, nearly 100 percent of the solid fuel used is indigenous; and in France and West Germany, two thirds and three-fourths of indigenous production respectively. Until World War II, indigenous production almost covered energy requirements. In 1929, 95 percent of total primary energy requirements (460 mtoe) were met by solid fuels, and only 4 percent came from oil. In 1964, the proportions were 49 percent approximately (380 mtoe) met by solid fuels; 45 percent approximately (334 mtoe) oil, and six percent natural gas and other fuels. This increase in the use of oil has resulted in the rise in the proportion of oil requirements met by imports from 15 percent as late as 1950, to 46 percent in 1964. Coal, consequently, has declined in industrial, transportation, and domestic uses. The market for coal, however, has increased where it is transformed into other forms of energy. In spite of the nationalization of the coal industry, European coal prices are higher than American, and oil prices are also highly competitive. Natural gas can also be expected to compete as present reserves are developed and new discoveries come into light. It is estimated that coal production will decline in the future, from 431 million tons in 1965 to between 375 to 400 million tons in 1970, to 300 to 380 million tons in 1980. Natural gas production is expected to rise from 18 billion cubic meters in 1970, to 80 to 120 million cubic meters in 1980. This would still represent only 10 percent of the total requirements, as compared with natural gas's provision of 30 percent of the requirements of North America.

It is estimated that oil production will rise from 21 million tons in 1964, to 25 to 30 million tons in 1970, to 20 to 40 million tons in 1980. Imports of petroleum products are expected to rise from 131 million tons in 1964, to 186 million tons in 1970, to 299 million tons in 1980. With a refining pattern similar to today's, estimated specific demands could involve the import of approximately 370 million tons of crude oil in 1970 and approximately 620 million tons in 1980 as a minimum. Thus

imports, which represented approximately 33 percent of total primary energy requirements in 1960 and 46 percent in 1964, could rise to 50 to 60 percent in 1970 and 55 to 65 percent in 1980.

PRICES OF PRIMARY FUELS IN OECD EUROPE. While trade secrecy prevents obtaining detailed figures for coal production costs, it is possible to quote pithead prices published in the European Coal and Steel Community countries which currently range from \$15 – \$17/ton for industrial and coking coals, and from \$30 – \$34/ton for anthracite. In addition, various taxes must be paid which are usually very low. However, actual production costs are frequently higher than these prices and are subsidized to a certain extent by governments. In the United States in 1964, average production costs were known to be somewhat below \$13/ton. Prices of heavy fuel oil in 1964 ranged from \$14 – \$15/ton in Italy to \$19 – \$20/ton in certain French and German cities. (Fuel oil prices rose by one or two dollars per ton in these areas by the end of 1965.) Scandinavian power supply companies have, in comparable years, bought heavy fuel oil for an average of \$12 – \$13/ton. These prices all include taxes. Thus fuel may be considered to be competitive with indigenous or imported coal in OECD Europe. This is not only true when comparing prices per unit of heat content but is even more obvious when allowances are made for differences in the efficiency of utilization. It is believed that natural gas from indigenous sources is also highly competitive in most of the European OECD region. The ability of imported natural gas to compete with other primary fuels in the market depends largely upon the transportation costs involved.

OECD – North America: While energy consumption in North America has rapidly increased over the last 30 or 40 years, the trend has fluctuated. In the period between 1937 and 1964, however, overall growth increased by 176 percent. In the first half of that period, the rate of increase was approximately 4.5 percent per year but in the last 14 years, it was closer to 3 percent, notwithstanding the fact that consumption per capita is considerably greater than the European figure (2.2 toe – Europe; 3 toe – North America). It is expected that by 1980, average per capita consumption for Europe will rise to 3.6 toe (in most highly

industrialized countries well over 5 toe) while per capita consumption in North America will range around 8.7 toe. The consumption pattern according to sectors of demand is similar to that of Europe except that the transportation sector accounts for a larger amount of total consumption (more than 25 percent).

The conventional reserves of North America (coal, oil, natural gas) are more than sufficient to meet its fuel requirements estimated at 1,341 mtoe in 1964, approximately 1,700 million tons of oil in 1970, and, conceivably 2,400 mtoe in 1980. The relative importance of coal in the total requirements has declined from 68 percent in 1929 to 22 percent in 1964. Coal has almost disappeared as fuel in the transportation market. In the domestic sector, it has dropped from 80 percent in 1929 to 5 percent in 1964 but productivity in American coal mines has more than doubled since World War II. On the other hand, natural gas, which provided 9 percent of the requirements in 1929, reached 32 percent of total requirements in 1964. Reserves of conventional resources in the region are more than sufficient to meet domestic requirements. Since indigenous oil, however, is more expensive than foreign oil, some is imported (20 percent of total oil requirements). Conversely, some 32 million tons of coal (23 mtoe) was exported in 1964. Total imports of all fuels in 1964 amounted to approximately 7 percent of the region's requirements. It is expected that 145 million tons of oil will be imported in 1970 and 185 million tons in 1980. It has been estimated that the United States could export up to 300 million tons of coal per year covering a wide range of quality. There are sufficient supplies of natural gas to permit exports.

OIL AND NATURAL GAS. North America is the only OECD area with important oil reserves. Proved reserves amount to one-sixth of the world total if tar sands and shale oil are excluded. Proved reserves in the United States have averaged approximately 12 to 15 years supply of current production rates since the turn of the century. The North American region currently produces, from indigenous resources, approximately four-fifths of its requirements, and its proved reserves of liquid petroleum total approximately 6 billion tons or 13 times the annual production rate. As far as ultimate reserves are concerned, it is believed that

approximately 40 billion tons are to be found in North America which could be recovered from extensions of existing fields, or in new fields considered to be recoverable under present conditions. In addition, there are the very large potential reserves of shale oil (mostly in the United States) and tar sands (in Canada). The expansion of the use of petroleum products has begun to decline, and the question of the size of indigenous reserves (which are growing) is less important than that of price. In the future, petroleum can look primarily to the transportation sector for a continuously increasing market. Domestic users seem likely to turn more and more to gas and electricity.

Seventy-five percent of the world's production of natural gas in 1962 was consumed in North America. Thus, it is not surprising to learn that the majority of proved reserves of natural gas are also located there, 8,500 billion cubic meters (7,400 mtoe) or at least 20 years supply at present production rates. Hitherto undiscovered but recoverable resources are believed to equal 5 times that amount. Natural gas is the new great competitor on the North American energy scene, both because of price and flexibility. At present, natural gas meets almost 30 percent of the potential power station demand for fossile fuels and more than 40 percent of the requirements for domestic space heating. There is enough gas in the region to encourage export but it is a matter of price and competition.

COAL. North America is also the richest OECD region with respect to coal resources, possessing a wide variety of coals in sufficient quantities to meet any foreseeable internal demand for any grade, and the ability to supply a large export market as well. Total coal and lignite in the ground, which have not been estimated in detail, are believed to approximate 3,000 to 4,000 billion tons; inventoried coal and lignite in the ground are estimated at about 1,530 billion tons; recoverable reserves available at present costs, assuming 50 percent recovery, total 243 billion tons, of which 50 billion tons are high quality bituminous coal in the Appalachian region. These recoverable reserves correspond to over 250 years of production at present rates. The use of coal has declined as automobiles, diesel trains, oil-fired ships, and planes do not require this fuel. In the domestic sector,

oil, gas, and electricity are more flexible and convenient fuels. Coal is expected to maintain or improve its marketing position in industry and power stations. In fact, coal has recently shown a significant growth as a fuel for power stations. Since reserves of coal are nearer major consuming centers, economic measures in the transmission of electricity at higher voltages could aid coal. The coal reserves of the United States provide an export potential of up to 300 million tons per year with a wide range of quality.

PRICES OF PRIMARY FUELS. In the United States, the low production cost of coal, because of favorable mining conditions, extensive modernization of pits, and decreased transportation costs, makes it especially competitive in certain areas of energy use. In 1964, the average price of coal per metric ton (f.o.b. mine) was \$4.53. The average price of imported residual fuel oil at New York Harbor was \$13.30/metric ton while natural gas cost \$6/ton of oil equivalent. The costs of producing crude oil in the United States are high as compared with world costs. Consequently, at domestic refineries, emphasis is placed upon the efficient production of more valuable products, and yields of residual fuel oil have been reduced with a resultant increase in imports. The average price of imported residual fuel oil in 1964 at New York Harbor as quoted above, rendered it competitive in certain areas. The average value of natural gas (at the well) in the United States in 1964 was \$0.54/cubic meter and this price has been below those prevailing for competing fuels in some regions. American coal in Europe has been priced at \$14.50/metric ton for coking coal, and \$12.50 to \$14.70/ton for steam coal (f.o.b. European ports) as of the end of 1965. It seems that allowing for large purchases, differences in grade, unloading, and inland transportation cost, American coal can compete with indigenous coal in Western Europe at prices at least \$2/ton below the European coal prices, with the margin diminishing with distance from the coast.

OECD - Japan: The greatest increase in energy consumption during the last decade has occurred in Japan. In the period between 1929 and 1964, energy consumption increased four and one-half times. (However, the 1950 figure was the same as 1929 due to the consequences of World War II, and thus the great

current increase occurred between 1950 and 1964.) In Japan, the industrial sector accounts for more than 50 percent of total final energy consumption; the domestic and miscellaneous sector, 19 percent; and transportation, 23 percent as compared with a figure of approximately 40 percent for industry in OECD Europe and less than 30 percent in North America (and the proportion in both regions is expected to decline). Japan's growth rate with respect to energy requirements is estimated at approximately 8 percent per year (8.3 percent up to 1970 and 7.2 percent in 1970 - 1980). The share of total final consumption of the transportation sector is expected to increase from 23 percent in 1964 to 28 percent in 1980. Independent requirements would continue to be more than 50 percent while the share of the domestic and miscellaneous sector would decrease. Japan's energy requirements could rise from the 1960 level of 86 mtoe to 240 mtoe by 1970 and to approximately 465 mtoe by 1980. Between 1950 and 1964, the share of coal in total indigenous production of commercial forms of energy fell from 85 to 79 percent. The share of natural gas and oil rose slightly. As late as 1950, indigenous resources supplied more than 90 percent of total requirements for primary energy. By 1964, imports represented more than 60 percent of total primary energy requirements. By 1970, they are expected to rise up to 70 percent; and 80 percent in 1980 (388 million tons).

OIL. Proved oil reserves in Japan are very small, both with respect to the remainder of the world and internal requirements. Thus, the greater part of Japan's fuel imports will consist of oil. Energy requirements in the transportation sector are expected to rise almost 7-fold between 1960 and 1980. This trend, plus the rapidly growing requirements of oil as an element in petrochemicals, lubricants, bitumen, and asphalt, will result in a specified demand for petroleum products amounting to approximately 51 million tons in 1970, and approximately 118 million tons by 1980. These needs will be chiefly met by importing crude oil at an estimated rate of 150 million tons in 1970 and 330 million tons in 1980. Fuel oil requirements are estimated at approximately 28 million tons in 1970, increasing to approximately 85 million tons in 1980.

GAS. Japan's proved reserves of natural gas are very small. Exploration is continuing but there are no indications of sufficient deposits to warrant a sizable production. It is expected that, with rapid exploitation of existing reserves, approximately 8 percent of total indigenous production in 1980 will be represented by natural gas. The Japanese have signed a contract with Canada to receive approximately 1.4 billion m³ of liquid gas annually to be piped from the Cock Inlet and Kenai gas fields starting in the spring of 1969.

COAL. Japan's total coal and lignite reserves are presently estimated at approximately 21 billion tons. Measured reserves are estimated at approximately 6 billion tons, about half of which is considered to be recoverable. This amounts to approximately 50 years of production at present rates. Because of shortages of coking coal and anthracite, these fuels are now being imported in considerable quantities. Production increased from approximately 39 million tons in 1950 to almost 60 million tons in 1961 but is now on the decline. As a fuel for final consumption, coal is expected to decrease from 18 million tons in 1964 to approximately 10 million tons in 1970, and 6 million tons in 1980. The proportionate contribution of coal to indigenous energy production will be 59 percent in 1980 as compared with approximately 79 percent in 1964. The requirements of Japan's steel industry for high-grade coking coal will cause coking coal requirements to rise from approximately 20 million tons in 1964, to approximately 29 million tons in 1970, and approximately 38 million tons in 1980. Small amounts of briquetting coal will also be required. Thus imports of high-grade coking coal have been estimated at approximately 20 million tons in 1970 and approximately 26 million tons in 1980.

PRICES OF PRIMARY FUELS. Coal production costs in Japan have fallen approximately 25 percent between 1958 and 1963, with a similar effect upon prices. In 1963, pithead prices for general industrial coal ranged from \$9 to \$15/ton according to grade which corresponded to approximately \$13 to \$21/ton of oil equivalent. At such prices, coal is frequently competitive with oil. Crude oil prices have fallen steadily since 1957 but wholesale

prices of fuel oil in 1963 fluctuated around \$20/ton, according to grade. Prices of crude oil are aligned with those of imported crude. Indigenous natural gas prices have also dropped, and in 1963, in terms of oil equivalent, were comparable with the lowest fuel oil prices at less than \$20/ton of oil equivalent.

Non-OECD Countries: The USSR has ample supplies of the three primary fuels which it consumes in large quantities. It is assumed that by 1980, per capita consumption in the USSR will be over 2 toe.

Proved reserves in the USSR were estimated at the end of 1967 to total approximately 4.4 billion tons (the total for the Soviet Bloc is 4.8 billion tons) which represent approximately 20 years production at present rates. In addition, approximately 27 billion tons of oil in the USSR are estimated to be recoverable from extensions of existing fields or in new fields which could be discoverable under present conditions. (The deepest zones in the oil-bearing areas in the South are particularly promising. High discharge deposits are now being worked in Mesozoic strata at depths of 3-4 thousand meters in the Northern Caucasus.) Approximately 6.3 percent of total imports in OECD Europe in 1964 (more than 25 million tons) was purchased from the Soviet Bloc. Petroleum production in the USSR amounted to more than 310 million tons in 1968. (From a planned 350 million tons of crude oil in 1970, Russia's target for 1975 is 460 million tons and for 1980, 630 million tons.) Soviet trading policy has always regarded the export of oil as a prime means of obtaining needed foreign exchange. It is apparent from recent negotiated long-term export contracts, newly constructed pipelines, and the large tanker building program under way that exports are likely to continue. Moreover, the required reserves are available to maintain or increase the present level of exports if they are exploited rapidly enough. It is possible that an increasing use of natural gas internally will release more oil for export. Thus, it seems that the USSR will make considerable efforts to continue and increase oil exports to OECD countries.

While natural gas is being rapidly developed in all the Soviet Bloc countries, the largest proved reserves appear to be located in the USSR which is so far the largest producer. They are estimated

at 4,000 billion m.³ (3,600 mtoe) or approximately 20 years production at present rates. It is planned to increase production rapidly. In 1965, 129,200 million m.³ of gas were produced in the Soviet Union; in 1966, 145,000 million m.³; in 1967, 160,000 million m.³; and it is expected that approximately 225-240,000 million m.³ will be produced in 1970. It is possible that there is a sufficient supply in the Soviet Bloc to warrant participation in a large-scale operation to promote the inter-regional trade of natural gas. Indeed, Italy, envisioning a tremendous increase in the use of natural gas, has, in addition to obtaining Lybian gas, contracted with the Soviet Union for a reported 6 billion m.³/year to be delivered via a new pipeline from Lvov to Trieste. The USSR is also interested in supplying Austria with one and one-half billion m.³/year, and France with two and one-half billion m.³/year. Moreover, the Russians have concluded a series of gas export arrangements with Finland which include the construction of a two hundred mile pipeline from thousand mile pipeline system (48-56 inches in diameter) to carry gas from the Tyumen area of western Siberia to the Urals, and the central and western regions of the Soviet Union. (In addition, however, the Russians have been importing Iranian gas in considerable quantities under the terms of a 15 year contract providing for a rate of delivery of 10 billion m.³/year.)

Coal is the biggest factor in energy supplies in the USSR, and it is, in fact, the world's number one producer. Production of coal and lignite amounted to approximately 595 million tons in 1967. Coal deposits are widely distributed. Measured reserves in the Soviet Bloc countries are thought to be between 400 and 500 billion tons, representing something like 200 years production at present rates, assuming 50 percent recovery. Although demand and production may be expected to expand rapidly for a period of years, reserves should be abundant enough to satisfy even fast-growing requirements for many centuries. Twenty large deposits have been discovered in the Kansk-Achinsk Basin in Siberia from which approximately 100,000 million tons of coal can be extracted by the open-cast method alone. The new Ekibastuz coal deposit in North Kazakhstan will supply 45 million tons of coal annually when its new coal pit is completed. While

large quantities of these reserves consist of brown coal, it is considered that availability and favorable geographic position indicate the strong likelihood that in the future the Soviet Bloc will remain a regular supplier to Western Europe and Japan. In 1964, the Soviet Bloc exported coal and lignite amounting to 19 million tons of coal equivalent to Western Europe and 1.1 million tons of coal to Japan.

Since exports of Soviet Bloc coal are often made with the main object of acquiring foreign exchange, prices do not always reflect production costs. Between 1933 and 1963, Polish coal was offered to European countries at prices which ranged from \$6 to \$20/ton. It must be noted that Soviet Bloc coal is often sold more cheaply than indigenous coal or coal imported from North America, and recent imports from the Soviet Bloc have tended to be of the same order as those from North America.

Energy Policy: Since energy is such a basic commodity in modern economies, two principal objectives of energy policy may be observed which are common to all countries of the OECD area:

The assurance of adequate and satisfactory secure supplies of the various forms of energy required to sustain economic growth;

The assurance of fair energy prices and the encouragement of the reduction of the cost of energy to the community as a whole as well as to the individual consumer.

While it would appear to be a simple process for most OECD countries to obtain sufficient supplies at fair, stable prices in the free market, especially because of the ample resources of energy available in the world, such is not so. The essential significance of energy supplies and the structural changes in the pattern of energy supply and demand have made it impractical for governments to rely completely upon market forces to insure the optimum development of the energy sector in their countries to achieve goals of their energy policy. Competition and free trade have been constrained by security factors, maintenance of the balance of payments, the need to maintain full employment, and regional, social, and economic issues. Although some areas and countries, such as North America, can cover all their supplies, still others must import to supplement their own resources. Thus, policy

measures to encourage exploitation and development will differ according to place.

Energy production not only helps to finance the national budget through taxation but also assists in balancing foreign payments. Home refining can yield substantial savings since the foreign exchange costs of imported products are usually greater than those of the crude oil needed to produce them. The production of competitive indigenous fuels aids in limiting the outflow of foreign exchange. Conversely, the United States has attempted to improve the competitive position of its coal in foreign markets through technological advance and contributing to the credit side of its balance of payments.

Protective tariffs have been erected of late to strengthen domestic producers against foreign competition, such as Middle Eastern and African oil in the United States, and North American coal in Europe. In addition, direct and indirect subsidies to indigenous energy include wage subsidies and subsidies to miner's pension schemes; subsidies for coal transport, or to secondary fuel industries using coal; recuperable advances; and low-interest and state-guaranteed loans. Import restrictions or quotas are common tools of protection. For example, coal imports to the United Kingdom are virtually prohibited. The United States has maintained a quota system to regulate the importation of crude oil and petroleum products since 1955. Taxation is also a formidable weapon for protecting indigenous industry.

The possibility of interruption of supply, as well as of artificial increase in the price of oil, has caused governments to diversify supply even if the actual price level were to rise. They have increased the number of suppliers by assisting in the creation of publically-owned or mixed companies to locate and produce oil abroad. For example, Japan has aided in the birth of two oil companies which now operate in Saudi Arabi, Kuwait, Indonesia, and Malaysia. Governments have also participated in the negotiation of oil import contracts or helped to insure that the national market is divided between different international, private, national or government-owned companies. To provide insurance against a temporary interruption of these vital supplies, most countries require stockpiling, particularly of oil. Economy in

energy costs has not always been reflected in prices paid by the ultimate consumer. However, costs and prices have been low enough to permit a sustained increase in total and per capita use of energy and steady economic growth in all OECD countries.

FUTURE ENERGY POLICY. It is obvious that modern countries (and thus, the OECD area) will require increasing quantities of energy to sustain economic growth since it is estimated that the total demand in 1980 will probably be more than twice as great as it was in 1960. It is further estimated that energy import requirements will grow at a rate of approximately 6 to 7 percent/year which will be even greater than the rate of increase of total consumption. While world physical resources will be sufficient to meet foreseeable demands in this period at costs similar to those of today, some indigenous producers are not only unlikely to improve their competitive positions but may lose ground. It is possible that nuclear demand will become fully competitive and, thus, be able to make a significant contribution to energy supplies by 1980.

It is also conceivable that natural gas, whether indigenously produced or imported as liquefied methane, will have an impact upon many European energy economies through the price mechanism and the competitive position of other forms of energy, whether imported or indigenous.

Although an increase in imports will necessitate a sizable expenditure of foreign exchange, this should not be a problem if the general trading position of the countries is good, and if their competitive position, given low energy costs, is unimpaired.

Even though some limited measures have been taken with respect to international cooperation (witness OECD, the Common Market, and Euratom), there is a need for obtaining policy objectives common to at least a number of countries, if not all. All nations are affected and concerned by energy costs, stability of consumer prices, regularity and security of supply, competition in energy markets, freedom of choice of consumers, safeguarding of public health, and conservation of resources. All the countries of the world are affected by energy policies but the developing countries which comprise the chief petroleum exporters, are in

particular affected. Here it is believed that the producing and consuming countries are interdependent.

There are some precedents for fruitful international cooperation in this area. Since World War II, international electric power grids have been established, one of which links many of the European countries in the OECD area, and another, the United States and Canada. In addition, recent and proposed developments in the long distance transportation of natural gas are encouraging. The Dutch and the French have a joint pipeline which could be extended from Paris to Lyons and Northern Italy. The Russians have proposed a pipeline from the Russo-Czech border to Italy and possibly to France.

The basic problem of energy policy consists in finding a satisfactory balance between sources to guarantee adequate and secure supplies at a low cost and fair price, on a long-term basis. It may be seen that, for many purposes, the various forms of primary energy are alternatives to each other. Through the consumer's freedom of choice, governments foster the development of different sources of energy from varying sources of supply in competition with each other. It also appears that ample energy supplies will be available for OECD countries at reasonable costs up to the year 2000 and beyond. Governments have an important role to play in finding a satisfactory balance between differing sources to ensure adequate and safe supplies at reasonable costs within the framework of the broader economic and social purposes that are the legitimate objects of national policy.

URANIUM

As was mentioned earlier in this book many authorities believe that the future mainstay for energy will be found in the use of uranium. The concluding pages of this chapter will be concerned with the vagaries of uranium-based energy; and of these, attention is placed on the sources of usable uranium in the world.

Due to the rapid expansion of nuclear generating capacity over the coming decade and the resulting demand for uranium,

consumption will rise during the seventies from some 18,500 short tons of U_3O_8 in 1970, to 44,000–54,000 short tons *per annum* by 1975, and will finally reach 73,000 to 106,000 short tons of U_3O_8 , by 1980. A significant rise in additional uranium production capacity is unlikely to be achieved unless preceded by the discovery of new low price uranium reserves.

*Expansion of Installed World Nuclear Generating Capacity
in Gigawatts (10^3 mwe)*

	1970	1975		1980	
		low	high	low	high
Western Europe	10.6	28.6	43.1	88	118
North America	13.1	65.8	74.1	128	184
Rest of the World	1.9	6.7	8.0	18	26
<i>Total Nuclear Capacity</i>	<i>25.6</i>	<i>100.1</i>	<i>125.2</i>	<i>234</i>	<i>328</i>

*Breakdown by Reactor Type
in gigawatts (10^3 mwe)*

	1970	1975		1980	
		low	high	low	high
Magnox Type Reactors	7.0	9.9	12.6	12.6	12.6
Light Water Reactors	16.6	78.5	90.3	173.3	230.0
Advanced Gas-Cooled Reactors	0.9	6.7	12.3	20.5	39.7
Heavy Water Reactors	1.0	5.3	8.0	13.4	22.4
High Temperature Gas-Cooled Reactors	0.1	0.7	2.0	13.1	22.9

Source: OECD *Uranium-Production and Short Term Demand*, January 1969 (A joint report by the E.N.E.A., and the I.A.E.A.).

The requirements of natural uranium by OECD countries are dependent upon the installed nuclear capacity, the types of

reactor, the efficiency of uranium utilization (a factor interconnected with the rate of introduction of fast reactors), and military demand. OECD estimates in the category range up to 1985 (with assumption that natural uranium will not be utilized to produce additional material for military purposes after 1970, and that further improvements in fuel utilization will be made). While the estimate of approximately 350,000 mwe of nuclear capacity to be installed by OECD countries by 1985 has already been mentioned, allowance in considering nuclear fuel demands must also be made for reactors in non-Communist countries outside OECD. Total usage over the whole period 1970 to 1985 is estimated at approximately 600,000 tons of uranium.

