Feasibility of Storing Large Quantities of Crude Oil in Salt Dome Solution Cavities

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ABSTRACT

With the increasing dependency on imports of crude oil and petroleum products the national security and the economic welfare of the United States may be in jeopardy should such supplies be seriously curtailed. A possible short term solution is suggested to replace the lost imports until a replacement source for our energy needs has been developed. This solution consists in storing large quantities of crude oil in salt solution caverns on and offshore. The feasibility of constructing large caverns in salt domes is studied and a program for the construction of storage space of 1 billion barrels over an eleven year period is developed.

INTRODUCTION

The United States is the largest consumer of energy in the world. In 1967 this country consumed 30 percent of the world's energy requirement while representing only 7 percent of the world's population (U.S. Department of Interior, 1968).

In 1971 the National Petroleum Council projected an increase in energy consumption of 4.2 percent per annum through 1985. One can visualize the serious effect on this country if one of its major energy sources such as oil were taken away or seriously reduced. In 1970 petroleum liquids (crude oil, condensate and natural gas liquids) accounted for 43 percent of this country's energy consumption (National Petroleum Council, 1971). Figure 1 shows the relative importance of each of the elements of our energy supply.

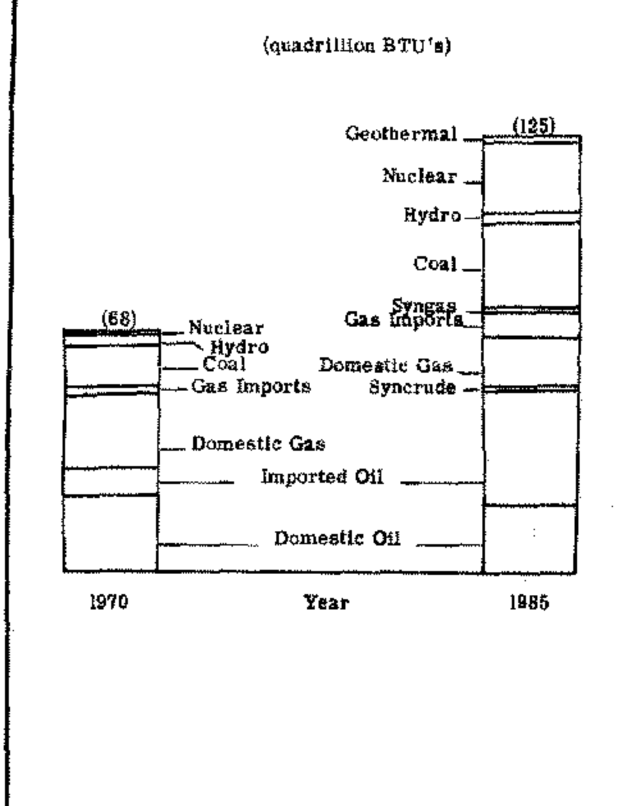

Figure 1. Total Energy Demand for the United States.

Since 1948 when petroleum imports into the U.S. surpassed the exports for the first time (American Petroleum Institute, 1971), a growing dependency on foreign crude oil and petroleum products has developed. Figure 2 illustrates this growing dependency on imports.

Imports of crude and products come from Latin America, Canada, Africa, the Middle East, and the Far East. There are several possible situations (political, military, or natural disaster) that could obstruct the flow of foreign oil to the United States (See also Corcoran, 1972).

Under existing conditions, loss of the Panama Canal,

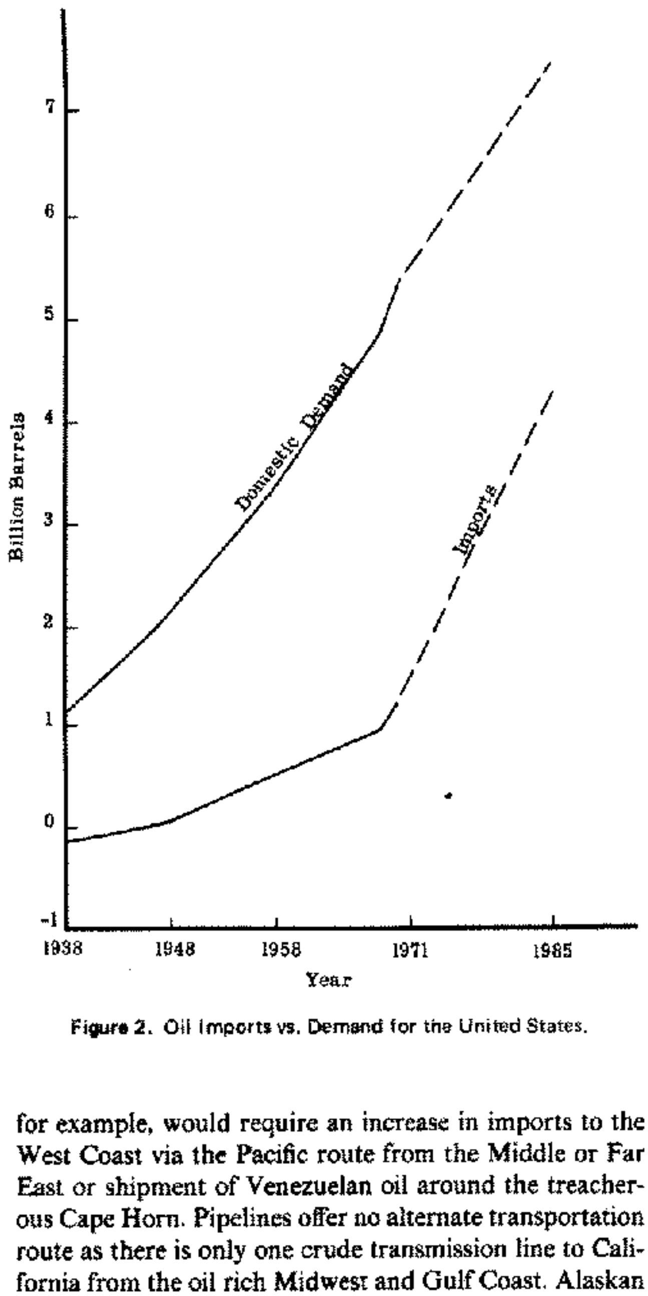

Figure 2. Oil Imports vs. Demand for the United States.

for example, would require an increase in imports to the West Coast via the Pacific route from the Middle or Far East or shipment of Venezuelan oil around the treacherous Cape Horn. Pipelines offer no alternate transportation route as there is only one crude transmission line to California from the oil rich Midwest and Gulf Coast. Alaskan North Slope oil will certainly lessen if not completely do away with the West Coast dependence on imported petroleum when and if it becomes available.

Based on 1970 figures, a blockade of the Strait of Gibraltar by an unfriendly nation would mean the loss of 6 percent of our crude imports. A blockade of the Persian Gulf would result in the loss of 12 percent of our crude imports (Independent Petroleum Association of America, 1972). A world wide naval conflict stopping all international tanker traffic would halt 77 percent of our imported crude and petroleum products and amount to over one billion barrels of oil in a year's time (loc. cit.). Any loss of imports that caused this country to dip into its stocks of crude and products would place not only our military security in jeopardy but also our economic security. As our dependence on imported oil grows our bargaining position with respect to the price we pay becomes more tenuous.

The purpose of this study is to offer a possible alternative to the catastrophic effects that a serious curtailment of petroleum imports or unreasonably high costs of foreign crude would have on the United States' economy should these events occur.

This alternative is to store a large quantity of crude