It is believed by the OECD that the generating costs of the thermal reactors which are expected to be the main source of nuclear power until the 1980's will not vary by more than 10 percent with respect to the price of uranium in the range of \$5 to \$10/pound. Estimates of uranium reserves in this price group in 1970 vary from approximately 500,000 to over 600,000 tons. It is expected that the price of uranium should remain on the average below \$10 in the 1980's. Moreover, at that time, breeders and reactors with higher conversion factors should be available which will aid in conserving uranium reserves. As for the additional uranium and thorium resources available in the higher price brackets, a doubling of the natural uranium price is estimated to cause an increase of only approximately 5 to 10 percent in total generating costs.

The main source of enriched uranium at the present time is the United States Atomic Energy Commission which is prepared to enter into long term contracts linked to the United States domestic price scale for the supply of uranium to specific foreign reactors over their operating life. The United Kingdom expects to be able not only to meet domestic requirements for low enriched uranium by production from its own diffusion plants in the future, but also has indicated a willingness to supply other nations. In addition, the French plant, now operating in the early stages, will be coming into full operation over the next few years. It is possible that American enrichment costs could be lower than the others because U.S. plants are already large in scale and possess

cheap supplies of electricity. While the costs of enrichment in diffusion plants would depend mainly upon the size of the plant, advancements in design, and the availability of cheap electricity, such costs could not differ more than in degree from prices presently quoted in the United States, and, furthermore, a charge of 20 percent in enrichment costs would not alter unit generating costs by more than 5 percent.

Nuclear power will make a definite contribution to energy supplies in the OECD area in the period until 1985. Dependence upon fossil fuels in Western Europe will, consequently, be reduced, rendering a more flexible energy policy. The impact upon fossil fuel prices for thermal power production will tend to be felt with an increasing effect in the direction of subsidy and protection.

The discovery of new uranium deposits was not the only factor in the fall in uranium prices — demand had also abated. Now, on the other hand, there is little danger of a slump in demand. Nuclear power stations replacing oil and coal-fired units in England and the United States are competitive with a price advantage which is constantly increasing. Moreover, it appears that the price of uranium forms such a tiny part of the cost of a modern nuclear power station that it could more than double without any visible effect upon the cost of the electricity product.

The English experiments to extract uranium economically from the sea, carried out in the last few years at and under the resources of the Atomic Energy Research Establishment at Harwell, appear to be nearing success. Present studies based upon the titanium hydroxide, which selectively absorbs uranium, might extract the metal at a cost of £25,000 to £40,000/ton. This would indicate a possible price of \$20/lb. of uranium oxide which is slightly higher than the estimates of \$12 to \$15/lb. for oxide from Swedish alum sales but much cheaper than the price of the granite ores (\$150 to \$200/lb.) which the Americans are starting to explore. Uranium is found in sea water at the rate of 3.34 millionths of a gram per liter (4,000 million tons).

Some have estimated the cost of extracting uranium from sea water to be approximately \$20/lb., at a time when uranium is priced on the market at \$5 to \$10/lb. This has spurred a new

search for native sources of uranium in England with improved air surveying and advanced prospecting techniques to detect uranium and thorium from 500 feet.

Nuclear Demand Forecast For Western Europe
(July 1967)

Year	Mean gwe	Low gwe	High gwe
1970	10	10	10
1975	40	40	40
1980	110	110	110
1985	230	218	242
1990	392	352	432
1995	580	504	656
2000	800	622	978
2005	1,060	770	1,350
2010	1,350	900	1,800

Source: OECD, *Illustrative Power Reactor Programmes*, May 1968.

Uranium resources throughout the world are grouped into three original price ranges (on the basis of 1967 costs) — less than \$10/lb., \$10 to \$15, and \$15 to \$30.

While large areas in Australia, Canada, the United States, France, Portugal, and Spain have been systematically prospected for uranium, prospecting has not been exhaustive, and further discoveries may be expected. In addition, many other countries (as well as large areas in Australia, Canada, South Africa, and the United States) remain virtually unprospected.

Mining uranium constitutes a big business in the United States. In 1967, ninety-five companies owned 368 mines of which twenty-four produce more than two-thirds of the ore. The latter is shipped to sixteen processing mills owned by fourteen companies to be converted to a concentrate. Cumulative requirements are expected to reach 250,000 tons of uranium concentrate by 1980, and annual requirements will approach 40,000 tons at that time as compared to 16,000 tons annually in 1971. The rate of

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exploration for uranium is constantly increasing as potential demand increases. Practically every major oil company has indicated an interest in searching for ore, and nearly a dozen are now actively engaged in this task. While uranium conversion is performed by private companies as well as government-owned plants, uranium enriching is still dependent upon the government. Moreover, estimated requirements for uranium enriching services are expected to represent approximately one-third of the total dollar value of the entire nuclear fuel cycle.

Reserves in conventional deposits in the \$10/lb. price range in the United States are located in relatively few large deposits and numerous small deposits. The 120 largest deposits contain over 90 percent of the reserve, and are relatively shallow (less than 800 feet deep, 50 percent is found in deposits less than 350 feet deep.) Approximately 55 percent of the reserve is located in the Colorado Plateau Area; approximately 35 percent in the Wyoming basins; and the remainder throughout the rest of Western United States. Besides conventional deposits, resources of uranium also exist in phosphate rock deposits and copper leaching solutions to be recovered as a by-product. Besides uranium reserves in conventional ore deposits in the \$10/lb. range, there are 650,000 short tons of U_3O_8 in the \$10 to \$15/lb. range; 350,000 short tons of U_3O_8 and 400,000 short tons of U_3O_8 in the \$15 to \$30/lb. range.

In the past few years, the discovery of new uranium deposits in Utah, New Mexico, Wyoming, Texas, and Washington, has been announced by several companies. In anticipation of future requirements, the U.S. uranium industry has undertaken a large exploration effort. In 1968 almost 24 million feet of exploration and development drilling was carried out. The estimate for four years (1968 through 1971) is nearly 100 million feet.

During 1967 5,500,000 tons of ore averaging 0.21 percent U_3O_8 were processed and slightly over 11,000 tons of U_3O_8 in concentrate were produced. Sixteen mills were operated by fourteen different companies, and were supported by the production of 368 mines. Thirty-seven of the mines were open-pit operations and 331 were underground. About 30 percent of the uranium produced comes from open-pit operations.

Several corporations have announced plans to build new mills of 2,000 tons and 7,000 tons per day capacity, scheduled to start production in 1970. By about 1973/75 the U.S. production capacity could be increased to 20,000 tons of U_3O_8 per year or more if production is needed. In addition to direct production from uranium ores, it is expected that by-product uranium will be produced in conjunction with phosphoric manufacture and leaching of copper ores. In 1967 about 3,750,000 tons of P_2O_5 equivalent was produced in wet process phosphoric acid plants in the United States. The uranium content of this material was approximately 1,800 tons of U_3O_8 . United States experience in producing by-product uranium in phosphoric acid plants in the 1950's indicates that production is feasible at U_3O_8 prices of \$10/lb. in large phosphoric acid plants. The initial production of such a by-product is anticipated by the mid-1970's.

The presence of uranium in copper leach solutions has been known for some time. Metallurgical research performed in the last few years indicates that the uranium can be economically recovered at less than \$10/lb. of U_3O_8 . Initial production may start in the early 1970's. U_3O_8 prices in the U.S. for sales to USAEC in 1969/70 are expected to average about \$5.85 with a maximum price of \$6.70. Sales have also been made to commercial buyers at prices which range from less than \$6/lb. in some early contracts to prices in later contracts of over \$7/lb. Uranium prices in the future will increasingly reflect and anticipate costs for delivery, development, and production from new deposits.

Substantial commercial-sales commitments have been made by U.S. producers. The quantities scheduled for delivery as of April 1, 1968, were as follows:

The bulk of present Canadian uranium resources is found in quartz pebble conglomerates. These deposits require relatively little exploration for their development. Pitchblende is found in the \$10 to \$15/lb. category. At present, there are 490,000 tons in the less than \$10/lb. category, 300,000 tons in the \$10 to \$15/lb. category, and 400,000 tons in the \$15 to \$30/lb. category. In Canada, there is an excellent geological potential for a substantial increase in resources beyond those presently known.

Year of U ₃ O ₈ delivery	U ₃ O ₈ (tons)	Cumulative quantity (tons)
1968	5,300	6,200
1969	4,500	10,700
1970	7,500	18,200
1971	9,800	28,000
1972	10,500	38,500
1973	7,900	46,400
1974	6,000	52,400
1975/77	6,200	58,600

Source: E.M.E.A. and I.A.E.A., *Uranium*, January, 1969.

Exploration for uranium is again under way in Canada. Mining companies, both foreign and domestic, and several petroleum companies have entered this field for the first time. The geological potential for deposits is considered to be excellent. Past experience has shown that there is a normal lag of about 8 to 10 years in Canada from the initial planning of an exploration program to the start of production. Today four companies produce 4,000 short tons of U₃O₈ per year for export contracts and the government stockpiling program. All produce from underground operations. More recently, a series of domestic and foreign commercial contracts have been accepted by several Canadian producers so that, as of January 1968, 40,000 tons of U₃O₈ have been committed for delivery between 1968 and 1983.

In France the total production capacity for uranium concentrated from national ores is 2,000 short tons of U₃O₈ a year. Resources are such that it should be possible to maintain this rate of production for about 30 years. It is now expected that the production capacities established in French speaking Africa, will amount to about 3,000 short tons of U₃O₈ per year, by about 1974/75.

While the principal effort in India is being made in the Singhbhum thrust belt in Bihar (some new deposits have recently been discovered there), exploration and core drilling is also being

undertaken in several other areas. The bulk of the evaluated reserves of 72,500 short tons in the Singhbhum area is of low grade uranium (only 15,000 short tons contain ore averaging 0.05 percent and above), and only approximately 1,000 short tons of estimated additional resources may be classified in the \$10 to \$15/lb. category (the cost being near the top of the range), and the remainder is considered to be marginal because of lack of by-products, and remoteness from the established mill which, of course, has an impact upon hauling.

Economic retrieval of the remainder of these reserves depends upon the use of large scale open-cast operations, low cost methods of treatment, and by-products of copper mining. The monazite deposits of India contain one part uranium to 25 - 30 parts thorium. Total resources from this source are estimated at 16,500 short tons, of which the reasonably assured 10,000 short tons of uranium are found mainly in the states of Kerala and Madras. While the ultimate price of these resources will be influenced by the market for the thorium and rare earth chlorides produced, the entire quantity at present may be provisionally in the over \$15/lb. category. Additional resources are likely to be found in the Singhbhum belt below the current explored depth of 600 meters, and the grade may possibly continue to improve with depth. Moreover, exploration below 600 meters is contemplated in the near future at Jaduguda and Narwapahar, and untested parts of the Singhbhum belt, covered with alluvium, are believed to be favorable for further near-surface deposits.

Uranium in South Africa is mainly a by-product of gold mining. Four thousand tons of U₃O₈, including that stockpiled, were expected to be produced during 1968. It is anticipated that South African production will continue to expand so as to raise production to some 6,000 tons annually before 1975.

Of the known resources of thorium (estimated at over half a million short tons of thorium oxide), more than half is to be found in placer deposits in India and other parts of the world, and a large part of the remainder is in veins in the United States and in uranium ores of the Elliot Lake district of Canada.

The conversion of primary energy into electricity is probably the most versatile transformation extant, and its importance may be measured by the fact that the need for electricity in the modern world, principally by the industrial nations of western Europe, North America, and Japan, is of tremendous proportions. While in 1964 these consumers utilized 21 percent of primary energy for generating electricity, by 1970 it is expected that 25 percent of primary energy will be needed, and will rise to 30 percent by 1980.

Electrical energy is particularly remarkable for its flexibility. It can be transported for hundreds of miles by high voltage transmission lines — 400 kv. in England, 735 kv. in Canada, 700 — 1500 kv. in the Soviet Union, and 1100 kv. in the United States. Transmission is also effected by using underwater cables e.g., to connect the English Channel between England and France, to connect Vancouver Island with mainland Canada, and to connect Sweden and Denmark. The development of high voltage transmission lines makes possible the construction of central power stations generating thousands of megawatts. Hydroelectric plants can then be located near remote waterfalls and thermal power plants can be situated near coal mines far from industrial centers, thus eliminating the necessity of transporting coal from the mine and polluting the air. Use of high voltage lines also allows for the construction of larger power stations fueled by oil which receive their oil supply directly from the sea or rivers which may be quite distant from consumer areas.

Nearly 12,000 km. of new transmission lines operating at 380/400 kv. should be connected to the existing network in the

period 1967-1970. An important part of the expansion program will involve additional interconnection between OECD European member-countries.

Transmission line expansion by the United States will continue to emphasize network interconnections. The introduction of DC transmission and 765 kv. AC are two important factors in this process. A major DC link operating at 750 kv. between the Pacific Northwest and the southern part of California should be completed in 1970, the same year the first 765 kv. AC lines should be energized. About 25,000 km. will be extra-high-voltage lines energized at 345 kv. and up.

Transmission line development in Canada will include further interconnections between the different provincial networks as well as additional lines with United States grids. Major transmission lines in Ontario and British Columbia will be based on 500 kv. as an operating voltage, while in Quebec an additional circuit of 735 kv. lines will be constructed.

A national or regional electrical structure permits a balanced electrical supply according to yearly peak season needs, and guarantees peak hour demands: it also makes possible, for example, to take advantage of the time difference between the east coast and the west coast of the United States and the differences in the hours of consumption demand and the electrical load. In the future, it is not impossible to foresee the expansion of the electrical supply grid over a wider area and even greater distances.

Today, we are witnesses to the increasing tendency in industrial nations to centralize electrical energy production in specialized power centers concentrated in a small number of large units of increasing size, fueled either by oil, coal, or uranium. The trend is to render the small units obsolete, thus taking them out of use. Those electrical power centers (either oil- or uranium-based) will no doubt be situated on the coastline as they will need great quantities of water for cooling. They will utilize national super grids and regional grids which will spread over the face of industrial Europe and North America.

It is possible, for example, to take advantage of the surplus of gas in Iran to produce electricity there and then to transport the

power by high voltage transmission lines to Russia and along a regional grid to Europe. The capital investment in pipes to carry gas to a European electrical plant is more expensive than the investment along the same distance in high voltage transmission lines from the source of gas in Iran to the regional grid of Europe. The same conclusion may be drawn regarding the vast reserves of gas in the Persian Gulf which are still not being utilized. In the future, it will be possible to produce electricity there and transport it by high voltage transmission lines westward to all the countries of the Middle East, Turkey, and the Balkans. These are merely middle-sized distances when compared with those traversed by high-voltage transmission lines in the United States, the Soviet Union, and England.

Estimated Growth of Electrical Generation 1970 - 1980

	1960	1970	1975	1980
Total net electricity generation, Twh.:				
North America	955	1,780	2,380	3,140
Europe	535	1,120	1,570	2,150
Japan	110	300	420	600
Total:	1,600	3,200	4,370	5,890
Total output capacity, Gw.:				
North America	193	375	500	650
Europe	131	290	400	540
Japan	23	65	90	130
Total:	347	730	990	1,320

Source: *Primary Energy*, OECD, 1966.

CONVENTIONAL THERMAL POWER PLANTS

At present, in Western Europe electricity is rapidly increasing its share of total final consumption. The growth rate for the period 1964-1980 is estimated at approximately 7 percent per year which would result in a rise from 756 Twh. in 1964 to 1,117 Twh. in 1970, and 2,130 Twh. in 1980. While the greatest proportionate increase in demand is estimated to occur in the domestic sector, other uses would still comprise 53 percent of the total.

Greater efficiency in electrical generation should be given impetus by technical advances and the use of larger units. The average efficiency of thermal generation could then rise less than 30 percent in 1964 to 35 percent by 1970, and 38 percent by 1980. Thus, primary fuel requirements for electrical generation in 1980 will still be three times what they were in 1960. In fact, requirements of primary energy for electrical generation would account for nearly half of the increase in the total primary energy demand between 1964 and 1980, and 32 percent of total energy used in 1980. Accordingly, primary energy requirements for electrical generation will rise from 185 million tons of oil equivalent in 1964 to 259 mtoe. in 1970 and 460 mtoe. in 1980. Competing for this market will be, in addition to indigenous coal, imported coal and oil, hydroelectric power, nuclear power, and natural gas.

Gross hydroelectric power production increased in the decade of the 50's but its share in total electricity production in the region as a whole declined from approximately 40 percent in 1950 to 32 percent in 1964. By 1980, most water power resources will have been harnessed and their gross production may rise from 243 Twh. in 1964 to 330 Twh. in 1970 and, perhaps, 470 Twh. in 1980. Thus, its share of total gross production would fall to about 20 percent. The reverse is the case of nuclear power. Its development is just beginning. As long as there is no shortage of fissile fuel, it should continue to develop with the prospect of steady reduction in the cost of generating electricity from nuclear sources. The rapid expansion of electrical uses, however, promises a growing competitive market for the conventional fuels at least

until the year 2000 (possibly 270 mtoe. in almost 1980). While natural gas will meet a share of the need, thermal electricity will continue to provide the primary market for indigenous coal. Hard coal, today, meets more than two-thirds of conventional fuel requirements for thermal generation. While many coal-fired stations, now in operation or in the construction stage, will continue to use coal much beyond 1980; their consumption may be on the decline before then. On the other hand, multi-fuel plants built in the later 1960's and 1970's will still be supplying power in 1980, and a share of the market should continue to participate in a demand for coal.

Electrical enterprises in the OECD European area should install 60,000 mw. of conventional thermal plants in the period 1967-1970. Approximately 45 percent, 26,900 mw., will consist of units of 500 mw. or over. An additional 19,300 mw. will consist of medium-size units ranging from 200-250 mw. Thus, 75 percent of planned additions of conventional thermal plants in Europe will consist of units of a size virtually non-existent in 1960. The largest conventional units scheduled to be put into service in this period will have ratings of 600 mw. and will be constructed in France, Germany, Italy, and the United Kingdom. Indeed, the United Kingdom has ordered units of 660 mw. to be commissioned after 1970.

The United States is probably the greatest user of electricity in the world. While at present electricity accounts for somewhat less than 30 percent of the nation's gross national energy consumption, it is expected to reach 50 percent by the turn of the century. Between 1967-1970, electricity projects will add 90,000 mw. of new generating capacity, making a total installed capacity of 340,000 mw. Seventy-six percent (68 Gw.) of the 90 Gw. to be installed by public utilities will be in conventional thermal plants; 13 percent (12 Gw.) in nuclear reactors; and 11 percent (10 Gw.) in hydroelectric plants, including pumped storage installations. By 1980 total electricity capacity in the United States is estimated at approximately 600,000 mwe. By the year 2000, it is estimated that total electrical capacity will reach 1,556,000 mw., and total US power consumption at eight trillion kwh. compared with 1.2 trillion kwh. in 1968.

The general trend toward larger plants has been spurred by the fact that the unit cost of electricity drops as generator size increases, and it is cheaper to build and operate one big plant than two or more smaller plants. It has been estimated that \$20/kwe. in total plant costs can be saved by increasing the size of the plant from 600 to 1000 mwe. At present in the United States power costs for energy delivered in the form of fossil fuel range from 17 to 35 cents/million btu.

By 1970, total production capacity of electricity in Canada will reach 40,000 mw., which includes an increase in capacity of approximately 10,800 mw. between 1967-1970. Canadian thermal capacity will be increased by approximately 5,600 mw. Proposed thermal plant expansion includes the installation of three conventional 500 mw. units through 1970.

Japanese electrical producing capacity should be increased by 37 percent between 1967-1970 with the addition of 14,000 mw. of new hydroelectric and thermal plants. Eighty percent of new Japanese capacity (11,500 mw.) will consist of units over 500 mw. Approximately 65 percent of the new conventional capacity will operate on heavy fuel oil (by 1980 fuel oil may cover 70 percent of the energy requirements of electrical industries, 23 percent of coal, 10 percent of imported natural gas).

Electricity has played a major role in the modernization of the Russian economy. In 1950, the amount of electricity generated in the U.S.S.R. was almost double that of 1940. Since 1955, it has been doubling every six years but some authorities have doubted that this rate will be sufficient to meet the planned growth of industrial production. In 1967, total electric output amounted to 589 billion kwh. and by 1970 it is expected to reach 839 billion kwh. (180 million kw.). It has been estimated that by 1980 installed capacity will increase to 600 million kw.; per capita consumption will be over 2 toe. In the last Seven Year Plan period, approximately two thirds of total postwar capacity of power plants was developed.

The USSR has a very large power potential in terms of her resources of coal, lignite, petroleum, gas, and water power. Large power stations in the country are fueled by lignite. Natural gas is a cheap source of power since labor costs are half of oil production

and one-twelfth of coal production. Hence, it is piped long distances such as from the producing regions of Bokhara-Khiva in Central Asia to the metallurgical center of the Urals. 500 kv. lines are now being built to transmit high electric current. Moreover, the Volgograd-Donbas 800 kv. DC line has been in operation for several years and the laying of a 750 kv. AC trunk line from the Konakovo Electric Station to Moscow is now nearing completion. The USSR plans to construct large electrical stations in the vicinity of cheap open-cast coal in the east and then to transmit the electricity in large amounts to the European area of the USSR. It is expected that preparations for the creation of a 1,500 kv. DC, 25,000 km. electric line will be completed in 1970, capable of carrying 6,000 mw. generated at a newly discovered, low grade coalfield near the Caspian Sea. Thus, consumers today are receiving approximately 93 percent of their electricity from the united power grids. These power grids permit the most rational use of the installed capacities of each electric station, assuring the consumer a reliable supply of electricity.

HYDROELECTRIC POWER

Hydroelectric power is only one of many elements in the total energy picture of the major regions, although it is a highly essential factor in certain individual countries, and, in others, the cheap power provided is of crucial significance in launching of new industries. The World Power Conference has estimated that all sites in the world that have been surveyed might be equipped to generate approximately 5,000 Twh. per year as compared with 800 Twh. produced today from hydroelectric power. Approximately 80 percent of the present world generation is in the OECD area but its development potential is not very large. Although by 1980 generation from water power in OECD countries could reach 1,100 Twh./year (120 mtoe.), the most economically exploitable sites will have already been harnessed. A number of sites, however, remain to be developed in the other main world regions and some of these have an extremely large potential. In addition, hydroelectric capacity may increase at a more rapid rate than its contribution to total energy consumption.

Hydroelectric plants that were to be installed from 1967-1970 in OECD Europe total approximately 16,500 mw. producing more than 44 billion Kwh./year. At that stage, total hydroelectric capacity will equal approximately 94 Gw., capable of an annual production under normal hydraulic conditions of 330 Twh. equal to approximately 29 percent of OECD Europe's predicted electricity production for 1970. It is estimated that 55 percent of the 600 Twh. of annual economic hydroelectric potential attributed to OECD Europe will have been harnessed. By the end of 1970, several major hydroelectric projects, with average potential output exceeding 1,000 Gwh. annually will have come into service. Of these, the Tonstad plant in Norway is the largest. It is capable of producing 1,700 Gwh. in a normal year, containing an installed capacity of 320 mw. Other larger plants scheduled for operation include the Wallsee Plant in lower Austria (204 mw., 1,300 Gwh.); the installations at Bourg-les-Valence and Vallabregues on the Rhône River in France (180 mw., median output, 1,000 Gwh.), and the Telsi plant in Sweden (300 mw., 1,250 Gwh.). The Alcantara storage project in Spain will be notable since it is to be equipped with 4 x 200 mw. generators, the largest hydroelectric unit in Europe.

Hydroelectrical power production has achieved the greatest boost from the development of pumped storage techniques. The increasing adoption of pumped storage techniques increases electrical production capacity. The rising role of large capital-intensive conventional and nuclear plants has emphasized the importance of the relatively recent form of using falling water, namely pumped storage. In such a complex water is pumped from a stream, lake, or other source of water into a natural or man-made reservoir at a higher location from which it is released to rush back down through the blades of a turbine at such times of the day as the system of which the pumped-storage installation forms a part demands extra amounts of energy.

The key to the economics of this combination is low-cost of peak power from other parts of the system which will be available for pumping water normally late at night, and on weekends. Operating existing thermal facilities for this purpose is profitable because the revenue from the power generated by the

pumped-storage plant exceeds the cost of producing the off-peak thermal power which consists almost solely of the cost of the fuel. A number of installations have operated in Europe for some time, but pumped storage has only recently gained major attention in the United States. Installed capacity is still quite small but there are several large projects afoot, of which the Storm King on the Hudson River, a short distance upstream from New York City, is the most prominent and, because of its impact on landscape and fish life, also the most controversial.

The development of the reversible pump-turbine, a device that functions as a pump on the way up, and as a turbine-generator on the way down, has done much to advance the use of pumped-storage. The resulting savings in capital costs help offset the drawback that some 25-30 percent less power is generated than is consumed in pumping.

Approximately two-thirds of the hydroelectric capacity which was to be installed in Europe between 1967-1970, and 80 percent of the additional energy which was to be developed, was to be in pumped-storage power plants. Of the new potential to be harnessed, over 25 percent was to be in Spain; slightly less than that in Norway; approximately 15 percent in France; and the remaining third in other parts of the OECD area.

Hydroelectric power production in the United Kingdom has been concentrated in Scotland and parts of Wales. Indeed, production of hydroelectric power by the North of Scotland Board increased approximately 800 percent in the period 1949-1962. The Loch Awe-Cruachan hydroelectric power plant, utilizing pumped-storage and with a capacity of 400 mw. came into operation in 1965. A similar installation at Balnau Ffestinoig in North Wales has a capacity of 320 mw. An additional pumped-storage facility is planned for Loch Sloy in Scotland.

Sweden lacks coal in any significant quantities but is fortunately possessed of abundant running water so that she is able to draw upon hydroelectric power for approximately 35 percent of total energy consumed. By the end of 1970, the large Telsi project (300 mw., 1,250 Gwh.) will be in operation. By the end of this decade, all the economic hydroelectric power resources will be harnessed. Sweden has conceived a plan for installing

pumped storage even in places where there is no suitable lower reservoir by means of blasting the latter artificially deep in the underground rock. The significance of such a system is that even the sea could serve as the upper reservoir.

In the United States, new hydroelectric power installations will average 2,500 mw./year between 1967-1970, of which one-third will be in pumped-storage stations. The average unit rating will be 75 mw. This new capacity of 10,000 mw. will increase the average production potential to 45 Twh. per year. It is estimated that by the end of 1970, total hydroelectric capacity installed will amount to 55 Gw. and average annual production to 250 twh. The Grand Coulee dam, with an installed capacity of 1,974 mw. and an ultimate capacity to be greatly expanded, includes two stations with a total capacity of 1,074 mw., and a third of twelve groups of 600 mw., so that by 1990 the three plants will have a total capacity of 9,174 mw.

The hydroelectric potential of the United States has been put at 134 million kw. by the Federal Power Commission; of this amount, 40 million kw. were developed for power generation at the end of 1968. About 10 percent of the undeveloped capacity is now under construction. Hydroelectric power development in the United States, however, is not the sole province of the government as it is in many other countries. A very large portion of this power is generated by private companies in the status of public utilities.

Pumped-storage power facilities in the United States tend to be large-scale in character. The planned capacity of the Storm King project on the Hudson River in New York is 1,350 mw.; another proposal envisions an installation of almost equal size on the Delaware River. Other projects on the Susquehanna River, the Arkansas River, and elsewhere run in multiples of 100 mw. Moreover, the term "peaking power" is quite elastic. The Storm King plant, for example, might be drawn upon to supply power from New York City during most of the day, then receive power from other units of the system for night pumping, with any net loss in water between the upper and the lower reservoirs suffered during the week to be made up by weekend pumping.

Existing Canadian hydroelectric capacity will be increased by approximately 5,000 mw. This new capacity will include the first

units as several major sites where final work will be completed in the early 1970's such as the Peace River project in British Columbia (2,270 mw.), the Manic 5 plant (1,344 mw.) on the Manicouagan River in Quebec, and the Mactaguac development on the Saint John River in New Brunswick. Large quantities of hydroelectric power have assisted Canada in the development of vast enterprises such as the aluminum installations at Kitimat in British Columbia, which opened in 1964 with a full installed capacity of 212,000 tons/year. The site also possesses sufficient power for an expansion by an additional 100,000 tons. Arvida, on the Saguenay River, is another large aluminum installation. In July, 1967, work was begun on the Churchill Falls, Labrador plant, which will eventually comprise ten groups of 450 mw. with an annual production of 32 billion kwh. The Nelson River project in Manitoba, based on six stations totalling 5,000 mw., also entered the construction phase in 1967.

In Japan hydroelectric power is an important indigenous source of energy which provided 6 percent of her energy in 1964. Approximately 56 percent of the total of almost 2,500 mw. of new hydroelectric capacity will consist of pumped-storage stations, but 950 mw. of natural storage plants will also be installed. These units will have a median potential of 3,340 Gwh. per year. By 1970, approximately 82 Twh. of annual production will be harnessed.

In the Soviet Union there is much unused water-power potential. A vast amount of water has been going to waste northwards across the Siberian tundra, and the partial harnessing of three great rivers there, the Irtysh, the Ob, and the Yenisei, has already begun. The largest power station either in the planning or construction stage is the Krasnoyarsk on the Yenisei River. It was originally designed to produce 3,200 mw. but further planning has increased it to at least 6,000 mw. Three 500 mw. water-turbine generator sets have already been installed and nine more are to follow. Four more stations are to be built on the Yenisei, producing together 25,000 mw. On the Lena River in Eastern Siberia, turbines of 700 mw capacity are planned. The Irkutsk station on the Upper Angara River has a capacity of 4,500 mw; the Bratsk station on the Lower Angara River, originally designed

for 3,200 mw, has been increased to 4,500 mw.; the Volgograd station, originally designed for 2,300 mw capacity, was increased to 2,500 mw; the Kuibyshev station, on the Volga River, was increased from 2,100 mw. to 2,300 mw. and at Saratov, also on the Volga River, is a 1,000 mw. plant. Some fifteen great dams and power stations harness the Volga River and its tributaries, producing electrical power estimated at 40 billion kwh. while 90 billion kwh. of electricity is visualized upon completion of the Arctic project with the power stations at Buktharma, Novosibirsk, and Irkutsk.

Of the various forms of energy available to man, the potential energy of water is the most convenient for conversion into power. There is no fuel problem at all, no waste products of any kind of which to dispose. The subsequent energy conversion process is extremely simple. The acquired potential energy of water is converted by gravity into kinetic energy, by the turbine into mechanical energy, and by direct coupling to a generator into electrical energy. Modern generators achieve efficiencies as high as 95 percent coupled to turbines operating at 90 percent efficiency that convert about 85 percent of the water available as potential energy into electricity. Control, too, is simple and the response to control immediate. In a steam-powered plant, there is a very considerable delay in bringing the generator from rest to high power – that is, the time taken to produce the required steam. The same is even more true of the nuclear power station, in which it may take hours or even days to bring a reactor core to the point where the fission chain reaction begins.

One of the major problems of electric power supply is the constantly changing pattern of demand. To meet these huge and sometimes rapid fluctuations in demand, power supply systems must be capable of rapid alternations in output. Of the three basic types of power stations in use today, the nuclear-powered plant is the least flexible. It takes literally days to bring a nuclear reactor up to full power output, and if power is to be produced economically from a nuclear reactor, output must remain virtually constant. The only method of reducing power temporarily at a nuclear power plant is to let steam run to waste. This expedient would defeat the entire object of nuclear power production, which

In 1969, a total of 100 stations with an aggregate capacity of 60,000 mw. were in operation, or were being built by six American companies, while there were 20 stations either under construction or on order in the European Community. These have a total capacity of 6,000 mw. and involve twelve contractors. In addition, the power of the water reactors in use or on order in the European Community already exceeds that of the gas-cooled reactors of European design.

*Estimated Growth of Nuclear Capacity and Generation
1970-1980*

Nuclear output capacity Gw.	1970	1975	1980
North America	7	30	90
Europe	10	40	90
Japan	1	5	10
Total:	18	75	190

Annual Nuclear generation Twh.

North America	50	210	630
Europe	70	280	630
Japan	5	35	70
Total:	125	525	1,330

Oil equivalent of nuclear heat released million tons:	31	120	205
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Source: *Energy Policy*, OECD, 1966.

REACTORS

In nuclear parlance, the term reactor refers to a device in which a controlled nuclear chain reaction takes place. This reaction involves the continued, self-sustaining splitting of the atoms of nuclear fuel resulting in a great release of energy, primarily in the

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is to produce electricity at low cost. This applies also, though to a lesser degree, to conventional coal-fired and oil-fired plants.

The hydroelectric power plant, by comparison, is extremely flexible. A trickle of water will keep the turbine and alternator spinning when the level is low, and it takes only seconds, or at most a minute or two, to open the water intake and bring the output up to its maximum. Shutting down is equally rapid. The flexibility of hydroelectric power is such that it can be used economically for all components of demand, and is eminently suited to this role.

NUCLEAR ENERGY

Whereas by 1960, OECD countries possessed only a few hundred mw. of nuclear capacity, comprising experimental or military production reactors, by 1966 installed nuclear capacity had risen to over 6,000 mw, mostly in the form of larger electricity producing reactors. By about 1970 nuclear power should be competitive for base load in most OECD countries even if conventional generating costs continue to decline. With an annual output of approximately 630 Twh. (145 mtoe.) from 90,000 mw. of nuclear capacity in 1980, nuclear power should be meeting approximately 20 percent of total electricity requirements. By 1970, the currently committed total of nuclear power should be 10,000 mwe.; by 1975 - 40,000 mwe.; by 1980 - 110,000 mwe. By 1985, it is estimated that approximately 350,000 mwe. of nuclear capacity might be installed in the OECD countries. The Euratom forecast for 1980 predicts a market for nuclear equipment among the members at between 60,000 - 70,000 mw., which represents a capital expenditure of approximately \$15 billion, approximately \$1 billion of this sum for fuel facilities, enrichment, and treatment. Approximately 16,000 mw. will consist of gas-cooled reactors, an equal amount will comprise water reactors, and one fifth of the total will consist of advanced converters such as the high temperature Dragon type or heavy water designs.

form of heat. A nuclear reactor performs the same function as the steam boiler in a conventional thermal power plant, but instead of generating heat by burning coal, oil or gas, it generates heat by the fission of uranium atoms. In a power reactor, this heat is used to generate electrical power. While all reactors convert some U^{238} to plutonium, the reactors which are more efficient at this conversion are known as *advanced converters*, and those reactors which produce more nuclear fuel than they consume from the natural uranium are known as *fast breeders*. This fuel utilization compares with 1 percent to 2 percent for present light water reactors. Besides offering an essentially unlimited supply of fuel, the fast breeder promises cheaper electricity.

The great diversity of reactor types results from different combinations of fuel material, moderator, and coolant which can be used in a reactor system. Basically, three fuel systems, three moderators, and five coolants have widespread application.

Competition in the reactor field is developed through more efficient endeavors in connection with the nuclear fuel cycle. Although nuclear fuel as mined contains very cheap energy, the whole cycle of ore processing, isotope separation, fuel element fabrication, fuel reprocessing, and waste disposal is relatively costly. The fuel cycle (up to the introduction of the fuel into the reactor) includes the exploration for, and the mining and milling of, uranium ore; converting uranium ore concentrate (U_3O_8) into uranium hexafluoride in separate gaseous diffusion plants; converting the enriched material into uranium dioxide (UO_2) pellets; manufacture of zirconium tubing used to hold the fuel pellets; and fabrication of fuel elements from the pellet-loaded tubes. While the fuel elements are assembled in the reactor at the core, at the other end of the cycle the reprocessing of spent fuel recovers the remaining usable enriched uranium, plutonium and other valuable isotopes, and finally disposes of radio-active wastes.

Although nuclear power plants are expected to have a life in excess of 30 years, a fuel charge (the core) is considered to possess a life of three to four years.

Fast Breeder Reactor. Fast breeder reactors are being developed in a number of OECD countries as a result of long-term considerations. They project the possibility of breeding, and there

are many scientists who feel that this method will prove to be the most economic way of utilizing the plutonium which is produced in thermal and fast reactors, ultimately very efficiently. It is expected that a 1980 on-power date can be maintained for a 1000 mwe. fast breeder reactor, fuelled with plutonium oxide fuel and cooled with liquid sodium. The development of advanced systems of nuclear reactors and the utilization of depleted uranium would serve to augment measurably the energy produced from the world's reserves of natural uranium which form the only natural source of fissile material. Eight fast breeder prototypes which are now being constructed or are to be constructed in the near future are in the 250–500 mwe. size.

Because of its ability through the conversion of U^{238} to Pu^{239} to produce considerably more plutonium than it consumes, the fast breeder is receiving priority in the U.S., Russia, and Western Europe. Successful performance of test facilities and demonstration plants in the 1970's should lead to commercial development of the fast breeder in the 1980's. The fast breeder's great advantage is that by using "fast" unmoderated neutrons, it should achieve a breeding ratio up to 1.4, thus producing up to 1,400 kg. of Pu^{239} for every 1,000 kg. U^{238} used up. Fuel cycle costs should be less than 0.5 mills/kwh. for light-water reactors in 1970 in the range of 2 mills/kwh. of the total generating cost.

In the OECD region, varying circumstances have influenced member countries in their choice of systems. The United States, for example, has concentrated at the outset on light-water moderated and cooled systems; Canada has elected to develop the use of heavy-water as moderator and coolant; and France and the United Kingdom have concentrated upon the gas-cooled, graphite moderated concept, while a number of other reactor types are at different stages of development in the member countries.

All of the commercial reactors now in operation or committed are thermal reactors. In thermal reactors, the neutrons are slowed by a moderator such as water to thermal energies where they are most likely to collide with other fuel atoms. Neutron absorbent rods control the rate at which this fission occurs, and the water coolant is pumped through the fuel assembly in order to transfer the heat into steam.

Light-Water Reactors (LWR). These are reactors which are moderated and cooled by light water. There are altogether 26 power reactors (about 3800 mwe.) in operation, with another 59 reactors (about 3900 mwe.) under construction and a further 52 (about 3900 mwe.) firmly planned. Of the LWR's in operation, 11 are in the range of 150–300 mwe. and two in the range 300–500 mwe., most of the others being small prototype plants. Of the plants under construction, 85 are over 500 mwe.

What may be called "standard LWR's" are of two types: pressurized-water reactors (PWR's) and boiling-water reactors (BWR's). Both use slightly enriched uranium dioxide fuel clad in zircaloy; both use steel reactor pressure vessels.

Heavy-Water Reactors (HWR). These are reactors which are moderated by heavy water. There are altogether seven power reactors (about 460 mwe.) in operation. Twelve reactors (about 2900 mwe.) are under construction and a further eight reactors (about 4400 mwe.) are firmly planned. The use of heavy water as the moderator permits a wide variety of designs e.g., there is a choice of several alternative coolants, and, with heavy-water cooling the choice of pressurized or boiling heavy water, and of pressure vessel or pressure-tube construction. This choice has made for diversification of effort on HWR's with the result that no one variant has received as intensive development as have the BWR and PWR. The type which accounts for most of the existing and planned HWR capacity is the CANDU-PHWR developed in Canada. This has natural uranium dioxide fuel and pressurized heavy water as the coolant. The CANDU-PHWR can be offered with appropriate guarantees, in size from 100 to 500 mwe. and above. Reactors of this type are under construction in India and Pakistan. Local fabrication of the fuel and manufacture of many components is possible. For the first Rajasthan unit, about 50 percent of the total project cost is payable in Indian currency and the corresponding percentage is expected to be much higher (about 80 percent) for the more recently ordered units in India.

Graphite-Moderated Gas-Cooled Reactors. Graphite-moderated reactors cooled by carbon dioxide and using natural uranium metal fuel have been developed by France and the United Kingdom. The technology of this system is very fully established

by the 31 reactors in operation (totalling over 5200 mwe.), most of which have achieved very high reliability and availability. However, largely because of its low power density, unit capital costs are high and increase rather rapidly with decrease in size. Although development of the system in large sizes is continuing in France, it has been superseded in the United Kingdom by the advanced gas-cooled reactor (AGR).

The AGR uses slightly enriched uranium dioxide fuel clad in stainless steel. The 33 mwe. prototype reactor has performed very satisfactorily since 1963. The eight commercial reactors under construction are all of 600–625 mwe. and the United Kingdom considers the AGR to be more suitable for plants in excess of 400–500 mwe.

The technology of high-temperature gas-cooled reactors (HTGR's) is not well-developed, and the system may be considered almost, if not quite, ready for commercial application. HTGR's use helium as the coolant and fuel elements consisting of coated particle fuel contained in a graphite structure. Among their advantages are good fuel utilization, high thermal efficiency, low fuel inventory and the choice of several alternative fuel cycles.

In the search for an economical type of fission reactor, the U.S. Atomic Energy Commission is now experimenting with fissionable, man-made uranium isotopes e.g., U^{233} . U^{233} does not occur in nature but is made by irradiating thorium. The first reactor to run on this fuel was originally brought up to the modest power level of 100 kw., and its power is being increased and watched for a year.

The deciding factor in the scale of installation of nuclear power reactors and its timing will depend primarily upon how competitive they will be with respect to conventional plants. In predicting comparison of costs of different types of generating plants, whether nuclear or conventional, reference should be in terms of their costs to the generating system as a whole over their life-time. While methods have been developed which take into consideration the effect upon total system costs of such characteristics as the proportion of thermal to hydro capacity, the trend of system load factor, the size of the base load, and the proportion of it available to nuclear power (which may vary

widely from one country to another), it is impossible to apply this technique in general studies.

Illustrative Generating Costs for LWR's (PWR's)

Net Plant Capacity (mwe.)	100	200	300	400	500
Direct capital costs (\$/kwe.)	280	210	180	160	147
Indirect capital costs* (\$/kwe.)	116	76	61	53	48
Total plant costs (\$/kwe.)	396	286	241	213	195
Fuel inventory (\$/kwe.)	40	33	30	28	26
Total capital costs (\$/kwe.)	436	319	271	241	221
Unit Costs (mill/kwh.)					
Operating and maintenance	1.30	0.70	0.50	0.40	0.30
Nuclear insurance	0.55	0.32	0.24	0.20	0.17
Fuel replacement	1.50	1.35	1.30	1.25	1.20
Sub-total:	3.4	2.4	2.0	1.9	1.7
Capital (at 7% F.C.R.)	4.4	3.2	2.7	2.4	2.2
Capital (at 14% F.C.R.)	8.7	6.4	5.4	4.8	4.4
Generating cost (at 7% F.C.R.)	7.8	5.6	4.7	4.3	3.9
Generating cost (at 14% F.C.R.)	12.1	8.8	7.4	6.7	6.1

*Includes interest during construction (13.8%) and contingency (3%).

Source: Briggs, D.S. et al., "Small and Medium Power Reactors: Present Status and Prospects," *Atomic Energy Review* VII (October 1969), 119.

Accordingly, a simpler method, based upon calculating generating costs on stated assumptions, is used to indicate the general trend. However, it must be borne in mind that even for stations of similar type and size, cost estimates are apt to vary from one country to another because of differences in engineering, building and material standards, and varying conventions with regard to financing and costing. Other complications arise because

of such commercial factors as the organization of the nuclear industry in different countries, the degree of local participation in nuclear construction, the size of the program over which overhead is to be spread, the degree of competition, and the desired profit margins.

Nuclear plants are determined cohorts of the economy of bigness since it is cheaper to construct and operate one big plant than two or more smaller plants. Even though it is more expensive to build a nuclear plant than a conventional plant of the same size, the former, if run at full capacity, is cheaper to operate per unit of energy produced as it becomes larger. This decreasing cost results from the manner in which the reactor is engineered. While the range of the capital of the different types of reactors is wide, the range is relatively narrow in computing generating costs. Station capital costs are estimated at between \$150-\$240/kwe. for a 400-500 mwe. single reactor station in the early 1970's, and between \$110-\$180/kwe. for larger stations incorporating units of approximately 1,100 mwe. or, perhaps, more by the late 1970's. These costs relate to net output and represent final costs to be paid by the operating utilities and cover both direct and indirect cost such as interest during construction. The assumption is that there will be, during the period under discussion (1970-1980), a nuclear industry efficiently organized enough to construct large power reactors and relate these to a series construction of reactors of a given type which might be in operation from 1970 and thereafter. The downward trend of costs reflects the efforts of economies of scale occurring from increased unit size as networks expand, standardization of design, engineering improvements evolving from increased knowledge, and flexibility as more and more stations are planned and built. The larger the installation the lower will be the projected cost. Fuel cycle costs are projected between 1.0-2.2 mills/kwh. for the early 1970's and between 0.8-1.8 mills/kwh. for the late 1970's. (The cost estimate for the heavy water reactor for this period is 0.5 mills/kwh.). These figures include the cost for the initial fuel charge which will vary from \$10-\$70/kwh. in the early 1970's, according to reactor type. Operating costs which include maintenance and other factors cannot be produced.

In spite of the fact that the United States continued after World War II to develop her atomic energy resources for various peaceful purposes, it has been the United Kingdom that has pioneered in the practical adaptation of atomic energy for industrial uses. The initial Magnox stations not only operated very successfully but also provided the country with valuable insurance against future uranium price rises in the form of plutonium which the reactor manufactures from uranium while working.

The capital cost of an AGR is now considerably lower than the original Magnox stations in the United Kingdom but high as compared with that of a coal or oil-fired station. A recent conventional coal-fired station, Brax, cost £54/kw., and the Pemborm oil-fired station cost as compared to £105/kw. for Dungeness "B", and for Hinkley Point "B" £94/kw. (including the cost of initial fuel). Generating costs, however, were 5.6 mill/unit for Dungeness "B", 5.2 mill/unit for Hinkley Point "B", 4.5 or 4.6 mill/unit for Hunterston "B" as opposed to 5.6 mill/unit for Drax. Furthermore, it is expected that with additional development, the AGR system costs should be reduced at least 20 percent.

It has been predicted that some forty nuclear power stations would be built in the period 1980-2000, at which time nuclear power would contribute more than coal or other conventional fuels to total energy consumption. Since nuclear generated electrical power requires vast quantities of water, nearly all presently existing stations are located on the tidewater.

Until the end of 1970, some 6,500 mwe. of nuclear capacity should be installed in OECD European member countries. These installations would increase the total nuclear capacity of OECD Europe to nearly 10,600 mwe. slightly more than 3.5 percent of total generating capacity. At the end of 1970, nine European member countries will have nuclear plants operating. The United Kingdom will account for the greatest capacity, 5,200 mw.; France will have installed 2,100 mw.; West Germany 1,000 mw.; Italy 600 mw.; and the remaining 1,600 mw will be distributed over Belgium, the Netherlands, Spain, Sweden, and Switzerland. Reactor sizes will range up to 600 mwe., although nearly 700 mwe. will be in experimental reactors of 100 mwe. or less. Although the rate of ordering nuclear stations has not been as

rapid in Europe during 1965-1968 as in the United States, the long-term plans for OECD are, nevertheless, as ambitious as those of the United States. Programs outlined through 1970 for the most part, call for the installation of reactors and generators in the 300-500 mwe. and 750 mwe. range. These promise major economies over conventional plants of the same size. These larger units will benefit from advances in pressure vessel construction and fuel fabrication resulting from experience gained by the first round of station construction between 1960 and 1970.

It is expected that in most OECD countries, nuclear power will compete with fossil-fuelled generating stations although further reduction in capital cost of conventional stations is expected, but at a slower rate than in the past. It is estimated that a representative value for the countries of the European Economic Community will be, for a 2 x 500 mwe. station, \$110/kwe. by about 1970, falling with further increases in station size to \$90/kwe. later in the 1970's. Fossil fuel costs vary widely, even within individual countries, based upon station location *vis a vis* fuel supplies. It has been further estimated that nuclear stations could be competitive on base load in the early 1970's with stations using fossil fuel costing approximately \$13/toe., and by the late 1970's, with stations using fuel costing about \$10/ton.

The British nuclear power program, as has been noted, is based on a series of gas-cooled, graphite-moderated reactors the first of which (Magnox) served the foundations of the nuclear programs and will continue in service throughout the life of these stations, which will last till towards the end of the century. The British fast reactor will be sodium cooled. One of its principal attractions in any country (i.e., the United Kingdom, which does not have a local supply of uranium) is that it utilizes by-product plutonium fuel from thermal reactors, and it produces from U²³⁸ more plutonium than it consumes. Hence, fast reactors are complementary to gas-graphite reactors, owing to their initial dependence upon the plutonium fuel produced by the latter. The United Kingdom will, therefore, derive great advantage from its present Magnox and AGR stations as these will provide the plutonium needed for the reactor stations of the future. The 1965 White Paper established for planning purposes a second nuclear

power program of 8,000 mwe. and the government envisages the completion of that program by the mid-1970's.

The British expect fast reactors to provide cheap electricity. Such stations are estimated to cost approximately £50/kw. installed, and generating costs are to be reduced ultimately to approximately 3 mill/kwh. Furthermore, considerable reduction in nuclear costs are confidently expected from developments in the AGR system for the period after 1975. The prototype of a fast reactor on a commercial scale (250 mwe.) is being built by the Atomic Energy Authority at Dounreay and is expected to be completed in the early 1970's. Assuming progress is maintained, it should be practicable to incorporate large fast reactors in the nuclear power programs for stations to be commissioned towards the end of the 1970's.

In the United Kingdom, operational nuclear capacity, together with capacity under construction or on order, has reached 10,185 mwe. The program of Magnox-type reactors is being completed with the power station at Oldbury, Gloucestershire (two groups of 312 mwe. each) and at Wylfa, Anglesey (four groups of 327 mwe. each). The construction of power stations of the AGR type at Dungeness B, Kent (1,200 mwe.) at Hinckley Point, Somerset (1,330 mwe.), and at Hunsterton B, Scotland (1,250 mwe.) have continued, and it has been decided to construct a fourth AGR type station at Hartport, Durham (1,250 mw.).

According to the *Economist* (August 30, 1969), both Electricite de France and the Commissariat a l'Energie Atomique (the only agencies in France concerned with nuclear power), have reached agreement about the American reactors, and it is likely that the next nuclear power station that France builds will be of an American design (BWR and RWR) fuelled by enriched uranium bought from America. After spending nearly \$7 billion on nuclear research in the past decade (about half of it, admittedly, on weapon design), France is now licensing reactors from the U.S. However, France has been spending heavily on the next generation of nuclear power design — the fast breeder reactors, of which "Phenix" is a prototype of 250 mwe. French nuclear power reactors include: Chinon — 80 mwe.; Chinon 2 — 230 mwe.;

Chinon 3 — 500 mwe.; St. Laurent 1 — 530 mwe.; St. Laurent 2 — 530 mwe. (under construction).

At the present time, all except one of the commercial reactors in operation or committed in the United States are thermal reactors. The basic difference in framework of the nuclear energy industry in the United States and Europe has, not surprisingly, produced varying results. The Europeans have proceeded to construct their initial plants at a more rapid rate because their industries and public utilities are nationally owned. In the United States, competitive and self-sustaining industrial capacity necessitates another approach. In the U.S., final decisions are made regarding plant design, research, development, and construction timing by the ultimate user.

In the United States, the nuclear industry is a big business which is growing larger every year. In early 1968, over 60 million kw. of civilian nuclear generating capacity were in operation, under construction, or definitely planned (more than the country's entire production twenty years previously). This total represented a capital investment of almost \$7 billion. While the use of atomic energy as a major power source progressed slowly at first, the Atomic Energy Commission in 1962 took a significant step in scaling up its Power Demonstration Reactor Program by offering to provide financial support for the design of water-cooled and moderated power reactors capable of producing at least 400 mw. of electricity. Then, in 1964, industry was for the first time permitted to own enriched uranium fuel and plutonium. The AEC has spent more than \$2 billion on civilian light-water plant technology, and the industry has spent about \$8 billion more to bring the light-water plants to their present stage of development.

In 1965, utilities ordered seven nuclear stations, six of which were purchased under the "turnkey" arrangement by which the contractor provided not only the reactor but also the complete electric plant, including the building and all the equipment. In 1967, utilities ordered a record number of nuclear steam supply system, and uranium exploration advanced at twice the pace of the previous year. Approximately half the new steam-electric

generating capacity announced during 1967 was nuclear capacity, 30 reactors with a combined capacity of over 24,000 mw. In 1967, also, there were more than 40,000 employees in the private atomic energy field working in over 400 industry units (including the total number of persons employed in AEC-owned, contractor-operated facilities, the number reached approximately 140,000). By 1980, it is expected that civilian needs for uranium concentrate will approach 40,000 tons annually; nuclear generating capacity will range from 120,000 to 170,000 mw. of electrical energy or between 30–35 percent of the country's total steam capacity, and total nuclear plant investment of utilities will amount to approximately \$19 billion investment increasing at an annual rate of approximately \$2.75 billion.

The average yearly increase in nuclear commitments between 1968–1980 in the U.S. is expected to approach 20,000 mw., perhaps 15 to 25 new plants/year; cumulative fuel costs will range around \$13 billion with accumulated sales of uranium ore of approximately \$4 billion (uranium enrichment in AEC diffusion plants – approximately \$600 million, and approximately \$400 million available to the rest of the western world); annual sales for fabricating cores approximately \$420 million, and annual replacement fuel sales almost \$300 million. Utilities have been awarded contracts for the construction of 14 nuclear-fuelled generating plants with combined capacity of approximately 13,000 mw. At the year's end (1968), U.S. nuclear-generating plants in service, under construction, and on order represented a combined output of about 64,000 mw., considerably more than twice the nuclear total for other nations together, and a capital investment of about \$10 billion. None of the newly ordered U.S. plants was small, and about half were rated at more than 1000 mw. each. The trend toward even larger projects was exemplified by a single order placed by a utility system for a three-unit station designed to generate 2,400 mw. Such a commitment would have been almost unimaginable a few years ago.

In 1968, the situation in the U.S. was the following: 15 nuclear power stations were in operation (2,798 mwe.), 31 under construction (22,500 mwe.) and 42 on order (34,980 mwe.). By far the greatest number of these reactors were light-water reactors,

and the two principal types, pressurized water reactors (PWR) and boiling water reactors (BWR), represented almost equal quantities in the U.S. nuclear program.

The first nuclear power station in Russia to produce electricity went into operation at Obninsk in 1954 with an electrical output of 5 mwe. It is still in use today. The first commercial station built at Troitsk has been in operation since 1958, using uranium with light-water cooling and graphite as the moderators, and its output has exceeded 600 mwe. Another station was built at Belyoarsk, in 1963, a boiling water reactor, and has produced about 100 mw. In 1967, a second station at Beloyarsk began to function and has produced 200 mw. Development work has been undertaken on two new types of reactors for uranium-graphite reactors, one of which would produce 1,000 mw. Here the cost of electric power should be cheaper than from present coal-fired stations. Projects were also developed for power stations with output of 2,000 – 4,000 mw. to prove that they could be competitive with ordinary thermal power stations even in locations where fuel was mined. At the end of 1963, a pressurized water reactor power station, which has an output of 210 mw., was put in operation at Novo Voronezh on the River Don. During this operational period, it became apparent that the capacity of the station could be raised to 240 mw. without any construction change. A second station with an output of 365 mw. went critical at the end of 1969 as well as construction on third and fourth blocks of the Novo Voronezh type. The two additional reactor blocks in this station will each have a capacity of 440 mw., coming into service within the next three to four years, and making it the largest station in the USSR. Each of the two new blocks will have two turbines of 220 mw., and this station is now beginning to compete successfully with conventional power stations even though it is located in close proximity to conventional coal reserves. Nuclear stations in operation or under construction in the USSR represent a capacity of about 6,000 mw.

In Japan around the mid 1980's, it is estimated that nuclear stations will represent between 15 and 20 percent of total installed capacity and will account for more than 25 percent of Japan's electrical production. In Japan, three stations (one PWR and two

BWR's) with a total capacity of 1,100 mw., were under construction in 1968, and a decision has been made to build three others, also made up of two BWR's and one PWR, with a total capacity of 1,780 mw. Japan has negotiated a long-term agreement with Canada to produce the necessary uranium to develop a sizable nuclear program. She now has two reactors operating and plans for 6,000 mwe. of installed capacity for 1975, and 30,000 - 40,000 mwe. by 1985.

In January 1968, 70 reactors were in service in the world, representing a total capacity of 10,195 mw. Of these, Gas-Graphite Reactors generate 6,700 mw.; Heavy-Water generate 450 mw.; Advanced Gas-Cooled Reactor (AGR) generate 40 mw.; and High-Temperature Gas-Cooled Reactor (HTGR) generate 55 mw. The total electric power produced by all these reactors was 38.6 billion kwh., less than 1 percent of world electrical power production in 1967.

One hundred eighteen power reactors were under construction or on order in the world, with a total capacity of 71,105 mw. Of these, Gas-Graphite Reactors will generate 4,700 mw.; Light-Water - 58,435 mw.; Heavy-Water - 3,680 mw.; AGR - 3,960 mw.; and HTGR - 330 mw.

WATER DESALINATION

In 1966, the United Nations issued end-of-the-century world population projections, specifying populations for the economically developed and developing areas. According to the U.N., the world population will rise from about 3.3 billion in 1966 to 7 billion by the year 2000 - an increase greater than two-fold. The U.N.'s projections indicate that the lesser developed areas will have a population of about 5.4 billion by the year 2000 (comparable with 2 billion in 1960), whereas the developed areas will have a population of about 1.6 billion. The population increase in the lesser developed areas will be more than five times as great as in the developed areas. In the next half century, under these projections, Asia will increase its proportion of the world population from about 53 to 57 percent, Africa from 9.4 to 13 percent. Among the more developed areas, Europe (excluding the U.S.S.R.) will decline from 13.5 to 6.8 percent of the world's total, North-America from 6.5 to 5.1 percent, and the U.S.S.R. from 7 to 5.5 percent. Concomitant with the population increase in the developing nations is the need for increased food production. Almost a doubling of world food output is now needed to supply a nutritionally adequate diet to the present populations in the lesser developed areas. If an adequate diet is to be maintained for a world population that will be more than double by 2000, food production must be more than quadrupled what it now should be.

The vast increase in world population has resulted in Malthusian anxieties as attempts are made to cope with the problem of feeding the hungry multitudes. Previously, as the population grew, the demand for more food was met by placing more land in production. However, the supply of new, productive, easily tilled agricultural land has almost been exhausted. There is not a shortage of land itself since the average fraction of the land used for agriculture is only 11 percent: the shortage is the availability of fertile, well-watered land. Most available land is too dry, too salty, too rocky, too wet, or in a climatic region where rains occur at the wrong time.

based upon an individual water supply or a large demand based on a water supply system. In the former instance, desalinated water will often be cheaper than the alternative of conveying water over long distances. In the latter instance, research and development projects will probably find the answer to current problems over the next twenty years.

The cost of desalinated water is related to technology, unit size and energy requirements, along with the art of application. Since a technological break-through in order to lower the cost of desalination appreciably is not expected in the near future, it can be assumed that, over the next twenty years, 50 cents/1,000 gal. is a more or less realistic estimate for the desalination cost of a single purpose plant.

Water desalination on a large scale for municipal, industrial, and agricultural purposes is presently and most economically accomplished by "dual purpose plants" which also generate power on a large scale.

Size is affected by market conditions. Since energy requirements are proportionate to output and do not decline noticeably with increase in unit size, market conditions would appear to mitigate against increase in unit size. Indeed, one study has indicated that, at a size between 50 - 100 million gal./day, unit costs would rise again. Energy costs can contribute to lowering desalination cost, and a considerable savings can be obtained in dual purpose plants.

The art of application refers to the various methods involved in the mixing and grading of water, the possible combined production of water with power, or water with minerals through utilization of brine. Thus costs to consumer can be reduced in unexpected ways. As costs are lowered, desalination will become an important factor in the economic development of arid areas, both in mineral and agricultural development. It is simpler to settle a desert once a water supply has been provided than to develop jungles, mountainous areas, and marshes.

In the summer of 1968, the U.S. Atomic Energy Commission sponsored a study of the food factory concept at Oak Ridge National Laboratory, Oak Ridge, Tennessee. The study explored the technical and economic feasibility of large nuclear powered

Since U.N. experts claim that there exists a supply of warm, fertile, accessible (albeit, arid) land which is several times greater than the total amount of land now used for major food production, and since much of this land lies close to the sea in latitudes potentially favorable for year-round crop production, it is not surprising to find almost feverish interest in the idea of large scale desalting of sea water to irrigate these coastal deserts.

The rapid spurt in interest in water desalination occurred after World War II, and in 1962 a United Nations world-wide survey discovered that approximately 80 land-based desalination plants were in operation, with a combined output of approximately 56 million gal./day, and in 1965 it was estimated by the same source that approximately 120 desalination plants were in operation or under construction with an output of 120 million gal./day. Approximately 90 percent of desalination plants are in developing countries and the majority in areas where they are the only source of water.

The consistent increase in the demand for water is associated with the growth in population, the rise in the standard of living, and the growth in commodity production and service industries. Since world population is rising now at an average rate of approximately 1 percent/year, it would appear that world water demand will double about every thirty-five years. The move from primitive to modern housing and rapid urbanization in all countries lead to even greater water requirements for human consumption. Increased production of goods, increased development of the chemical industry and its use of electricity, the rise in service industries (e.g., commercial laundries and hotels), all result in a concomitant increase in the demand for water.

Desalination is an answer to the problem. Its success will be interrelated with demand and cost for this type of water. There are three aspects to this demand; demand governed by geographic location, by economic sectors, and by size. Desalination is presently applied in arid areas, semi-arid areas, and areas of concentrated water demand. As to economic sectors where a desalinated water supply exists, desalination is in use in all sectors except irrigation. Demand by size involves either a small demand

agro-industrial complexes situated on an arid coastal desert. These complexes contained dual purpose power and desalting plants utilizing the inherent thermodynamic saving to be obtained. The electric power produced was to be consumed primarily within the complex, in captive power intensive processes, including the manufacture of electrolytic ammonia and phosphorous fertilizers, caustic soda and chlorine, and aluminum.

It would appear that arid tropical and semi-tropical regions with year-round growing climates are potentially capable of producing food at costs in or near the world market import price range, employing desalted water at prices ranging around 20 cents/1000 gal. The additional expense for this water can be at least partially offset by the opportunity to conduct intensive year-round food factory agriculture in favorable growing climates with many conditions under exceptionally good control.

The nuclear powered agro-industrial complex may well become an impressively powerful instrument for developing nations. But it is idle to speak of the agro-industrial complex unless the main ingredient – the cheap and reliable fast breeder reactor – is available. The food factory would naturally be accompanied by other energy-intensive chemical processes, particularly those based on electrolytic hydrogen which is so important for many heavy chemical processes (such as production of ammonia, or electrolytic refining of bauxite to produce aluminum, or the production of caustic soda and chlorine). Very cheap nuclear energy could become the basis for a new kind of industrial development in which energy intensive processes replace raw material intensive processes. With power available at 2 mills/kwh., many more industrial processes will be performed electrically than will other power at 3 mills/kwh. It appears that, while at 1.5 mills/kwh. the effect is very important, at 1 mill/kwh. the effect may be revolutionary.

WATER DESALINATION PROCESSES

The U.N. Inter-Regional Seminar on the economic Application of Water Desalination arrived at several relevant conclusions

relative to the effective use of water desalination as an additional source of water supply for current dwindling water sources. These include such observations that a decision to construct a water desalination plant requires the choice of the most appropriate desalinization process. These processes include multistage flash distillation (MSF); long-tube vertical effect distillation (LTV); multiple-effect boiling (falling film and submerged tube); vapor compression; freezing; electrodialysis; ion exchange; and reverse osmosis. Among all the processes which have been tested and put into operation, multistage flash evaporation for desalting sea water, and electrodialysis for treating brackish water are considered to possess the best immediate and potential economic advantages. Hence, it would appear to be desirable, depending upon the feed water source, that either of these two processes be evaluated in the majority of cases where employment of desalination is under consideration.

Dual purpose plants which can supply both desalinated water and electrical power possess advantages over water-only desalination plants in certain instances. In those areas where a need for additional power is evident, it is particularly important to undertake a study to decide which type of plant is more economical. Developing countries which do not have electrical and water grid systems, and also limited additional water and power requirements would seem to have little use for a large scale dual purpose plant, particularly when capital and, especially, the foreign exchange component is lacking. Distinction must be made, however, between locations where desalinated water might be a major or sole source of supply, and those where desalination is integrated within a system which is partly dependent upon desalination. In the initial instance, reliability in supply constitutes an overriding factor and additional investment will probably be required to ensure this element. The appropriate relationship between storage capacity and load factor of the plant is a consideration during the planning stage of a plant. Because the most economic combination of plant output and storage capacity must be secured, the planners must pay attention to this variable.

One method which is advocated to reduce desalinated water costs in the future (aside from advances in desalination

technology) is the further development of the application of methods which involve either the blending of high-cost desalinated water with low-cost brackish water to obtain an economically attractive product, or the production of desalinated water in combination with other products, either dual purpose as previously mentioned or multi-purpose, where minerals are extracted from the residual brine.

Reduction in the cost of desalination as a result of technological advance is expected to occur either through the improvement of known processes by employing less and cheaper material per unit of capacity and by developing better designs, or by developing new processes or known processes which have not yet been produced commercially. In the continuing research to produce reasonable cost large seawater evaporators, it has been discovered that heat transfer advancement is a considerable advantage to these designs. For example, it has been observed that doubly finned or doubly fluted vertical tubes gives several times the heat transfer of plain smooth tubes and can appreciably shrink the size and cost of a plant.

The economic development of water-short areas, which otherwise indicate economic growth potential, is dependent upon the availability of an adequate water supply. Presently existing desalination technology is satisfactory for application in areas where the need for water is primarily for such operations as tourism, mining, and industry. However, desalinated water for domestic use is apparently feasible only in such areas where the cost of water from existing and potential conventional sources is very high. The use of desalinated water for domestic purposes in any other area would seem to require subsidization based upon the purchasing power of the population and government policy. Even when desalinated water is blended with brackish water, it is too expensive at the moment for irrigation except in such cases as the supplementary irrigation of high value crops.

The goal of the U.S. Federal desalting program is to achieve fresh water from sea or other saline waters at low cost. The impetus for this operation lies in concern over the acute shortage of water in the arid areas of the country and the excessive use of underground waters. In 1900, the United States used

approximately 40 billion gal. of water/day; in 1920, approximately 80 billion gal./day; and in 1944, approximately 160 billion gal./day. Current use is estimated at approximately 360 billion gal./day and is increasing at the rate of approximately 25,000 gal./minute.

The short range objective of the U.S. Office of Saline Water is to provide processes and plant designs with the lowest possible engineering costs at the earliest possible moment. While the largest desalting plants built in the United States have design capacities of only 1 million gal./day, analysis is being undertaken to disclose the best method of incorporating into the conceptual design a desalting plant capable of producing 50 million gal./day. The long range goal of the Federal program is still basic research. Any knowledge generally applicable to any process of saline water conversion is of interest. Processes presently under study in the entire program include distillation (employing either nuclear or fossil fuels); membranes; crystallization; humidification; and chemical.

Among the experiments in the distillation field, research in the development of the long-tube vertical multiple effect distillation process to adapt it for use as a sea-water conversion method plays an important role. A demonstration plant has been built at Freeport, Texas, which has indicated a process potential of producing 1,000 gallons of fresh water for less than \$1 in the 1 million gal./day size range. When a mixture of vapor and hot brine emerges at the bottom of the evaporator during this process, the residue brine is pumped to the top of the second evaporator where, under slightly reduced pressure, it again falls through the inside of the tubes. The vapor, which has been produced in the first effect, flows to the outside of the tube bundle in the second effect. The vapor is then condensed to fresh water by yielding its latent heat of vaporization to the sea water dropping through the tubes which again causes part of the water in the tube to boil.

The plant at Freeport is composed of a series of 12 large evaporators, or effects, with approximately 500 tubes, 2 inches in diameter and about 40 feet long. These tubes, arranged vertically in the evaporators, give the process its name.

Another 7 million gal./day sea water conversion demonstration plant was built near San Diego, California; it uses a multi-stage flash distillation process. Here improved operating techniques resulted in an increase from 190°F. to 250°F. At the higher temperature, the plant succeeded in producing 1.4 million gal./day at only a slight increase in operating cost and no increase in capital investment. The cost of the fresh water produced in this fashion ranged from \$1 to \$1.25/1,000 gal. The process itself involves heating the sea water progressively, and introducing the brine finally into a large chamber where a pressure just below boiling point is maintained. This reduced pressure causes part of the liquid to boil or flash into steam. The process is repeated with the remaining brine at successively higher vacuum. The San-Diego plant utilizes 36 flashing stages.

A double phase change is involved, as we have seen, in the distillation process; from a liquid to a vapor and back to liquid. The crystallization process also requires a double phase change: from a liquid to a solid and back to a liquid. Since an ice crystal is pure water, a freeze-demineralization process must include freezing part of the sea water to form a slush or a slurry of ice crystals, removing the ice from the brine, washing it free of occluded salt, and melting it to fresh water.

Reverse osmosis is a process which has particular appeal since it avoids the expensive phase change required by both the distillation and crystallization processes and, instead, relies upon the application of hydrostatic pressure to saline water to produce a flow of fresh water through the membranes.

The electro dialysis process to desalt water utilizes direct electric current to separate soluble salt ions from the saline solution. The energy process, a function of the salts removed, currently precludes the application of the process to concentrated saline water sources. But at the present time, experiments are being conducted by the Israel Negev Research Institute for Arid Zone Research to evolve an electro dialysis process for sea water which may be competitive costwise with other known methods.

The electro dialysis process is believed to be potentially capable of desalinating brackish underground water to provide a main or supplementary source for a regional water supply. It can reduce

the salinity of marginal waters where comparatively low but excessive salinity may be injurious to certain agricultural commodities, and where the reduction can be achieved by a relatively uncomplicated application of the process. It can reject salt from coastal aquifers of high or relatively high salinities by disposal to the sea of concentrated brines from electro dialysis plants and returning the partially desalinated water to the system. It can control salinity of reclaimed sewage water which, after biological treatment, increases its salt concentration. The electro dialysis process has been developed commercially to include industrial chemical purification methods such as metal and salt recovery, and the concentration of salt brines for the industrial preparation of common salt. Most plants in use have a capacity of under 100 cubic meters (m^3) per day but some approach 1,000 m^3 per day and more, and there is a trend toward larger plants at the present time.

In operation at present are about 200 electro dialysis units, desalinating brackish water in widely distributed parts of the world.

The investment cost for a 1,000 m^3 electro dialysis plant at the present time varies between \$50 \$600/ m^3 /day. The expectation in the future is that it will be possible for electro dialysis plants to produce at 8 - 10 cents/ m^3 for chloridic water to 30 - 35 cents/ m^3 for highly sulphatic water. While the electro dialysis process has not been considered competitive in the past with evaporation as a means of sea water conversion, the Israeli experiment appears to indicate that the high energy requirements can be reduced quite considerably by operating the process at relatively high temperatures. A relatively complex plant is, however, still involved.

While it is apparent that sea water evaporation in a dual purpose plant structure is a highly advanced system for meeting water requirements, the cost factor seems to justify investigation of desalination by means of electro dialysis for naturally occurring underground saline water. This process can be considered to be economically viable where it can be employed in regions whose alternative supplies can only be furnished by underground pumping. The major proportion of the product cost is attributable

to capital charges. The process costs are affected by high membrane costs and limited life expectancy which has occurred because of paucity of demand which would be subject to change, of course, with increasing application.

The application of nuclear energy to dual purpose plants is favored because large scale power and water plants require large heat sources and, on a large scale, nuclear energy costs are relatively low. As a general rule, in a one million gallon per day desalination plant approximately one-third of the production cost is allocated to energy; one-third to capital cost; and one-third to operating and maintenance. Since operating and maintenance costs do not increase in proportion to size, while the costs for a one million gallon/day plant in the United States may be 20 cents-35 cents/1,000 gal., the comparable cost for a 50-150 million gallon/day plant will probably range around 6 cents-7 cents/1,000., of which 2 cents-3 cents/1,000 gal. are chemical costs if brine temperatures are over 200°F. Water costs in the 2-10 million gallon/day small dual purpose plant range are between 52 cents - 78 cents/1,000 gal., which is too expensive for each plant to provide a municipal or industrial supply. In a study of medium size plants, 50-150 million gal./day based on 7 percent fixed charges, 80 percent capacity factor, and gas fuel at 25 cents/10⁶ BTU, production costs ranged between 26 cents-37 cents/1,000 gal. (nuclear fuel is not cheaper); these costs were still too high, as United States experience in municipal and industrial water production costs are usually 10 cents-20 cents/1,000 gal. In a 1964 study of large plants, 170-970 million gal./day, and power plant size range from 180-680 mw., water costs based upon fossil fuel at 35 cents/10⁶ BTU, 7 percent fixed charges, and 80 percent capacity factor, water costs ranged between 26 cents-38 cents/1,000 gal., which was similar to the medium size plants.

The engineering feasibility study of the effect on costs of increasing capacity to 300 mw. in the proposed American-Israeli dual purpose desalting plant revealed that on a 1967 basis, the unit water cost/1,000 gal. of a 300 mwe. 100 mg/d. plant would be 23.6 cents at a fixed rate charge of 5 percent; 40.2 cents at a fixed rate charge of 7 percent; and 66.6 cents at a fixed rate charge of 10 percent while the unit water cost/1,000 gal. of a 200 mwe. 100

mg/d. plant on a 1965 basis was estimated at 28.6 cents; 43.4 cents; and 67.0 cents respectively. But if the capital cost for this plant is escalated to a 1967 basis to be comparable to the 300 mwe. 100 mgd. capital cost, the unit water costs of the smaller plant would increase. Thus, the actual unit water cost benefits of greater capacity are even larger than cited above.

Conveying water from large dual purpose plants can add another 7-11 cents/1,000 gal. to production costs if the conveyance distance is close to 40 miles. Furthermore, distribution costs and general administration overhead costs could range around 15 cents/1,000 gal., making the actual consumer price approximately 25 cents/1,000 gal. higher than production costs.

Most present-day dual purpose plants employ multi-stage flash evaporators because they are the most successful in operation and cost evaluation. Either a highly industrialized nation or a developing country lacking power can readily absorb large blocks of power with its required large quantities of water. However, since it is unlikely that water and power demand will be required in exactly the same area, the dual purpose plant may have a deterrent effect upon the flexibility of plant location. Thus, costs for power transmission (if the plant is not sited on an established power station), water conveyance (if it is not located near an established aqueduct), or a water distribution system must be computed. Also, large reactor size necessary for dual purpose plants presents a siting problem because of the increased fission product inventory. Thus, to evaluate the real cost of a dual purpose system, not only power and water production costs of a plant but also the effect upon the total power and water system must be considered.

Among the features which distinguish desalinated water from natural water are: 1) the relatively unlimited supply of saline water in the oceans are subject only to the capacity of a desalination plant as compared to limited capacity of natural sources; 2) there is no seasonal or annual variation in availability of supply; 3) the cost structure of desalinated water contains a high element of equipment cost and energy input so that if a country must import this equipment and energy, the desalinated

water project must be considered foreign exchange intensive; and 4) historical water rights do not apply to a desalinated water supply which permits marketing of the product to be feasible in every conceivable form.

One of the definite advantages of the construction and operation of a desalination plant, especially one which employs a distillation process, is that an economic source of chemical raw materials can be created by producing a concentrated brine in addition to fresh water. This effluent brine from a saline conversion plant will probably display the following characteristics: its dissolved-solids content will approximate 18 percent and be primarily composed of sodium and chlorine, along with smaller amounts of magnesium, potassium, and sulphur, with a fairly minute quantity of calcium; the bicarbonate content and the oxygen content will be negligible; total alkalinity will approach zero; and brine will be available at approximately 120°F., with a specific gravity of approximately 1.12.

Approximately 20 minerals can be recovered from effluent brine subject to the processes of evaporation and fractional crystallization. In a desalination plant desalting sea water, bromine is found in the effluent brine at a concentration of approximately 300 parts/1 million, and can be recovered. Further processing of materials directly obtained from the brine will result in such products as chlorine, caustic soda, and magnesium oxide. Brine-based chemicals, such as potassium chloride, potassium sulphate, magnesium oxide, and magnesium sulphate need little or no further processing to be used as commercial fertilizers. Knowledge of large-scale recovery of basic minerals from brines is widespread, and much research has been undertaken at commercial levels.

The chemical industry is characterized by a relatively high total plant investment with respect to the total value of the materials produced. The cost of energy is generally a relatively large item in the total operating expense of such a plant. This energy usually takes the form of heat as required for evaporation and drying, or electrical energy to operate pumps and other equipment, or for electrolysis. Thus, a change in the unit cost of fuel or electrical power would considerably effect total operating cost.

In a combination water and chemical plant the production of chemicals should be economic, competitive, and unsubsidized. Hence, the design of the desalination plant and even the process may be influenced by the effort to achieve the optimum combination of plants. The water and chemical plants would share facilities with a single steam and electrical source to serve both plants. They would also share shops and offices and, to a lesser degree, operating and maintenance personnel, along with supervisory labor to reduce dual facility capital and operating costs.

As the desalination process discharges brine containing dissolved minerals at a notably greater concentration than originally present in the feed water, the result is that the form of these minerals as potential raw materials for finished products is upgraded. The value added by the desalination process can be measured directly by a comparison of the decrease in recovery cost from the effluent brine with feed water recovery cost. A sizable decrease in recovery costs may be noted. Present technology involving effluent brine in the distillation process can result, for example, in savings in fuel cost alone of \$1.00/ton of salt produced depending upon feed water components and fuel cost.

A desalination plant also makes possible the immediate and constant availability of effluent brine to an adjacent mineral recovery plant at a small fraction of the cost entailed either to supply brine continuously from a subterranean source or to deliver sea water from an arm of the ocean to a plant site.

It is necessary to view the desirability of chemical recovery from saline waters as part of the total resource requirements of a region. Since the desalination plant must, as previously noted, be competitive, a known aquifer carrying a natural brine saturated with sodium chloride and containing 3 or 4 percent of magnesium chloride, is to be preferred since saleable forms of sodium chloride and magnesium could be produced from the more concentrated natural source at a lower cost than from that discharged by the desalination plant. While the desalination process increases the value of its feed brine with respect to mineral content, it may not be sufficient to justify its use economically in comparison with other purposes.

If sodium chloride were recovered from the effluent brine of a large proposed desalination plant in the region possessing some existing solar production, the latter could promptly be expanded by substituting the effluent brine for the sea water fed to the solar ponds. However, solar salt production must be in proximity to the desalination plant site or it could be forced out of existence. The large desalination plant which was planned for the Pacific coast of the United States at total recovery would yield a quantity of sodium chloride in its effluent brine equal to the existing consumption of this material in the entire western region of the United States.

As a final comment on the current state of affairs in desalination, it is interesting to note four differing proposals. The first is the Bolsa Island project, designed for a highly industrialized society; the second is the United States proposal for a dual purpose plant designed for the Middle East, particularly Israel; the third is the desalination aspect of the Oakridge agro-industrial scheme; and the fourth is the Soviet Union's Caspian Sea project.

California is the fastest growing state in the United States. The need for large amounts of fresh water and great amounts of electricity is felt more in Southern California than in other parts of the state. The need could theoretically be filled by the construction of a dual purpose water desalination plant. A joint agreement to build such a plant on a man-made island called Bolsa Island in Southern California was reached by the City of Los Angeles, the Metropolitan Water District of Southern California, the U.S. Department of Interior, and the U.S. Atomic Energy Commission. The plant was to have a capacity of 150 million gallons of water a day along with the generation of 1.8 million kw. of electricity. The original cost estimate in 1966 including water conveyance and power transmission was \$444 million, or 20 cents/1000 gal. In 1968, the re-estimated cost was \$765 million. The cost of the water became too high: 40 cents/1000 gal. The project was shelved.

The second proposal is the Israel-U.S. project to build a desalination plant on the Mediterranean sea-shore south of Ashdod. The plant was first envisioned to embody a nuclear steam-generating facility using a conventional light-water nuclear reactor. The generators would produce 300 mwe, of saleable

electrical power at 5.3 mills/kwh., and 100 million gallons of water daily. Total capital outlay was estimated in 1967 to be \$214 to \$240 million, or 24 cents to 67 cents/1000 gal. The over-all proposal was designed to satisfy the existing needs at the time. But in January 1969 the U.S. authorized only \$40 million for the financing of the further development of the desalting techniques, and this amount has been recently cut in half. The U.S., in making the grant to Israel, has allowed Israel to choose its own power source for the plant in Ashdod. What this indicates is that the U.S. now realizes that it is not the source of power for the desalination process, it is the *desalination process* itself, which needs to be refined.

The third major proposal in recent years is the Oakridge study of agro-industrial complexes alluded to in the previous pages. The philosophy behind the Oakridge proposal was that a power-water-agricultural complex could be conceived and adapted for use in varying geographic locations — in arid zones or along sea coasts. Several over-all designs were considered in the proposal: both "near-term" light-water reactors and "far-term" fast breeders reactors for the power source, and near-and-far-term desalting equipment. Total capital outlay would be about \$1.5 to \$2 billion. Despite the careful cost estimates in the Oakridge study, the concept itself can be criticized on other grounds. The desalination equipment suggested is that which is to be developed over the next decade or two, and not that based upon technologies tested in application today. Rapid breakthroughs in equipment do not seem forthcoming. The proposal assumes rather sophisticated agricultural techniques which are simply absent in most developing areas. Clawson, *et al.* question the agricultural aspect of the proposal and observe: "If these great agro-industrial complexes are economically feasible with desalted water, why are they not feasible with natural flow or ground water; it is simply 'water.'" (*Science* CLXIV, 2247).

Scientists are looking forward to the results of the dual purpose plant being built on the Caspian Sea by the Soviet Union. The source of energy is a fast breeder atomic reactor. If nuclear energy can be economically used for desalination, then future hopes may rest on the practicability of the fast breeder reactor.

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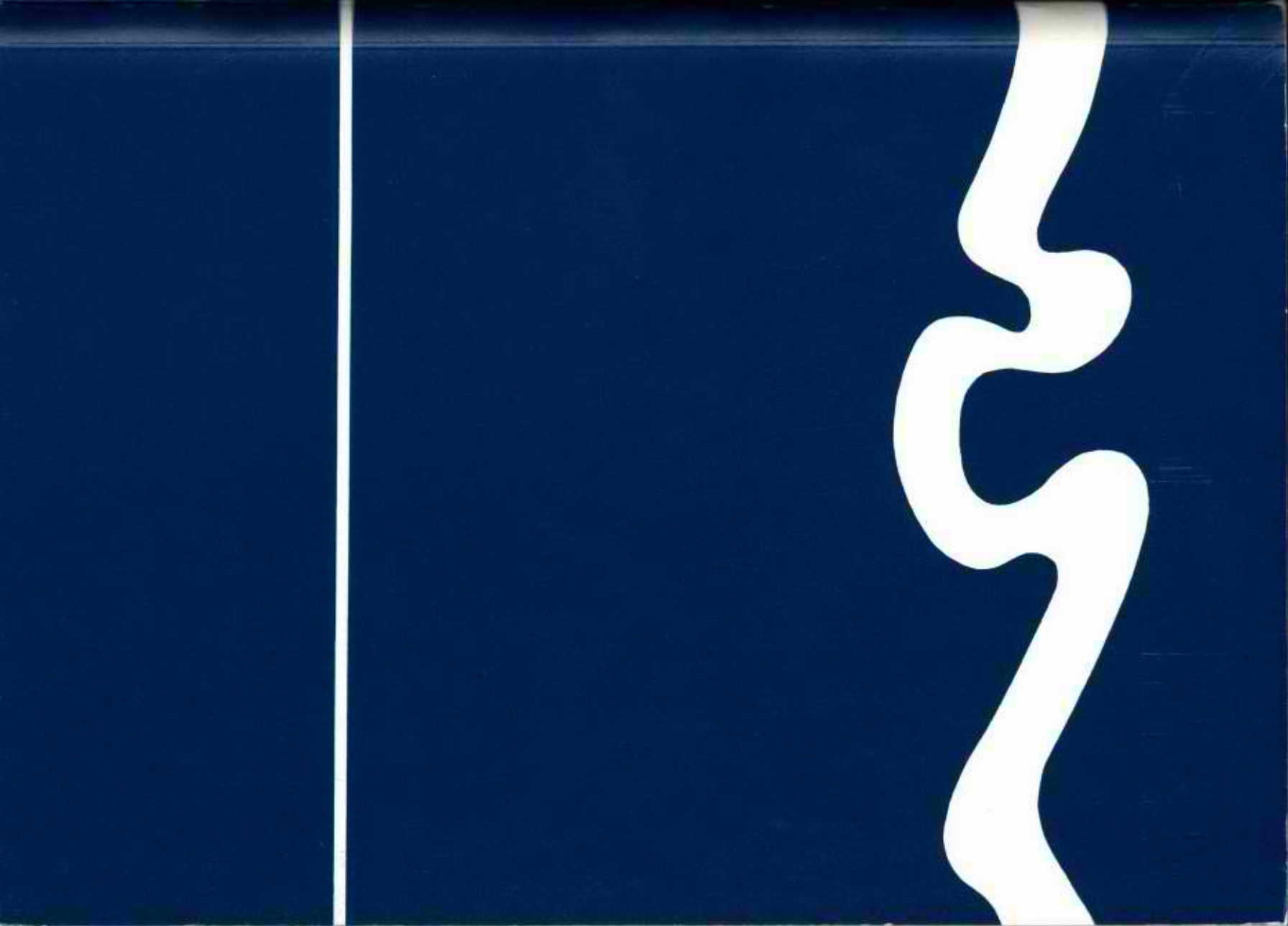
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3.3.71

Subject: A proposal for a Regional Development Plan for Peacetime

It is our pleasant duty to place before you a proposed regional development plan for peacetime, sponsored by the Rehovot Group.

This plan is concerned with the vast development possibilities encompassed by the Jordan Rift Valley, the Dead Sea, and the Arava Valley. This peacetime development plan envisages economic cooperation between the three countries bordering on the Jordan Rift Valley, Israel, Jordan and Lebanon. Jordan requires massive economic development in order to absorb hundreds of thousands of refugees by means of the development of a productive economy. Lebanon needs to develop industry as a base for her economy and, in this way, to be enabled to exterminate the refugee camps within her territory which are disturbing her delicate social, ethnic, and political balance. Israel requires industrialization on the very highest level to absorb more and more immigrants from Russia and the western countries.

The activation of this plan will bring in its footsteps a manpower shortage, and, thus, result in the elimination of the refugee camps. The State of Jordan will be interested in conserving the manpower within her boundaries for the purposes of economic development and to extol national power. Therefore, the refugee problem can be resolved within the State of Jordan.

Industrialization of the Arava and Development of the Jordan Rift Valley

It is possible to convert the Arava into an industrial blast furnace on an international scale. Here are found raw materials in the Dead Sea; here exists a potential for obtaining vast quantities of electrical energy by taking advantage of the difference in the water level between the Red Sea and the Dead Sea, which is cheaper than the electrical energy produced by atomic reactors. Petrochemical and fertilizer industries can be established in the Arava utilizing the potash and phosphates, and nitrogen fertilizers.



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A light metals industry based upon such metals as magnesium and aluminum can be established, and science-based industries whose range meets the needs of the State of Israel to absorb scientific workers from the United States, other western countries, and Russia.

Advanced conditions to develop industry exist here. It is expected that the Arava Valley will become one of the most advanced industrial centres in the geographical area located between the industrial states of Europe and Japan.

The Jordan Valley, through its exploitation of the waters of the Yarmuk and the Litani, can provide for the settlement of some 70,000 families (350,000 persons) engaged in agriculture, tourism, light industries, and crafts. The probable monetary investment is estimated at \$1½ billion.

On the other hand, in the Arava, which is the region designated for industrial development, it will be possible to settle 160,000 families (approximately 800,000 persons) to be employed in industry, business, tourism, and shipping. The probable monetary investment is estimated at \$1.7 billion.

The estimated period of time to execute the plan is ten years.

Eilat and Aqaba

The rate of development of the Arava will affect the rate of growth of the two cities - Eilat and Aqaba, which will be management centres for the industrial firms, trade centres, and centres of tourism, banking, and shipping. The population of these two cities is likely to reach approximately 500,000 persons.

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Furthermore, the fact must be faced that, at some time at the beginning of the third millenium, there will be a need to dig an international navigation canal, parallel to the Suez Canal (which will be incapable of carrying the full navigational load), and the only possible route is from the Bay of Eilat along the Arava, through the Jordan Rift Valley and Jezreel Valley to the Bay of Haifa. William Allen of England proposed this plan from Haifa to Aqaba in 1855, before Ferdinand de Lesseps of France suggested joining the Mediterranean Sea to the Indian Ocean.

The late Professor Chaim Weizmann, first President of the State of Israel, relates in his book, "Trial and Error", in the section, "The Decision", the story of a dramatic journey to U.S. President Harry S. Truman to persuade him to include Eilat within the boundaries of the State of Israel, and the reason which convinced Truman, according to the late President Weizmann's testimony, was not only that Israel required Eilat as an outlet to the Indian Ocean but that the day would come when a navigation canal would be dug from the Mediterranean Sea to the Red Sea. President Truman in his book, "The Years of Trial and Hope", Part 12, expands the description of this dramatic meeting, which took place at the White House on March 18, 1948.

In this connection, it is most important that Sharm-El-Sheikh and the Straits of Tiran remain in the hands of Israel, including a land connection to Eilat. And the route that the canal will follow along the Arava will be in Israel's possession (with slight boundary changes to the east along the Arava). Thus a greater importance is attached to the cities of Eilat and Aqaba, and the industrial region in the Arava, which will be located, when the project is completed, on an international maritime transportation artery, joining the Mediterranean Sea with the Indian Ocean.

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Execution of the Plan - with the participation of industrial nations

Approximately 3.5 billion dollars will be needed to finance this development plan which should not be undertaken by means of grants or donations, but rather according to a basic economic plan which will be conducive to financial investment.

The proposed method of financing this project is entirely based upon inviting the international corporations known as "Internationals" to locate their industries in the Arava.

1. They have an accumulation of international experience and knowledge in the systems and methods of industrial production;
2. They are in the forefront of research and development of new and modern materials;
3. They possess international markets;
4. They have the capacity to finance such projects.

The following advantages will accrue to these basic industries:

1. Favourable political climate;
2. Cheap and abundant energy;
3. Stockpile of local raw materials and easy access to additional raw materials from all over the world, via water transportation;
4. Distribution of finished products to all points on the globe via the above mentioned water transportation;
5. Productive and superior manpower - scientists, technologists, and technicians.

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The political climate of many Asian and African countries must be taken into account as deterring a warm reception to these companies. On the other hand, the geographical location of the Arava as a bridge between the continents of Africa and Asia to Europe besides the basic advantages that exist, and the guarantee of political stability under Israeli sponsorship, can provide these industries with a most suitable basis for their activities.

By inviting the participation of the international companies that enjoy the sponsorship of such industrial nations as the United States, Canada, the European countries, and Japan, together with the economic challenge presented, the latter will become partners in the economic development of this region and provide a solution to the refugee problem which will contribute to the political stability and the peace and well-being of the area.

The project will have economic relevance, and the same "authority" which will undertake the execution of the regional development plan will require long-term loans of 25-35 years duration, which they could obtain from the international financial institutions that deal with such projects, including the World Bank.

Moreover, if there is no plan to industrialize the Arava, the entire problem of rehabilitating the refugees becomes the concern of the welfare agencies. Monetary grants will have to be obtained from such governments as the United States, and, perhaps West Germany. The Government of Israel will have to contribute a portion of these reparations, perhaps even from her regular budget, and the annual sum total of these monies devoted to refugee rehabilitation will be small while the period of rehabilitation will be extended. (It could entail an entire generation, or even longer,

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and there is no guarantee that this plan would cope with the natural increase of the population). Basic rehabilitation processes would take the place of the building of an advanced economy. This is simply an unacceptable alternative for the State of Israel whose interests demand the creation of a flourishing and variegated economy.

Political Implications

There are many aspects to this plan. With respect to the eastern border of Jordan, there are definite political and defense advantages for Israel. With respect to the basic energy balance, it would render the country independent of external sources. And, furthermore, there is the possibility that, in the future, (not too remote) an international navigation canal will flow within the territory of the State of Israel.

We are all cautious, and we know that the Prime Minister is similarly inclined in her conduct of the political negotiations to hammer out a peace settlement but it seems to us that it would be both wise and prudent if we took the initiative in planning the economic development of the region.

The international community has great confidence in all the recommendations for development proposed by Israel, and any Israeli initiative in this area can only result, to the best of our understanding, in the country's obtaining a status of increased political power. We think that this development plan will capture the imagination of western statesmen and economists.

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The Nixon Plan for Middle Eastern Regional Development

This plan could be suggested to the President of the United States to bestow his sponsorship of this regional development project, and be known as the "Nixon Plan for Middle Eastern Regional Development" (in the same manner as the celebrated Eisenhower Plan was suggested and formulated in the '50s).

It would be desirable that the initiative for the regional development come from the President of the United States so that a working partnership could be created between the nations thus involved in the region, and, of course, that Mr. Nixon exercise his influence to secure the practical achievement of the plan.

The Rehovot Group attaches great significance to this plan, which has such a great bearing for all the inhabitants of the region, both from the factor of economic development and that of political stability, and offers excellent possibilities for an active and satisfying cooperation with our neighbours, within the framework of a joint development plan.

The Rehovot Group desires to continue to study, weigh and examine this plan in the scientific and technological sphere, and to cooperate with persons and international institutions who are interested in this type of proposal, such as the Simon Marks-Edmund de Rothschild group in England, Dr. Edward Teller, and the Atomic Energy Commission in the United States, as well as other persons or institutions that will join in participating to advance this plan.

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The Jordan Rift Development Plan is one of the promising and challenging proposals in the entire spectrum of peace initiatives awaiting Israel, and her pursuance of this plan is made possible, given the initiative and know-how available to the country.

- Attached:
1. The Jordan Rift Valley - A Challenge for Development
(publication);
 2. Various position papers which served as background for
the discussions of the Rehovot Group in connection with
this subject.



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15th November, 1970.

Professor M. Feldman,
The Weizmann Institute of Science,
Rehovoth.

The Jordan Rift Valley - A Challenge for Development

Dear Sir,

You invited me to appear before the "Rehovoth Group" (on November 25, 1970) to present and define the plan for a regional development scheme in the Jordan Rift Valley.

Those who did not have the opportunity of reading the book in its entirety will receive a more comprehensive impression of the plan if they read the introduction. For obvious reasons, I could not emphasize in the book the important considerations of this plan, from the point of view of the essential interests of Israel and the West, and I will try to complete the picture now.

This plan is comparable to the Eisenhower-Strauss Plan which was suggested to Israel, Egypt and Jordan in an earlier period. However, that plan, based upon nuclear energy centres for industrial and agro-industrial complexes and water desalination, was intended to solve existing development problems by means which are to be developed over the next decade or two, rather than those based upon technologies tested in application today.

The publication before you is concerned with the vast development possibilities encompassed by the Jordan Valley and the Arava. However, there is no need to wait for the technology of the future to turn this Valley into an industrial complex on the highest level.

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There is a vast electrical energy potential here which can be produced more cheaply than the electrical energy produced by an atomic reactor power plant. Furthermore, conditions necessary to develop an industry based upon the most advanced technology exist.

This is a development plan for peace involving economic cooperation between the three countries bordering on this valley; Israel, Jordan, and Lebanon. Jordan must develop her economy and solve the problem of the refugees residing within her borders. Lebanon should develop her industry, and, beyond that, she must free herself of the Palestinian refugees. Israel is dependent upon top level industrialization in order to absorb more and more immigrants from the West and Russia.

Implementation of this plan may cause a manpower shortage. Agricultural settlement activity in the Jordan Valley within Jordanian territory and development of industry in the Arava will attract a labour force from the neighbouring Arab States. The refugee camps will undoubtedly disappear in time. The refugee problem may be resolved within Jordanian territory.

There is a prospect that Israel will be transformed into an international industrial centre.

Long-run Israeli Defense Considerations.

The eastern border of Israel along the Arava and the Jordan (Jordan Rift Valley) may be considered most problematic from the Israeli point of view and requires special attention.

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This plan suggests the construction of a navigational canal along the Arava with a possible width of from 700-1,200 meters (wider and deeper than the Suez Canal). We learned in this war that such a canal forms a restraining barrier along the Arava.

By creating a new Lisan Lake, we are extending a water barrier along the Jordan Valley, including the Dead Sea to the Sea of Galilee at a width of from 2-12 kilometers, with a good possibility of efficient control.

Israel is concerned with her eastern border and various plans such as the "Allon Plan" or the "Dayan Plan" have been formulated to maintain the Israeli presence in the area, but it is obvious that these are temporary expedients. On the other hand, creation of the Arava Canal and Lisan Lake increase the security of Israel on her eastern boundary over the long-run.

The Energy Problem.

The fact must be faced that our energy resources are based upon oil imports, and, in the future, it may even be necessary to import enriched uranium. In periods of emergency, the regular flow of oil into the country may be disrupted, and, the proposed hydroelectric power will provide us with a balancing element in these periods, guaranteeing energy for defense industry and essential services. This problem is of great concern to the defense establishment.

The Interests of the Western Bloc

The Jordan Rift Valley conforms to the Suez. From a geo-topographical standpoint, it is possible to join the Bay of Eilat to the Mediterranean Sea by means of the Arava Canal and permit international navigation to the Indian Ocean. Such a need is likely to make itself felt at the beginning of the third milenium.

The Suez Canal is extremely important to international shipping in spite of the voices heard in this period, now that it is closed, on the lessening of its value. At present we are witness to the great desire of nations, large



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and small, for the rapid reopening of the Canal, evinced by the difficulties pursuant to the regular supply of oil to Western Europe which was plainly revealed once the waterway ceased to operate.

The Suez Canal is under Russian domination but there is an alternative. When the time comes, it will be possible to operate an international water route from Eilat along the Jordan Valley to the Mediterranean. This route must remain under western control (Israel). And herein lie the considerations with respect to:

- a) Sharm-El-Sheikh (the gateway to the Gulf of Aqaba);
- b) Maintaining a territorial strip from Eilat (in Sinai) to Sharm-El-Sheikh; and,
- c) In the Arava, it is necessary that the path of the canal be in Israeli territory (a slight rearrangement of the border along the canal).

Stages in the Execution of the Project

- a) This project does not engender an exorbitant rate of investment. If the agricultural resettlement project in the Jordan Valley is examined, there are limited possibilities. The limiting factor is the quantity of water attainable from the sources of the Yarmuk and the Litani. It will permit the settlement of 30-40,000 families (although large families) and, obviously, it is necessary to add other thousands of families who will find employment in services, education, management, transportation, etc. The financial investment will involve several hundred million dollars. This money can be obtained from international monetary funds. This stage may be executed at the outset even during the peace talks and peace "feelers" before signing a peace treaty.
- b) The primary emphasis of the plan relies upon basic industries of international scale in the areas of fertilizers, petrochemicals, inorganic chemicals, light metals of the future, and the entire polymer spectrum,

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together with the unlimited possibilities involved in the composition of those materials to produce new materials possessing higher properties. (This is thanks to the amazing spreading boundaries of science over and above all forecasts and imaginings).

I am referring to multinational companies in the area of petrochemicals, polymers, fertilizers, and light metals. They have the advantages and control over:

1. System of advanced production and store of knowledge and experience;
2. research and development of new products and materials;
3. international markets;
4. financial capacity.

This "elite" industry may be promised the following favourable conditions:

1. Comfortable political climate;
2. abundance of cheap energy;
3. qualified manpower high level professionals, scientists, technologists, technicians, etc. - and in this area, we have something to offer since we are anticipating immigration from the industrial states and Russia;
4. convenient water transportation to all nations (no cheaper form exists), and, specifically, a canal in the Arava.

Obviously, we have a certain resistance to multinational companies, and the amount of control over them which is necessary must be ascertained.

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The Arava Canal

The outstanding engineering operation in this plan is the construction of the Arava Canal. This canal has a designated task (if not the decisive one) in terms of industrial development in the Arava. If cheap energy exists, that is a decisive force for this industry which we are discussing here, and no less important to it is the easy accessibility to markets and to the sources of raw materials.

Obviously, it is possible to establish this industry on the Bay of Eilat-Aqaba which would convert these cities into ports and typical industrial centres, and thus create pollution and destroy one of the most beautiful bays in the world. It is necessary to conserve the Bay of Eilat-Aqaba in its entirety, and to dedicate it as a tourist site, also a major income producing industry.

The future of the Arava lies in industrialization, and the canal will be the lifeline of the Arava.

All the factors which can attract industry are found here, raw materials, cheap and abundant energy, top level manpower, and access to the oceans for the distributors and for sources of raw materials. It is also considered that the political "climate" will be comfortable.

Until this comfortable political climate is produced through the full cooperation of the three nations, it is possible to advance and execute development projects, each country within her own area, as a part of the general plan. Thus it is possible to undertake the Litani project in the North, the Yarmuk project in the East, and the production of cheap energy flowing from the Mediterranean Sea to the Jordan Valley (either through the Jezreel Valley or the Lower Galilee) and begin to produce Lisan Lake and the defense barrier in the East.

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The Jordan Valley places a challenge before Israel. The effectuation of this challenge is only possible through knowledge and planning. Now it is still in the nature of an idea. It is necessary to study all inherent limitations and possibilities and weigh all these from the point of view of Israeli interests. It seems to me that this plan can be suggested to the Americans, perhaps to sell them on the idea of a "Nixon-Teller Plan" (on the scale of the Eisenhower-Strauss proposed Plan) as a peacetime regional development proposal but its control must remain in the hands of Israel; and that is possible only through the medium of full knowledge and disclosure. Of course, there must be help and active cooperation from the foreign sources skilled in those technological and industrial areas which we lack.

Professor Edward Teller

Professor Edward Teller was invited by the late Prime Minister, Levi Eshkol, in 1965, to investigate this area. When I started to complete this study, immediately after the Six-Day War, Professor Teller displayed interest and followed its course. In the final review of the study, he indicated his belief that the project was feasible from a technical point of view, and expressed his desire to assist in the advancement of this project if the Government should decide to undertake it.

I am convinced that this plan is essential both for Israel's proper development and the advancement of peace in the Middle East.

Sincerely yours,

S. Gur.



PLANNING AND DEVELOPMENT CENTER LTD.

December 3, 1970.

Professor A. Patchornik,
The Weizmann Institute of Science,
Rehovoth.

The Jordan Rift Valley - A Challenge for Development

Dear Sir,

In connection with our meeting on December 5, 1970, with Professor D. Wofsi also participating, I wish to add some points to the plan to transform the Arava into an industrial centre including petrochemicals, inorganic chemical processes, and industry to produce light metals such as magnesium, aluminum, and titanium.

It is intended to construct industrial "Kombinats" of international proportions through the medium of the international corporations since they have the technological know-how, dominate the international markets, and possess the necessary investment capital. We must provide the basic conditions needed in the Arava to attract the internationals, and with their help, develop the region on the order of the industrial centres of Antwerp or Rotterdam.

The following is quoted from "The Economist": -

"Practically every large petrochemical company in Europe, and many from the United States (plus one from Russia in Antwerp and another quite soon from Japan) have set up large outposts in the Low Countries. They were the first natural exporting base for the Germans locked away farther south. Standing at the outlet of the Rhine they were also the easiest place to set up refineries and heavy petrochemical plants to transmute oil from the Middle East into products bound for Germany and the rest of northern Europe. Germany's ungenerous capital write-off rules also helped persuade its large chemical companies to service part of their own home market from such

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convenient common market countries as Belgium and Holland. Most of the American companies looking to Europe as a market have invested heavily there in manufacturing. Dow at Terneuzen has gone hook, line and sinker into ethylene production; Union Carbide, by contrast, makes polyethylene at Antwerp, but also uses its site there as a large base for importing polyethylene into Europe from the United States. The sheer density of petrochemical making in Antwerp can only astonish the layman. In a few square miles are packed five refineries, dominated by the 14 million ton/year refinery run and partly owned by B.P. Downstream from the huge Petrochem olefins complex and from a network of pipelines and jetties bringing in other building blocks are nearly two dozen plants; here cheek by jowl are men from St. Louis (Monsanto) and Moscow (Nafta B), from arch rivals in their own countries like Bayer and Degussen, the Belgian giant, Solvay (making mostly inorganics), and standing in lonely splendour at the outer end of the entire show, Badische's plant which, if BASF did not come from Ludwigshaven one would describe as conceived and planned in truly Prussian style."

The Economist - October 3, 1970 - The Big League - Petrochemicals.

If these regions in the Low Countries (Antwerp-Rotterdam) are the gateway to Europe, our industrial complex in the Arava is designated to be the eastern gateway to Asia and Africa. The geographical position of the Arava makes this development a natural eventuality.

Can the Arava attract large scale chemical and light metal industries? From an objective point of view, it is possible.

The raw materials for inorganic industry are present. They exist to produce magnesium. It is possible to bring alumina or bauxite for the aluminum industry from any place where they are found - Greece, Yugoslavia, East Africa, and even Australia (the source of alumina for Norway and Scotland).



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A widely ramified fertilizer industry can be established including nitrogen, potash, and phosphate fertilizers. An international petrochemical industry can be set upon the required scale, and abundant oil is found in the vicinity. It can be transported by giant tankers, and, possibly in the future, with changing times, will be carried to this point by gas and oil pipelines from the oilfields of Arabia and the Gulf of Suez.

Petrochemical "Kombinats" can be constructed in the Arava by the various firms according to the formula of the Japanese "Kombinats". At the centre of such a "Kombinat" are located the plants producing the basic materials (olefins and aromatics) feeding the plant producing plastics, fibres and synthetic rubber, and many chemical variations which produce a wide range of finished products.

Near the "Kombinats", many industries can be constructed of varying sizes in the more usual range to produce finished products in the sector of plastics, pharmaceuticals, detergents, paints and varnishes, and even proteins.

Similar "Kombinats" are likely to be constructed in the inorganic chemical field where a tendency to integrate is also constantly growing among the international corporations with a concomitant increase in production capacity.

What are the basic conditions required by industry in the Arava?

1. Cheap and abundant energy;
2. A navigation canal along the Arava from the Bay of Eilat north;
3. Fresh water.

1. Cheap Electrical Energy

The various possibilities for producing electrical energy through the

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use of hydroelectric power have been discussed in the publication, The Jordan Rift Valley. Erection of a 1000-1200 MW hydroelectric power station can produce from eight to ten billion kilowatt hours per year (the capacity of the Aswan High Dam). The magnesium and aluminum industries producing 200-250,000 tons per year would require four billion kilowatt hours per year. Four to six billion kilowatt hours would be designated for the chemical industry and home consumers.

It is evident that there are many possibilities to exploit the projected hydroelectric power station. If this station is integrated into the regional power grid, it will permit electricity to be furnished to the system at peak hours, and in non-peak hours, electricity from the regional system would flow to the industries in the Arava. Thus the exploitation of the regional system can be increased; the price of a unit of electricity can be reduced; and additional electricity can be provided for the Arava system. Additional variations of this theme exist, and they were discussed in the publication, The Jordan Rift Valley, previously cited. This quantity of electricity at a cheap price (\$0.002 per kilowatt) must attract the above mentioned industry.

2. The Arava Canal

The various industrial "Kombinats" will be erected along the canal. Here will sail the tankers bringing raw materials to the petrochemical industry; freighters bringing bauxite, alumina, and other minerals to industry; and fertilizers will be carried to markets. Container ships will bring finished products from the factory door to international markets. It is essential to this type of industry to be in close proximity to a deep water port, and to enjoy the variegated developments and possibilities of maritime carriers. Hence industry, situated beside the Arava Canal can benefit from a port along its entire length. The canal will carry the waters of the Red Sea to the hydroelectric power station.

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And what will be the situation if this canal will not be located in the Arava? It is possible to produce electricity at another site through exploiting the difference in height between the Mediterranean Sea and the Jordan Valley and to produce the same quantity of electricity. Two alternatives exist: one from the Bay of Acre by means of a tunnel through the mountains of the lower Galilee in an easterly direction, and the other from Haifa Bay through the Jezreel Valley by means of a tunnel or a canal.

But in the absence of the canal, the Arava will not develop at the same rate. Two industrial locations will be established, a heavy chemical industry and inorganic industry in the northern Arava, near the Dead Sea, and a petrochemical industry very near the Gulf of Eilat-Aqaba. It is possible that this industrial development will expand along the western shores of the bay (in Sinai) and the eastern shores (in Jordan and Saudi Arabia), and this splendid bay, known not only for its natural beauties as a nature conservation spot, but also for the tremendous economic potential embodied in the site, will be destroyed.

Without the canal, the growth of industry will be restricted, and will not develop fully the multitudinous possibilities of the region. Nor must the fact be avoided that, at a certain time in the third millennium, it will be necessary to cut a canal parallel to the Suez Canal for international navigation, and the only route possible will be that from the Bay of Eilat through the Arava and the Jordan Valley to the Mediterranean Sea.

And at an earlier date, the Dead Sea will be cut off from all its sources of water. This will occur at the same stage that the sources of the Yarmuk will be completely utilized for irrigation purposes; the Jordan River bed will be dried up; and only a minuscule amount of water will proceed to flow into the Dead Sea. Thus, it will be necessary to have sea water flowing into the Dead Sea to prevent its turning into a salty desert in the course of generations. It will be natural for this waterfall to be exploited to produce

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electrical energy.

Hence the Arava canal is of extreme importance for the industrial development and economic balance of the region.

Approximately 150 million cubic meters of water per year will be required by industry and the future population of the Arava.

This canal will supply an abundance of water for cooling and condensation. Such a quantity of water is less than 15 per cent of the water at the command of this project from the sources of the Litani, Yarmuk, etc. (see p. 28, The Jordan Rift Valley - Water Resources).

Another important aspect which can be commended to the above mentioned industry is the availability of scientists, engineers, technologists, and managers of high calibre.

A chemical complex of the quality and scope that we are considering is found only in developed countries for obvious reasons. We can produce in the Arava a European environment from the point of technological quality and services which are a prime consideration in the decision making of such industry.

The chemical industry is one which relies upon applied science. It is forever in a race with its competitors to achieve primacy in the technological development of new products. The huge research and development expenses in this industry amount to approximately three and one-half billion dollars this year.

The industry needs many scientists and technologists for its research departments or scientific institutions which sell such knowledge and services to these firms. In our case, too, it is reasonable to consider

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that the prevalent conditions will encourage the organization of groups of scientists and technologists to offer their services to industrial firms, and science-based industries will be established which will develop new products and even new technology. The existence of scientists and technologists within this large industry will permit the acquiring of information with respect to planning, establishing, and operating this type of diversified industry. Planning institutions will be developed for the advancement of industrial technology and will offer services on an international scale.

The chemical industries, particularly the heavy organic sector, are of the intensive capital investment type entailing big production complexes. The present plants to produce ethylene have a yearly production capacity of 300,000 tons (\$140 million) and plans are under way for expansion to a yearly production capacity of 450-500,000 tons per year (\$280 million). The size of production determines the profitability of the plants and their international competitive ability.

The chemical industry is a dynamic industry by comparison with other industrial groups. Its yearly growth is 8-8½% but the yearly growth of the petrochemical group including the polymer and synthetic fibre industry averages 12-14%.

The world production of this industry reaches \$130 billion, and it is expected that by 1985 it will reach \$450 billion. The value of exports in the past year was \$18 billion.

The chemical firms are established along the north shore of the Mediterranean Sea Basin (France, Italy). They appear to be moving in an easterly direction through Yugoslavia and Greece. The States east of the Mediterranean Sea do not comprise an attractive region for the heavy chemical industry, both because of the lack of technological knowledge and the absence of political stability.

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However, the same classic oil companies, that "invaded" the petrochemical industry, refrain from establishing petrochemical industries in the "oil" countries, at any rate not on a serious basis because of political instability. The bargaining power of these companies is greater with respect to the governments of the oil-rich lands if they guard their control over markets and over their petrochemical industry located in the industrial nations.

Thus, the conclusion appears to be that in the great area of the Middle East, the Arava region is one of the attractive sites to develop a large chemical industry. And in the future, it will be situated along an international waterway stretching from the Mediterranean Sea to the Indian Ocean.

Sincerely yours,

S. Gur.

Attached:

1. Nuclear Energy Centers, Industrial and Agro-Industrial Complexes, Summary Report, Oak Ridge National Laboratory, 1968.
2. Methods of Developing the Petrochemical Industry in Israel, Professor D. Wofsi, Weizmann Institute of Science, Rehovoth.



PLANNING AND DEVELOPMENT CENTER LTD.

May 14, 1971.

Professor D. Wofsi,
Professor A. Patchornik,
Weizman Institute for Science,
Rehovoth.

Gentlemen!

Subject: The Jordan Rift Valley - A Challenge for Development
Memorandum for Meeting of May 15, 1971

It is becoming apparent that it will be possible to execute this plan via a mutual agreement and cooperation between the three nations of Israel, Jordan, and Lebanon, who are the interested parties in this plan. The planning and execution of this plan can be undertaken by an authority, such as the "Jordan Rift Valley Authority", composed of a representative from each of the three above mentioned nations with rights and powers vested in them to plan and execute this regional project, and authority to receive and expend funds for development.

All this is possible if a state of peace exists. But what are the possibilities for action under present political conditions of "stalemate"?

In my opinion, the following alternatives are available. It is possible to start the general planning and, at a certain stage of the advanced planning, make contact with the "neighbours" through a "third party" in order to coordinate planning and information. This would be the beginning of a cooperation which could expand in the execution phases. It is interesting to note the statement of King Hussein of Jordan to a Washington Post writer during the visit to Rabat Amman of the American Secretary of State, William Rogers. (Attached is a clipping from Ma'ariv, May 4, 1971.)

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King Hussein referred in his statement to the World Bank, and thus indicated a nascent initiative. If the World Bank "will request a sign of initiative", it will be natural for the Bank to exercise control over the size and scope of the plan. It is possible that the plan will not correspond to the interests of the nations, according to the manner in which they view the progress of their economic development, so that the potentialities of regional development will not be fully realized, either because of a reluctance to embrace particular projects, or because of a preference for other development regions in the world. The World Bank is not free from political, regional, or global pressures.

Thus, the alternative must be weighed if it is not more viable to prefer an international consortium, under some formula which will make them the initiators of the "request" for a regional development project and even capable of proceeding in the task through the execution stages.

The amount of time given us to provide initiative in this area, is, indeed, brief. This is apparent from King Hussein's statement, and from the initiative indicated by the European consortiums, the American corporations, and the Japanese consortiums, both through plans to develop along the Suez Canal on the east (Sinai) and on the west, and by the proposal for financing the deepening of the Canal.

For these reasons, we must be ready to immediately propose even to the World Bank (if it will hasten its readiness to act) a comprehensive regional development plan, and to promote by means of quiet activity the creation of an international consortium to achieve this development.

The importance of undertaking this plan is explained in detail in my letter to Professor M. Feldman of November 15, 1970, and January 31, 1971, which are in your possession.

What can we do in this period of "stalemate"?

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It is possible to begin the general planning, and there are many projects which can be executed by each of the countries within their boundaries, and through cooperation by means of a "third party". It is expected that Israel will "passively cooperate" with the Government of Jordan in the execution of the same regional development projects that are located in the "occupied" territories. Tacit cooperation is also expected from Lebanon in the development of the Litani project.

The regional development plan contains a great number of economic projects of various sizes with respect to financial investment. Many are projects whose planning stage is short, and whose required financial investment is relatively small, and it is possible to hasten their execution date, and these projects are designated for execution in the initial stage of the regional development plan.

As has been previously mentioned, there are involved both great industrial plans and the development of the infrastructure of the Arava, for which the length of the planning period will be long and the industry itself is capital-consuming. It is natural that these plans be included in the second development stage. (It is entirely possible that the industrial advantages of the Arava will permit parallel development with the Jordan Rift project.)

In the initial development stage will be included the development plans relating to Jordan Rift and the Litani.

In the second development stage, the emphasis will be upon the development projects of the Arava and Eilat-Aqaba.

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Initial development stage - Jordan Rift

The development region is now divided between the Kingdom of Jordan; the area east of the Jordan, and the area west of the Jordan which is "occupied" by Israel, but the plan is unitary.

In the area within the Kingdom of Jordan, the development will be directly undertaken by the Government of Jordan. West of the Jordan in the occupied territory, the development will be undertaken not alone under the aegis of Israel but rather with Israeli stimulation and encouragement. It is reasonable to expect that "contact" will be established and quiet cooperation indulged in by both sides, if necessary by means of a "third party", and it is not unlikely that there will also be direct contact.

At this stage it will be possible to develop the Jordan Valley completely.

Water

1. Completion of the Yarmuk Dam, the storage lake, and the conduction of water to the fields east and west of the Jordan;
2. Hydro-electric power plant of the Yarmuk Dam;
3. Initial plans to desalinate the brackish waters of the springs according to the reverse osmosis or electrodialysis system or any other system which will be available and suitable for this purpose.

Agriculture and Rehabilitation

It is possible to begin immediately the operation of agricultural resettlement through establishing villages, community centres, and centres of agricultural industry, schools, and agricultural experiment stations, etc.

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Rehabilitation of the City of Jericho

It is necessary to rehabilitate the city to provide more suitable topographical conditions, and to plan a modern urban community sustained by winter tourism and other light industries.

Infrastructure services to the region such as the road system, electricity, sanitation, and communication must be provided.

Industrial cities - one of the most important projects in its own right is that of the establishment of industrial cities along the "green line" on the basis of Israeli-Arab cooperation, principally devoted to export industries.

Lebanon

The Litani Project

There are several variations of the Litani Waterfall plan to produce hydroelectric energy. However, in all the plans, the water which will generate the turbines disappears into the Mediterranean Sea. We are interested in reverting the waters of the Litani to the Jordan Rift. Thus, it would be possible to dam the waters of the Litani near the river bed under topographical circumstances which would make it possible to produce a large waterfall and to generate a hydroelectric power station in the low bed of the river. From here, the water would flow through a tunnel to the Hula Valley and the Jordan Rift.

Cooperation is possible in the planning stages and also in the execution stages according to the Israeli-Jordanian formula. Lebanon can build the reservoir, the power station, and the tunnel, and Israel can build the conduits to the Jordan Rift.

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Israel

Three great development projects can be executed by Israel.

- a) In the water area - to cause less water to flow to the Sea of Galilee, and to save the evaporated water for irrigation purposes.
- c) To construct an atomic power complex to produce electricity. Sites are limited by defense considerations. There is no possibility of constructing this project in the Arava because of a lack of water for cooling purposes. Water for such purposes is to be found along the Bay of Eilat and along the shore of the Mediterranean Sea but here security problems arise as the atomic complex must be protected from external attack.

It is possible to construct the atomic power complex in one of the ravines along the west coast of the Sea of Galilee.

Such an atomic complex is valuable for Israel as a source of electric energy (not cheap) and as an alternative to oil, and permits the conservation of the stock of uranium to operate the complex for a number of years. The technology of atomic complexes is extremely important to Israel.

The pumped storage hydroelectric station on the west coast of the Sea of Galilee - it is possible to erect in this location the first power station in Israel, utilizing pumped storage, which can take advantage of non-peak hour (night) energy which is unused throughout the entire national electric grid; to pump the waters of the Sea of Galilee to the upper storage lake, and to cause them to flow back the next day to the power station and produce cheap electricity at the daily peak hours. There is a higher rate of construction of pumped storage power stations in the world than of nuclear power



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stations. The trend is to combine nuclear power stations with pumped storage stations in order to fully exploit the production capacity of the atomic complexes for the production of electricity.

The proposed pumped storage station is the first station in the hydro-electric system of the regional development scheme.

As far as the development plan of the Arava is concerned, also including several stages of execution and a varied series of development projects, I propose to consider this at our next meeting.

Sincerely,

S. Gur.



PLANNING AND DEVELOPMENT CENTER LTD.

August 24, 1971

Professor D. Wofsi
Professor A. Patchornik
The Weizmann Institute For Science
Rehovoth

Subject: The Jordan Rift Valley
 A Challenge for Development

ARAVA PLAN

Gentlemen,

At our meeting on May 15th, we considered the possibility of the development in stages of the Jordan River Valley (north of the Dead Sea) in the present political circumstances.

On the list of projects suggested, we find projects that the Jordanians are capable of executing within their territorial jurisdiction, and projects that Israel can initiate in the western Jordan Valley (see the letter of May 14, 1971).

Arava Development Plan:

At our next meeting, August 24, 1971, we will consider the Arava plan. What are the possibilities of executing development plans under the present political condition of "not peace and not war"? What can Israel undertake within her borders and what can Jordan do within its territory within the framework of an inclusive development plan?

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The Canal and Electric Energy: -

We assumed that the Canal from the Bay of Eilat along the Arava would be cut by means of a nuclear fusion explosives. This method would have made it possible to execute the cutting of the canal in its entirety in a relatively short time, and, with a modest investment, as opposed to the complex cutting with prodigious new equipment. And with the completion of the canal to install the hydro-electric plant (on a topographical level of 212 meters below sea level) in the southern depression of the Dead Sea.

Two limitations appear to be involved in the use of nuclear energy: -

- A. The United States Government may refuse to let us participate in the program of using nuclear energy to execute engineering projects because Israel did not sign the "Nuclear Non-Proliferation Treaty".
- B. In the present political situation, the Jordanians could arouse international opinion against nuclear explosions along her border which could endanger, as it were, Jordanian citizens.

A section of the Canal 20 kilometers long: -

Under these circumstances, it will be possible to cut the first section of the canal, from the Bay of Eilat - 20 kilometers north, by means of conventional machinery. This section, a plateau, was intended to be constructed without using nuclear energy.

The path of the canal is entirely within the sovereign borders of Israel, to be constructed independently.

The financial investment is approximately \$100 million.

The rise in land values in 20 - 25 years will possibly increase to over \$200 million - a sum which would cover the expenses of cutting the canal and establishing an internal deep water port its entire length, and also cover the development expenses of the urban infrastructure of Eilat.

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The Bay of Eilat is a priceless treasure in the development of the spreading tourist industry, and we must guard its beauty and prevent its pollution. Thus, it cannot be used as a port for the anchorage of cargo ships and oil tankers.

By constructing the canal as a port along its entire length, it will be possible to guard the natural beauty of the Bay of Eilat.

Cutting the canal a distance of 20 kilometers in the first stage, will permit the development of an industrial area of approximately 50,000 acres (on both sides of the canal).

Obviously, in the future, it will be possible to proceed and cut further sections of the canal (in the direction of the Dead Sea) either by mechanical means or clean fusion explosives, without radioactive pollution (using High Power Lasers *).

Those circumstances will permit Israel to take the initiative in development within her sovereign territory.

It is reasonable to assume that the development plans within Jordanian territory along the canal may be activated by a third party (the United States) in the framework of the omnibus plan for the development of the Arava.

Cheap Electrical Energy: -

It is clear that, if the canal is not cut the entire length of the Arava, and, if it does not reach the southern depression of the Dead Sea, there is no possibility for the waters of the Bay of Eilat to flow to the Hydroelectric power station, and produce electricity.

Under these conditions, it would not be possible to take advantage of the difference in height between the level of the Bay of Eilat and the depression of the Jordan Rift Valley to produce electric energy.

*) See the article, "fusion by laser" by M.J. Lubin and A.P. Frass, Scientific American, June 1971.

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The Mediterranean Sea - the Jordan Rift Valley: -

However, it is possible to produce electricity by taking advantage of the difference in height between the level of the Mediterranean Sea and the Jordan Rift Valley.

Under these circumstances, it is possible to cut a canal from Haifa Bay through the Jezreel Valley to the depression (± 0) near Merhavia. The length of the proposed canal would be 40 kilometers. (The maximum topographical grade to be cut would be 55 meters). This work could be carried out by modern machinery.

The Hydroelectric power station (1000 - 2000 MW) would be installed along the topographical line of -212 meters below sea level (the shore of the future Lisan Lake) at the foot of the City of Beisan on the east. The financial investment in the hydroelectric power station under these convenient conditions (without building dams but rather on solid ground) is lower than the price of a conventional thermal power station, and, similarly, than a nuclear power station.

From here, this low-cost electricity will be available for the industrialization of the Arava.

The Jezreel Valley Plan: -

This plan could germinate some interesting results, both from the economic and the political point of view.

This plan promotes the industrialization of the Haifa and Jezreel Valley region, opening the area to international industries, and converts the small towns of Afula and Beisan into industrial cities and ports.

The characteristics of this region make it appear attractive to international industry.

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From the political standpoint, a free port zone in the Jezreel Valley for the "West Bank" territory is possible, and another one at Beisan for the Kingdom of Jordan.

The possibility of giving a convenient outlet to the Mediterranean Sea, both to the citizens of the West Bank, and to King Hussein, is a weighty reparation, both in an economical and political sense. (This outlet is to be preferred to that via the Port of Gaza, both from the point of view of Palestinian and Israeli interests.).

In the future when the level of Lake Lisan, in the Jordan Rift Valley, has been raised to the Planned level (~212 meters), King Hussein will be able to send his boats from his ports on the shores of the lake (e.g. Jericho) by means of two locks lifting the ships from the Lisan Lake to the Jezreel Valley Canal and the Mediterranean Sea, and, the convers, to send boats from the Mediterranean Sea to the ports of Lisan Lake.

Afula as a Port and an Industrial City: -

The Jezreel Valley Canal is a navigation canal which can accommodate in the first stage medium size boats up to 70,000 tons.

Along the Canal, an industrial zone with selected industries requiring water transportation can be established.

Afula can be converted into a port and an industrial city.

A free port for the West Bank opposite Jezreel and an outlet to the Mediterranean.

On the canal, near Jezreel, it would be possible to establish a free port for the West Bank with a direct outlet to the Mediterranean Sea. the distance from Jenin is short, and all the commerce to the West Bank and to the Kingdom of Jordan would be carried on by the Jezreel free port - the distance between the city of Jenin and the free port, it is possible to connect, by an elevated highway without any outlets to the Israeli road network.

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Beisan Port and a free port for the Kingdom of Jordan: -

The canal reaches Beisan (two kilometers north of the town) and, thus, converts Beisan into an industrial city and a port. (this is a blessed gift for the city.).

Along the canal, it is possible to establish a free zone as a port for the kingdom of Jordan which is very much in need of access to the Mediterranean Sea.

From the Hussein Bridge on the Jordan to the proposed free port is a distance of eight kilometers which can be connected by an elevated highway.

The financial investment in the proposed canal is between \$200 - 250 million. The investment in the canal may be recovered by the operation of the free ports, and through the increased value of the land in the industrial zone along the length of the canal.

It is interesting here to note the following excerpt from the New York Times, May 30, 1971:

LAND COST BOOMS IN JAPAN'S NORTH
Desolate Honshu Peninsula Will Be Industrial Area

By Takashi Oka

" A fever of land speculation has been sweeping across a desolate peninsula at the northern tip of Honshu, Japan's main island.

The region, now a wild, lonely landscape of sand dunes, scrubby uplands and barren hills, is scheduled to become in 15 years, one of Japan's major industrial areas, turning out annually 20 million tons of steel one million tons of aluminum, and 2,400,000 tons of petrochemicals, according to present Government plans.

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"Farmers, who have been scrabbling out a bare existence tending patches of beans and other meager upland crops, are being enticed to part with their land at prices comparable with those in the big cities - up to \$70 a square yard. So chaotic has the situation become that last month 150 leading Japanese companies got together with the Government to set up a joint land-purchasing corporation.

The largest of these areas is to cover an area of 75,000 to 160,000 acres on the Shimokita Peninsula."

Thus, it can be accepted that the value of 300,000 dunams (unimproved) would rise from \$75,000 per dunam to the astronomical sum of \$22.5 billion.

Electrical Energy Balance: -

The execution of the Jezreel Valley project would permit the incorporation of the hydroelectric power station within the national electric grid. It is considered that this station would supply electricity at peak hours, and would make the production system more efficient and reduce the unit price of electricity.

Let me remind you that three hundred billion cubic meters of water may flow from the Mediterranean Sea to create Lisan Lake. If a 1,000 MGW power station is erected, meeting the demand for electricity at peak hours, this station could be in operation for fifty years until the lake reaches its planned level. Obviously, if the production of electricity is doubled to 2,000 MGW, the lake will reach its planned level in twenty-five years.

The trend of installing large conventional thermal units and large nuclear reactors makes it important to incorporate the hydroelectric Pumped Storage system which will exploit the unused night energy of the system to supplement electricity for tomorrow's needs. A pumped storage system could generate up to 3,000 additional installed MGW.

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The possibility of water flowing from the Mediterranean Sea as an unceasing water source with the possibility of regulating the flow in the most flexible manner to the Lisan Lake in the Jordan Rift Valley, will permit the convenient and desired regulation of the entire national electric production system. It is estimated that towards the end of the century, the production of electricity in Israel will reach approximately 10 - 15,000 MW.

The Storing of Energy for Emergency Periods: -

Hydroelectric power stations with a capacity of 5,000 installed MW have enormous importance in emergency situations. Their yearly production capacity is equal to a reserve of 13 million tons of oil (approximately \$200 million). Such a quantity of oil for an emergency period would require storage pools whose financial cost would be very large (approximately \$300-350 million).

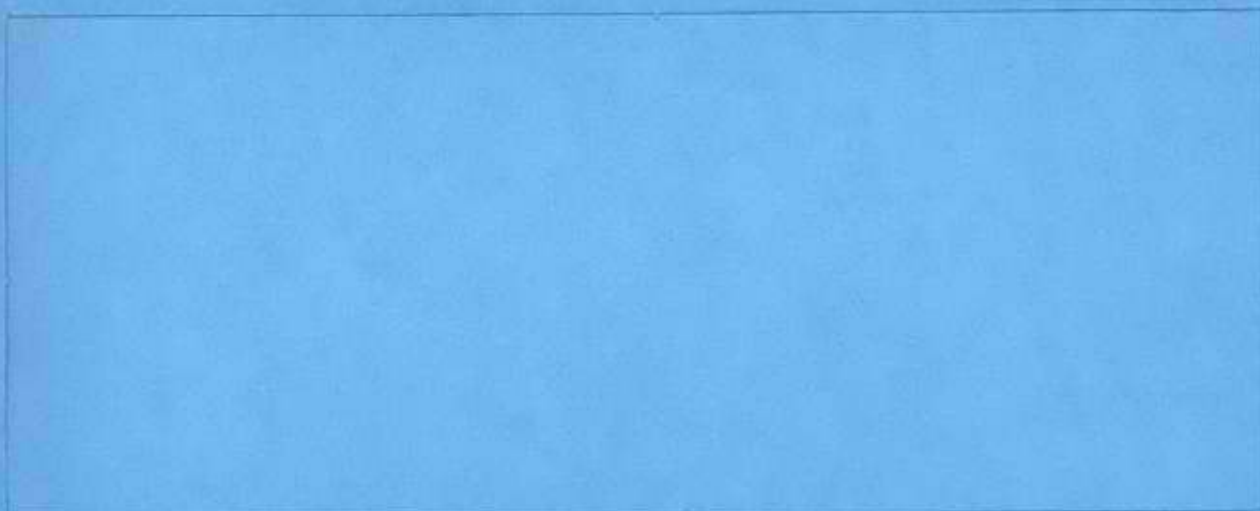
In emergency periods, it is possible to produce electricity at the full capacity of 5,000 MW for industrial and domestic needs, and services, and to reduce in this manner the oil stockpile and its storage for emergency periods, and, thus, to save some \$500 - 550 million.

In this period of the excessive exploitation of the world's resources of energy, such as crude oil, natural gas, and uranium, and, in addition to that, the ecological problems that accompany such activities including pollution and the release of excess heat into the atmosphere, the importance of hydroelectric plants increases because of the unlimited water resources of the Mediterranean and because they are clean.

In the framework of an overall regional development plan, that we are, naturally, interested in encouraging, there are "open" alternatives to operate one way or another, either in accordance with the existing or possibly changing political realities, or according to present or future economic considerations.

the development initiative is in Israel's hands, if she decides to make use of it.

S. Gur



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והצמח
שדע



WEIZMANN
INSTITUTE
OF SCIENCE

AN AGRO-INDUSTRIAL COMPLEX IN THE ARAVA.

A MEMORANDUM

Submitted to the "Rehovot Group"

by Prof. D. Vofsi

The Memorandum is based on an article published by the author in the July 1969 issue of "Olam HaDelek" ("Petroleum World"). The Israel Petroleum Institute, Tel-Aviv.

The development of the petrochemical industry began during World War II. Up to the beginning of the forties coal provided the raw materials base for most organic intermediates and products. The switch-over from coal to petroleum was stimulated by the expansion in oil refining, which made available for the chemical industry the off-gases at a nominal price of their fuel value. On the other hand, the appearance of polyethylene, and the large-scale production of synthetic rubber during the war, provided a ready "customer" for ethylene and encouraged the development of some basic petrochemicals, such as butadiene and styrene.

The tremendous growth of the plastics and synthetic fibers industry during the post-war period (average yearly growth of about 15%, see, f.i. Figs. 1 and 2), has placed increasing demands for oil-derived chemicals; this had the effect of shifting petrochemical operations from a marginal position in the oil refining business towards an increasingly independent status. Today petrochemistry is almost divorced from refining, and special plants are being constructed for the large-scale manufacture of basic chemicals from oil feedstocks.

While this expansion was taking place, the relative proportions of a small number of dominant materials did not change appreciably over the years. These are listed in Table I. It seems that our requirements for the "bread and butter" products are fully met by these chemicals, and the new and more specialized materials that keep appearing almost every year on the market, have a marginal influence, tonnage and Dollar-wise, although their impact on a particular application may often be incalculable (space, medical uses, electronics, etc.). The various products of Table I are being supplied at prices of between \$100 and \$2000 per metric ton.

Table I

Basic Chemicals	Plastics	Fibers	Rubbers
Ethylene	Polyethylene	Nylon 6	S.B.R.
Propene	P.V.C.	Nylon 6,6	Polybutadiene
Butadiene	Polystyrenes	Polyester	Natsyn (polyisoprene)
Vinyl chloride (ethylene dichloride)	A.B.S.	Acrylic	Butyl
Phenol	Phenolics		Polyolefin rubbers
Urea	U.F. Resins		
Methanol	Polyamides		
Cyclohexane			
Acrylonitrile			
Benzene-Toluene-Xylene			

Thus, from the production-volume point of view, progress in the petro-chemical industry is reflected mainly in the development of new and more efficient processes for the manufacture of established products, rather than in development of novel materials.

The ever increasing production volumes and perfection of technologies had the effect of pushing the prices of the above products on a downward trend. However, it is now generally accepted that optimal plant-sizes have approached a plateau and prices of chemicals are unlikely to decrease during the coming years. Today, minimal plants that allow for production of the above materials at "rock bottom" prices are, in the case of basic chemicals, between 50 and 400 thousand t.p.a; for production of various polymers, the minimal size would

be between 10 and 100 thousand t.p.a., and for fibers - a unit producing some 2500 t.p.a. would be about minimal size to turn out a product at a competitive price.

The obvious conclusion from all this is - that with prices approaching an asymptote - any advantage in the highly competitive market of petrochemical products can be gained only by heavy investment in both, R. and D. as well as construction of giant plants; furthermore, these plants would have to be amortized over a span of about seven years at most.

To appreciate the consequence of all this for a small country like Israel, one has to inspect some typical data on consumption of plastics and fibers in industrial countries. This is seen, for the U.S. market, in Fig. 1.

In an industrially developed country, consumption and production are well balanced; exports have a marginal influence, and are closely matched by imports. However, in a small country with a large petrochemical industry (Holland) the production and consumption curves do not run parallel: the former has to follow minimum plant size requirement, and a more steeply upward trend if it is to survive, while the latter reaches a saturation value at a lower production level. Thus, a small country with an ambition to join the "petrochemical club" has to rely mainly on exports, which may have to dispose 90% or more of total production. This should not worry a country like Luxemburg, that is part of a large common market. For Israel, however, large scale marketing of petrochemical products would most certainly present a formidable problem, unless they could be offered at lower prices than those quoted in the U.S. or on the Common Market.

If this is the situation with respect to the large volume products - would it perhaps be more advisable for Israel to pool its efforts in the production of the smaller volume specialty materials? Many of these products, f.i.

silicones, fluorine plastics, etc., can be profitably manufactured on a rather small scale (1000 - 2000 t.p.a.) and they sell in a price range of several Dollars rather than a few cents per lb. The production and price pattern is comparable to that of pharmaceuticals or certain pesticides. Such a production policy is followed by Switzerland, where almost none of the low-cost petrochemicals is being manufactured. It has succeeded, however, in developing a diversified industry of specialty chemicals that is almost entirely export oriented. Indeed, Dr. Weizmann has advocated a similar course for Israel's chemical industry stressing the need for the intensive know-how component rather than extensive capital investment in large-volume production of low-cost chemicals. The low-cost chemicals could be imported and our limited material resources should be used in upgrading them to high-value products, the main "investment" being brain-power and specialization.

Those who are taking this approach believe, that it would be rather easy to establish a highly specialized science-based industry in Israel. However, the fact is that most original know-how was generated also in the large industrial countries; those who turn out the low cost petrochemicals, also manufacture the advanced optical and electronic systems. Although invention and innovation can be generated by relatively few individuals, it seems that the time has passed when several inventors could seriously affect the economic structure of a country. The "amount" of innovation and output of original and creative research roughly parallels the research effort of a country, and this, in turn, is geared to the Gross National Product.

To illustrate this point, let us take a look at our pharmaceutical industry, or our pesticides manufacture. To the best of the author's knowledge, not a single original compound was developed here to date in either of these two areas, and all products being manufactured in Israel were invented elsewhere.

This is particularly disappointing in view of the strong position of organic chemical research in our institutions of higher learning.

Does all this mean that Israel has little chance to develop a competitive Chemical Industry? Not necessarily.

The conclusion from the above outline does not mean that we ought to "close shop"; it does suggest, however, that we ought to plan our steps with utmost caution, if our limited human and material resources should be put to optimal use.

What could then be some plausible guidelines for planning our Chemical Industry for the seventies?

Within the framework of this article, it will not be possible to present a concise review of the various plans for our future effort in petrochemicals and plastics. We shall therefore confine ourselves to drawing a rough sketch, without having the intention to present here and now a "Plan for Development of the Chemical Industry in Israel".

In the quite recent past there existed a clear-cut dividing line between the inorganic chemical industry (fertilizers, light metals, building materials, ceramics) and the one manufacturing organic chemicals (solvents, plastics, pesticides, pharmaceuticals). This is no longer the case. Today, there are no "dividing walls" between the two; on the contrary, mutual interaction is constantly increasing, one branch of the industry becoming more interdependent

on the other. As materials and products become more sophisticated, industry gets inevitably involved in a combination of processes and manufacturing lines in order to meet modern demands under optimized conditions. Light metals (aluminum, magnesium) are being joined with plastics in composites that displace the more traditional building materials. Oil refineries are closely linked with nitrogenous fertilizers, and sulfuric acid production (from petrochemical sulfur). The steel industry, that was always linked with coal and tar chemicals, is now extending this interaction to the field of plastics, which are considered a logical supplement (and sometimes even substitute) for its traditional products. More recently, new concepts are evolving, that tend to combine the chemical industry with the domain of energetics and large-scale water desalination schemes that would create a super-complex, whereby cost optimization with respect to energy, water and production of basic chemicals from the sea - would be achieved.

These general trends cannot possibly by-pass even a small country like Israel. We are committed to a course of fully developing our resources and the establishment of a technology-based economy, that ought to bridge our balance-of-payments gap.

Although not generously endowed by natural resources, this country does have a certain raw-materials base on which a chemical industry can be built. It is of interest, that the three major streams of this industry, namely, the inorganic, the petrochemical and the energetics branches - converge here on common grounds in a rather natural way.

THE CHEMICAL COMPLEX

Israel is rapidly becoming a factor of some importance in the fertilizers market. Potash production is approaching a level of 1 M tons, and a similar yearly production will be reached soon by the phosphate industry. The Arad complex will soon be turning out phosphoric acid on a large scale (150.000 t.p.a.), and the co-production of this material with potassium nitrate (100.000 t.p.a.) in Haifa Chemicals is already on stream. This means that we are moving towards the manufacture of upgraded products, rather than exporting the cheaper phosphate rock and potash. One should mention here that the technologies used in both, Arad as well as Haifa Chemicals, have originated and were developed in this country (The I.M.I. process). Another original Israeli development, the Aman Process, is also coming close to industrial realization (after some 30 Aman Reactors are now in operation in many foreign countries). This process holds very considerable promise for the development of the Chemical Industry in Israel.

The Aman Process is making use of the magnesium-chloride containing Dead Sea end-brines, that upon thermal decomposition produce hydrochloric acid and magnesium oxide. This latter product is suitable for high-grade periclase (refractories) manufacture. Concurrently with the projected manufacture of some 100.000 t.p.a. of periclase, an effort is at present directed towards the development of a cheap process for anhydrization of the aqueous hydrochloric acid that is being co-produced in the Aman reactor. There are already indications, that anhydrization costs should not exceed some \$6 per ton of dry product. Taking an initial cost of wet Aman hydrochloric acid as \$9 per ton, it will be possible to manufacture chlorine in Israel, on a large scale at under \$20 per ton, which would place us in a very competitive position with respect to this most basic chemical.

It is not difficult to see how these developments would affect the Israeli Chemical Industry. With very cheap chlorine at our disposal, we can now make the next move and link-up the inorganic industry with the future petrochemical refinery. This was, indeed, suggested in the master-plan of Israel Chemicals Limited (I.C.L.). The plan envisages the setting up of a sizeable cracking operation, that would produce ethylene at an internationally competitive cost. Part of the ethylene output would be used for large-scale manufacture of ethylene-dichloride (EDC) by combining it with chlorine. Thus, the cost advantage gained in chlorine manufacture due to the large-scale implementation of the Aman Process, would place us in a competitive position with respect to one of the basic, high-volume plastics, - PVC, that is being manufactured by thermal cracking of EDC. Availability of cheap chlorine will also enable the low cost manufacture of chlorinated solvents, pesticides and certain rubbers at costs that other producers would not find it easy to compete with.

On the other hand, the large volume of ethylene, that will be absorbed in the production of EDC (an ICL market study has estimated this amount at some 100.000 tons) will lay the ground for an economic cracker. Modern naphtha crackers are designed for ethylene outputs of up to 400.000 t.p.a., but already at an output of some 200.000 t.p.a., this product can be made at an internationally competitive cost (3.5 ¢/lb.). The excess stream of ethylene would be used mainly for polyethylene (PE) production, with smaller amounts diverted to such products as ethylene glycol (EG), vinyl-acetate (VA) dibromo-ethane, etc.

The processes described so far clearly show, how the production of petrochemical products such as PVC, PE, EG, etc., are interconnected with the manufacture of large volume inorganics: periclase, phosphoric acid, fertilizers. Needless to say, once a broad base is established for the production of a few large volume basic chemicals, an intensive diversification, so typical of the chemical industry - soon starts to operate. This happened to almost every one of the big complexes in any country, and there is no reason why it should not happen here.

The question should now be asked: suppose we are in a position to build up an industry that will turn out a large array and volume of products at competitive prices - where are we going to sell them? Should we succeed to become members of a large common market, the problem of sales would be an easier one - but the prospects for our inclusion are rather slim. There is also the possibility of joint ventures with large foreign interests, whereby already established marketing channels may be made available for our products; this approach has been successful occasionally, but is operative only in selected cases. The basic difficulty still remains: we may have the potential for establishing a big industry - but we are a country with a relatively small number of consumers. If our chemical industry is to depend almost entirely on exports we are running very grave risks that no venture - capital would be prepared to take. To avoid these risks, we must develop a local consumption that would absorb a good share of our industrial output. Is this feasible?

It may appear at first glance, that no matter how we try, it would hardly be possible to broaden local consumption significantly. Even if we reach the mark of 5 M. consumers by the end of the seventies - this is still considered a small market when compared to the giants: Europe, the U.S. and Japan.

On closer examination, however, the prospects for establishing a broad base for local consumption of petrochemical products seems quite feasible in view of future developments in agriculture as an export industry. To achieve this aim, the production streams discussed so far will have to be linked with an additional major factor of the economy: energy resources. This factor is, of course, directly connected with desalination.

THE AGRO-INDUSTRIAL COMPLEX

It is generally accepted, that future development of Israel's agriculture, or indeed of its economy, would depend on the development of new water resources, since we are rapidly approaching the point of full utilization of our conventional supplies. There is little doubt, that towards the end of this decade at least one large sea-water desalination unit will have to be put into operation. Whether such a unit would utilize conventional fuel or it would run on atomic power is still an open question. However, once large scale desalination units, exceeding a capacity of 150 M cubic meters per annum become feasible, atomic energy will step on stage.

In a recent study carried out in the U.S. (1967 Saline Water Conversion Report, U.S. Dept. of the Interior, O.S.W. p.362) it was concluded that in a certain situation, a large size atomic power installation may provide optimal conditions for sea-water desalination. The requirements are:

- (i) Existence of highly sophisticated techniques in agriculture
- (ii) Availability of areas suitable for intensive agriculture close to the sea, and
- (iii) Existence of a technological infra-structure, capable of supporting a modern power-consuming industry.

These requirements may well be met in Israel, and the conclusions of the above Report should serve as guidelines when selection of a suitable site for the future desalination plant is considered.

The site for this plant was tentatively chosen on the Mediterranean, between the cities of Ashdod and Askalon. However, when considering future plans for an Agro-Industrial complex, we have to examine the second alternative as a possible site for the Desalination Plant: The Red Sea coast in the Eilat area.

The choice of this location for a triple-purpose plant would have some advantages:

1. Our Mediterranean coastline is already quite congested, and placement of an atomic power plant in the midst of an inhabited and exposed area may involve unnecessary risks. On the other hand, should the Red-Sea coast be chosen, the granite mountains, that are very close to the sea, could serve as convenient shelter for the nuclear reactor. (v.i.)
2. The bay of Eilat has an arid hinterland that could be used for development of highly intensive agriculture. The few settlements that were established in the Arava have proven, that with the aid of irrigation, this area can be converted into a highly productive agricultural region. It could be made to support a sizable population in the southern Negev as well as produce high income export crops. (v.i.)
3. The availability of a natural harbour, that is already playing an important role in our trade with Asian and African countries, will encourage the development of a near-by heavy chemical industry. Eilat is also a terminal for the incoming oil, and is therefore the closest source of primary petrochemical feed-stock.

On the other hand, it is possible to deliver to this area - by pipe-Dead-Sea end brines. These would provide the feed for large scale manufacture of magnesium metal and chlorine with the aid of low cost electricity and imported, liquified gas (see Table 2 from Metals Week, May 1968, p.14).

Availability of cheap power and gas (for dehydration of the brine) are a necessary condition for competitive production of magnesium, and both could be provided in the Eilat area. Another possibility would be aluminum production from imported East African or Australian mineral. It is more difficult to assess the copper reserves available in the Timna region. These are currently estimated to last at the present production level for some 20-25 years. If supplemented by imported crude copper, an electrochemical refining plant may prove a viable venture. In short, the placement of a large scale power generating station in the Eilat Bay (v.i.) could lead to the development of a non-ferrous-metal electrochemical complex in this area.

4. Combination of cheap hydrocarbon stock with low-rate electric power are the necessary prerequisites for production of cheap nitrogeous fertilizer. This, together with the Dead-Sea Potash and the phosphoric acid that will be available from near-by sources, will create a basis for large-scale manufacture of compound fertilizers that would be shipped from Eilat to areas where these are most needed.

5. The Dead-Sea brine if conducted along the Arava would enable the exploitation of the Ein-Yahav phosphate deposits and their conversion to phosphoric acid and by-product magnesium oxide (periclase) utilizing the Aman Process for magnesium chloride decomposition. Production of cheap hydrochloric acid at Timna would be another possibility. Although prices of sulfur have recently declined very considerably, the possible substitution of sulfuric

acid by hydrochloric acid for the leaching of copper should nevertheless be studied.

6. Cheap electricity may also insure competitive production of elemental phosphorus, that together with chlorine, combine as raw-materials for the manufacture of various pesticides. In the coming years there will be an increased demand for these products. Indeed, it has been predicted, that by 1973, gross sales of pesticides and herbicides will exceed the total sales value of fertilizers. With stiffening competition, the local manufacture of phosphorus tri- and oxy-chloride may prove a key-factor in sustaining our position in this important field, since transportation of elemental phosphorus and/or its chlorinated derivatives is hazardous and costly.

7. Finally, large-scale development of highly intensive agriculture in the Arava, using desalinized brackish waters from local underground sources (for which cheap energy is required) and supplemented by water delivered from the Eilat desalination plant - would create a sizable market for plastic materials. In this way the local consumption of plastics film, pipe, building materials (foam) etc. will grow to an extent such that local large scale production of these materials from primary feed-stocks would become economically justifiable.

In summary: Big-volume consumption of plastics by modern, highly-intensive agriculture seems to us the only way whereby a basis for the development of a petrochemical industry in Israel may be established, without taking undue risks in relying heavily on exports.

Since the future of our petrochemical industry appears to be closely linked to the development of an Agro-Industrial complex, this latter point merits some further elaboration.

As availability of water - and not acreage - is the limiting factor in arid zones, future agriculture in such regions is envisaged to be developed under closely controlled environmental conditions. One possible concept of such a "Photo-synthetic Factory" is presently being studied (and even implemented on a moderate scale in Abou-Dhabi) by Dr. C.N. Hodges and his associates at the Environmental Research Laboratory of the University of Arizona (ERLUA).

It turns out, that this form of highly intensive agriculture will be a "hungry" customer for various plastic materials:

- (i) The water distribution grid for the agricultural complex will require a considerable quantity of pipe. So will the disposal of highly saline effluents, that will result from desalination of brackish waters* or from the cooling devices that will be installed in the Controlled Environment Enclosures (CEE).
- (ii) The CEE's that will cover quite extensive areas (whose function it will be to prevent excessive water losses by evaporation on the one hand, while containing a carbon-dioxide enriched atmosphere for stimulated photosynthesis, - on the other) will require considerable amounts of plastic film.

The concept of the ERLUA team for such CEE's is of particular interest, since the enclosures do not require costly supporting structures, as they are supported by a slight over-pressure of the carbon-dioxide enriched, controlled, atmosphere (Fig.2).

* Footnote: Whether reverse-osmosis or electrodialysis techniques are used for desalination - only part of the feed-water is desalinized. Another part (up to 30%) is concentrated at the same time, and has to be suitably disposed of.

Inside these enclosures nearly tropical temperature and humidity conditions prevail, and according to C.N. Hodges, it is possible to raise in these enclosures three crops per year. Due to the high carbon-dioxide concentration - which is maintained at a level 3 to 4 times higher than in our atmosphere - enhanced photosynthesis produces considerably higher yields of many selected crops.

Experiments of crop-raising in a carbon-dioxide enriched atmosphere are being carried out in this country with considerable success in some cases. It is of interest, that a cheap source of this gas is available as by-product from the Baniel process of phosphoric acid, that will be produced on a large scale in Arad, as well as in future installations of this kind in the Ein-Yahav area (Fig.3).

(iii) Agricultural storage facilities, silos, silage-towers etc. are increasingly being built from plastics materials (Fiber-glass reinforced plastics). Hydroponics is also making extensive use of plastics plant-beds and feed-solution containers.

Modern, highly intensive agriculture is consuming appreciable amounts of cheap protein derived from sea-organisms. The Fishing Industry, based at the Eilat harbour will also be using large quantities of plastics; not only fishing nets and fish-crates are nowadays made of polyethylene, but fishing boats themselves are being constructed from fiber-glass reinforced polyester (FRP) - on an increasing scale. This last item may easily consume thousands of tons of resin derived from petrochemical sources.

(iv) Export of agricultural produce is making use of large quantities of plastic packaging materials, in the form of bottles, film and crating materials.

Large quantities of shreaded plastic film (mainly polyethylene) are consumed for plastic bags, used in shipping of fertilizers, pesticides, fish-meal and other products.

In summing up, we believe that by having an Eilat-based Power-Desalination Plant with development of an Agro-Industrial Complex in the Arava, a basis for a petrochemical and fertilizers industry of considerable size would be established; a significant part of its output would find captive use for the production, packaging and transport of a highly upgraded quality product, - agricultural exports. Wide use of the industrial output on the local market will provide the base for large-volume manufacture of compound fertilizers, pesticides, and certain intermediates and plastics, that would be sold at competitive prices on various markets, primarily in African and Asian countries.

The proposed nuclear-power based Agro-Industrial Complex is shown diagrammatically in the Synoptic diagram below (Fig.4).

The project that was described here is by no means an attempt to offer a "General Plan for the Development of the Chemical Industry in Israel". Neither did we mention many other interesting possibilities that could be integrated within the framework of the above industrial complex in a rather logical manner. (f.i. Fluro-organics based on hydrofluoric acid, that is a by-product in the manufacture of phosphate, will be in large demand in the cold storage and air conditioning industries).

Should an Industrial Complex of this kind be set-up, it will not be the only "Chemical Giant" in the country. Israel is well placed geographically to conduct extensive trade with east and west alike - and there is little doubt that centers such as Haifa and Ashdod will provide focal points for extensive chemical industries that will interact with the Southern Complex.

The industrial scheme that was outlined in these pages should be seen as a "mental exercise", trying to describe an agro-industrial structure in the Arava.

There are many questions that may be asked on reading these lines. If we speak of a considerable export trade - what about the imports, that must balance it? What shall we import from the Asian and African countries and what are we to do with the imported goods?

Or, what is the point in such "mental exercises" without assessing the sources of financing such huge enterprises? Would our potential manpower resources be adequate in order to implement a program of this size and nature?

To give a reply to these and other questions, one would need a planning organization, that would include experts in many and varied disciplines. These should examine various alternatives and chart the optimal course of action.

However, even before detailed plans of such an enterprise are laid on the table we believe, that the present "thought experiment" is not an exercise in futility. True, each item that appears in the synoptic diagram (Fig.4) involves a multi-million Dollar investment, and integrating them all within a complex of this magnitude would call for a tremendous effort. But, large-scale consolidated efforts of a similar kind have been made in many countries, and regional planning of such, and even larger scope, has transformed large, under-developed areas into prosperous socio-economic entities. Large investments are required for big projects - but, conversely, giant projects often attract investment, particularly if they solve some real and pressing needs. It is, perhaps no paradox, that in Israel it may prove more facile to secure investment for a regional development project of this kind than for many small

and isolated propositions. A project of this scope and size will certainly provide a challenge to our young generation - both in Israel and the diaspora, and attract the skilled and enterprising ones, the intellectuals and professionals, that form a major proportion in any Jewish community today - in the Western countries or the Eastern block. But it will also provide extensive opportunities for the absorption of semi-skilled and even unskilled labor that comprises the bulk of the Arab refugees, contained in the camps of Gaza and in the West-bank of the Jordan.

THE SOCIO-POLITICAL SIGNIFICANCE OF THE ARAVA-REGIONAL DEVELOPMENT PROJECT

The object of this last paragraph is to examine some socio-political consequences that may follow from the implementation of a large-scale regional development in the Arava.

Should a project of this magnitude be realized, it would very basically affect the Israeli economic structure. One may ask: is a project of this kind a pressing necessity for this country? Why should we not plan our future economic expansion on entrepreneurial activities, coupled with Government encouragement, that would aim at establishing many small and medium sized industries - as we went along so far? Several factors combine to support a large-scale development project in Israel:

1. Our National Debt is growing at an alarming rate. It is estimated by the Israeli Treasury (HAARETZ, 19.1.1971) that by 1975 this debt would amount to about \$5.6 Billion (instead of \$2.7 Billion at the end of 1970). To meet the challenge of such a huge imbalance in trade and payments, the economy has

2. Israel is expecting a mounting wave of immigration. An absorptive capacity for the forthcoming immigrants - many of these being white collar workers, engineers and highly skilled professionals, - can be created only by greatly expanding the economy. At the base of such an economic pyramid there must be a heavy industry, that would provide some basic commodities at competitive prices.

3. As was already mentioned, in addition to the expected immigration, Israel must cope with the problem of the Arab refugees. This should be done in a manner such, that would not endanger its own future, which means: a solution on a regional basis.

4. Finally, the Arava is at present a barren region. Yet, its strategic importance cannot be overemphasized. We believe that it is of great importance, that this strip of desert land, that leads to the port of Eilat - should be inhabited and developed.

The Arava, although a bare desert, provides for a combination of most interesting features. Several of these were already mentioned above. In addition:

(i) It is one of the regions with highest incidence of solar energy per unit area (absence of cloudy days). This would be ideal for development of controlled environment agriculture.

(ii) It is almost entirely uninhabited on both, the Western and Eastern sides. The Moav Mountains on the eastern side (Jordan), although largely barren, have considerably more rainfall in the winter, than the eastern parts (Israel), and could, probably, be reafforested. The climate on the Moav

Plateau is good, and this region could be developed for the resettlement of large numbers of Arab refugees, that would form many urban communities of workers, supported by marginal, small scale agriculture. As will be seen below, the inhabitants of these small towns, that would be built on the Moav Plateau, - would be employed in the Agro-Industrial Complex (A.I.C.) of the Arava. It seems entirely feasible to develop cheap and efficient means of transportation, that would enable the future working population of the Moav to commute daily to work in the A.I.C. Thus, the bulk of these refugees would be transformed into an urban, industrial working community, even if many of them would find employment in the "photosynthetic factories" of this Complex. On the other hand, as a cultural entity they would be given all possibilities to maintain their national and religious identity, as they would be closely linked with their kith and kin in the Jordan Territory.

(iii) The Arava rift has also a topology that commands a potential for the excavation of a water-way spanning the Eilat bay with the Dead Sea. This possibility has been mentioned before by many, but was treated extensively by S. Gur in his recently published book: "The Arava Rift: A Challenge to Development". Discussion of the Gur Plan in the present memorandum would be entirely beyond its scope. Several points should, nevertheless, be briefly mentioned here in view of their relevance to the Arava A.I.C. described in these pages.

Although the Gur Plan also calls for large scale industrial development of the Arava (without, however, discussing agricultural development in this area) - the Regional Project suggested by him far exceeds the present proposals.

The Gur Plan can be implemented only as an International Project, involving the consent of the Arab States, since it envisages the inundation of extensive areas that are under Jordanian sovereignty. Before such consent is given (i.e., before real peace is established) - such a plan must remain shelved.

However, should Gur's idea of excavating a canal be adopted, but meanwhile be limited to the creation of an inland navigational canal, -without for the time utilizing its potential as a means for generating large scale hydroelectric power (ca. 1000 M.W.), - the following advantages would ensue:

1. It is assumed that consent for nuclear excavation may be obtained against guarantees that no damage would be done to any party bordering this region. In such a case the construction of the canal would become an internal Israeli project, since it would not entail any topological changes in foreign territory.
2. A water-way would be created, admitting ocean going ships to internal harbors close to the industrial clusters - with all the consequences that cheap transportation will create.
3. The nuclear power generating plant, whose placement was envisaged in the Eilat Bay (Fig.4) - could be placed in a convenient location along the canal. This will have obvious advantages. Any effluents that would cause disturbance and possibly considerable damage to the tourist trade in Eilat - would flow into the canal, and end up in the Dead Sea, which is devoid of any living organisms (except certain algae and bacteria). Thus, there would be no danger of contamination via biological assimilation processes of certain trace-isotopes.

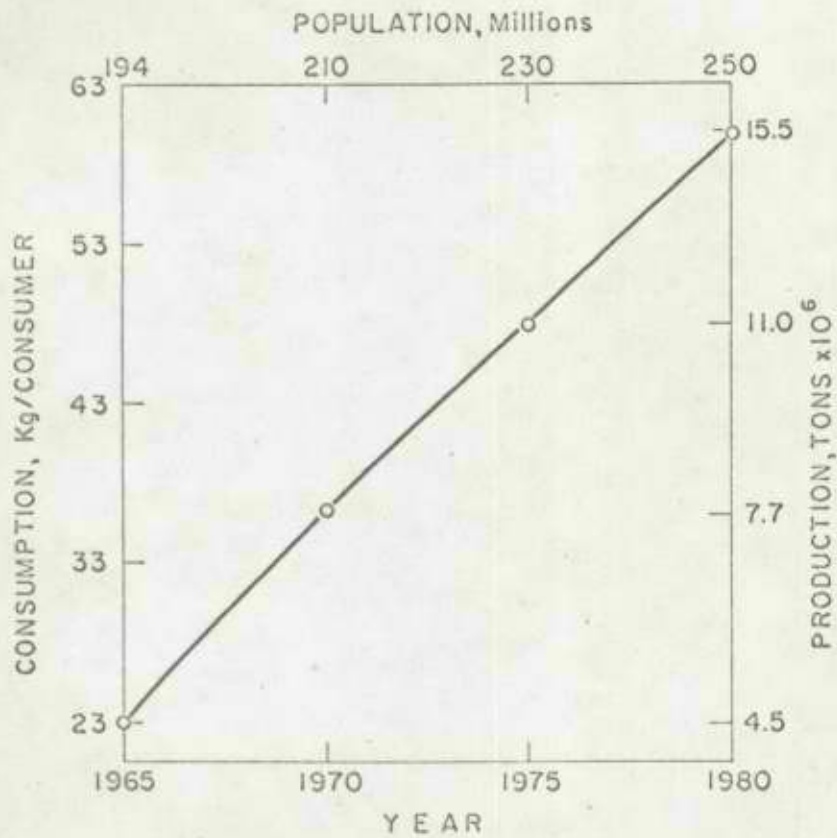
4. The canal would provide abundant cooling water for the heavy chemical industry of the complex, and also for desalination by the nuclear heat.
5. The water generated close to the power-station would be distributed in an area where it is most needed - shortening considerably the water grid and reducing pumping-power expenditure.
6. The option would exist to use the considerable gravitational potential for constructing a Pump-Storage Electricity Generating Plant. Should this plan be adopted, it would not only create an excellent buffering capacity for the Israeli overall power load, it would provide a possibility for emergency power generation for some time, without inundating presently inhabited regions.
7. Finally, it will provide a kind of natural demarkation zone between Israel and Jordan.

On both sides of this canal there would ultimately develop an array of industries as well as highly intensive agriculture. There would be very considerable interaction, with people eventually crossing the line. But there would also remain separation, - at least as long as both sides will prefer separation. The option for each nation to live its life as it pleases - would, hopefully, be given to both peoples.

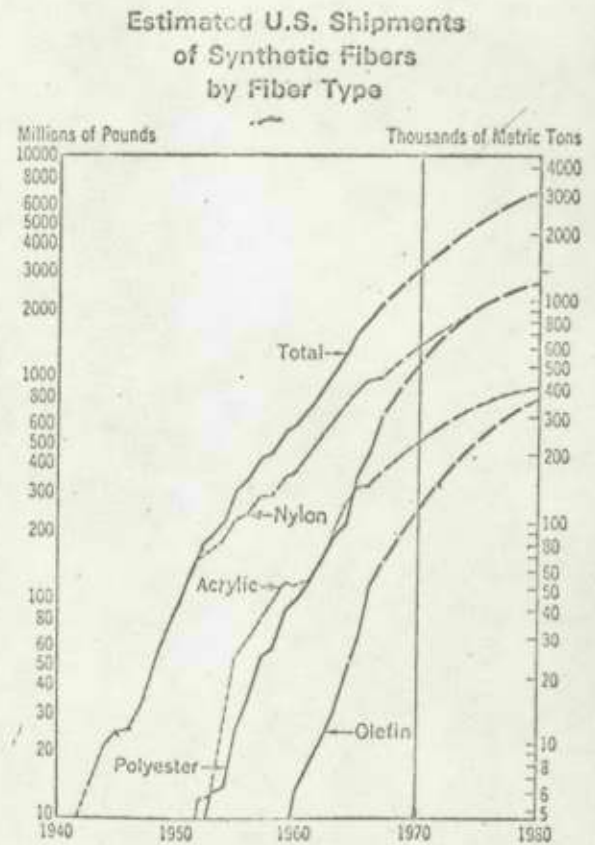
As to the more distant future - the Arava canal may some time become part of an international water-way - In accordance with the Gur Plan. This option would still be maintained, and it would be for the future generations to decide whether they would like to do so.

Rehovot, February 4, 1971

Fig. 1. a and b



CONSUMPTION OF PLASTICS IN THE U.S.A.
TAKEN FROM MODERN PLASTICS, NOV. 1968.



Sources: Textile Organon, Projections by SRI

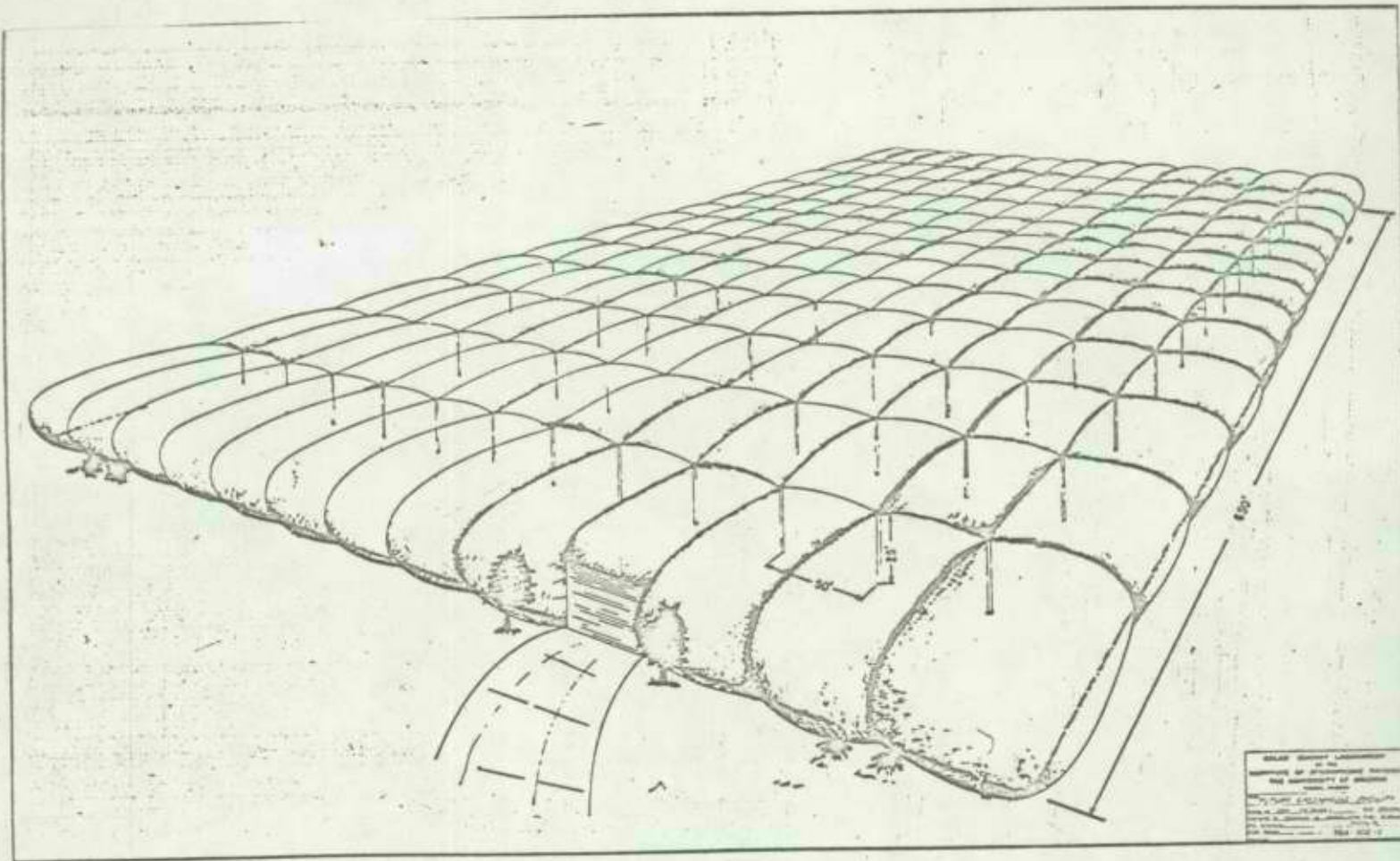
Growth of the Plastics and Synthetic Fibers Industry in the U.S.
(From Stanford Research Institute Reports).

Fig. 2a

Inflated Greenhouses. 1

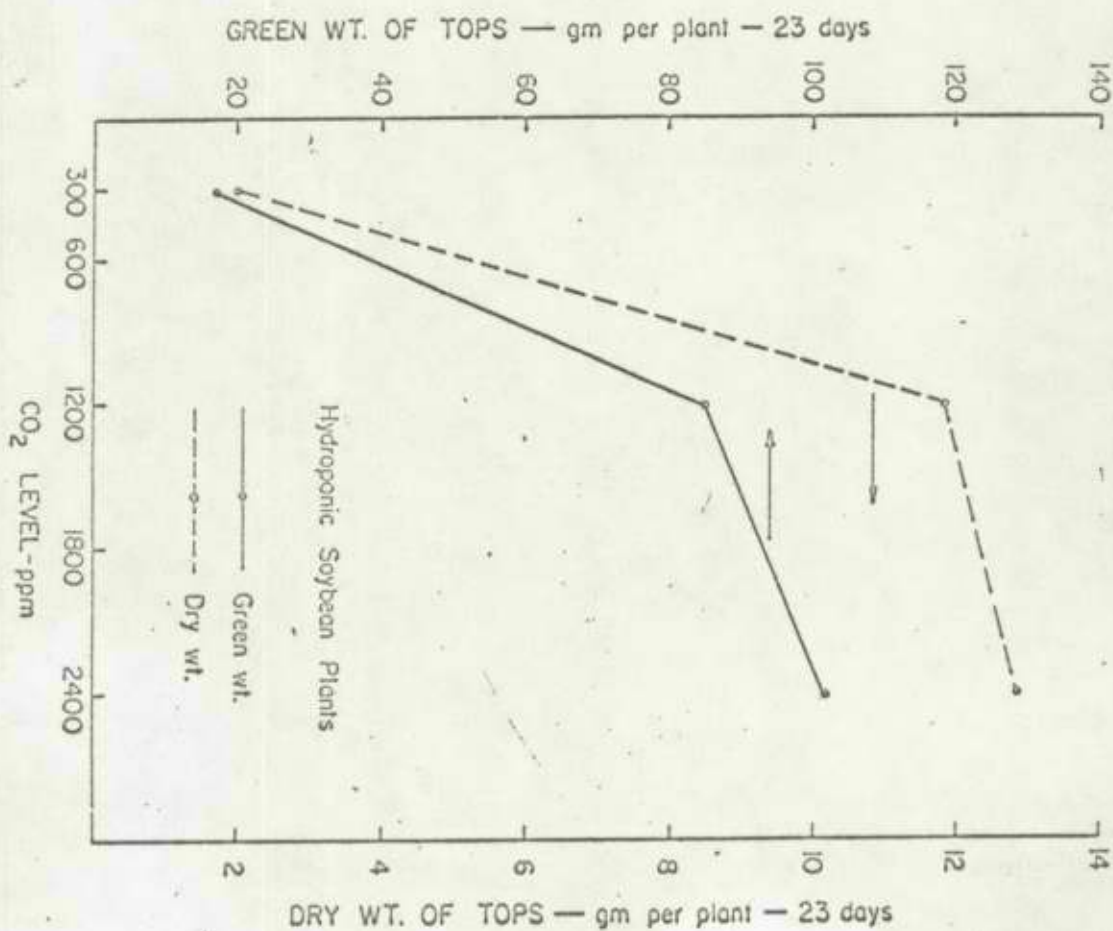
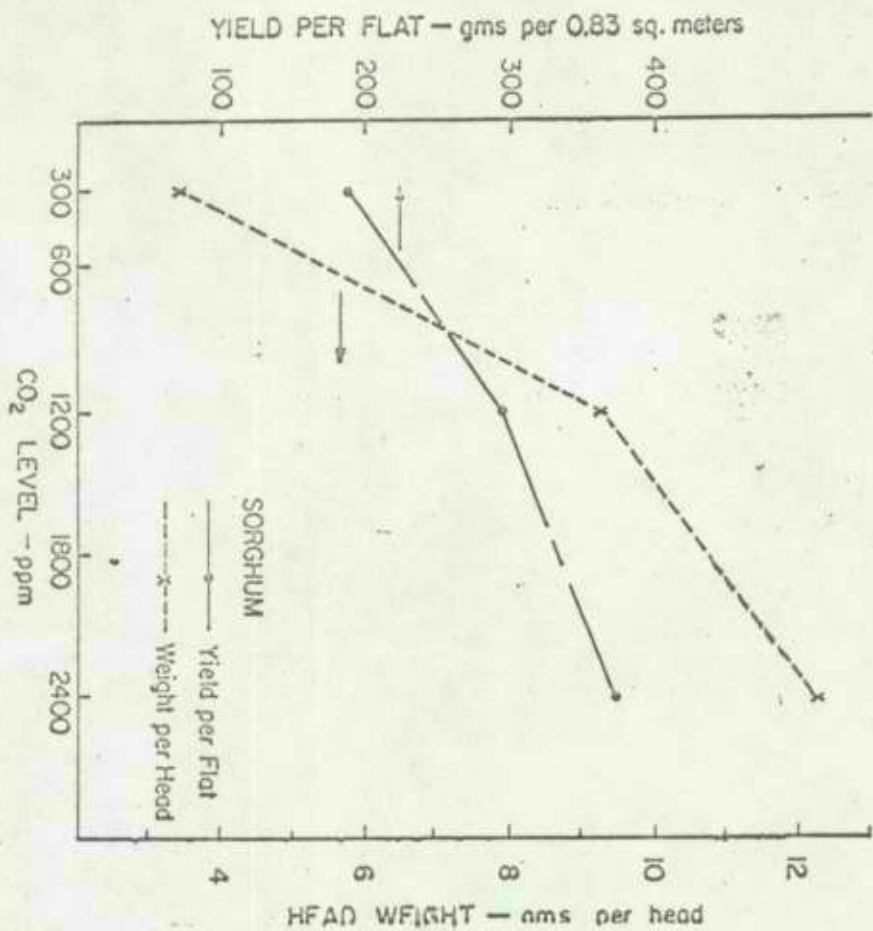
(Puerto Penasco Project, University of Arizona)

Fig. 2b



Controlled Environment Enclosures: A Multi-unit Concept. (According to C.N. Hodges, University of Arizona). ERLUA Report, Tucson, July 1967.

Fig. 3 a and b



Enhanced Growth of Industrial Crops by Increased Carbon Dioxide Concentration in the Controlled Atmosphere.
(Taken from: C.N. Hodges, Controlled Environment Agriculture, University of Arizona, July 1967).

FIG. 5

ALAYA PROJECT PROPOSAL

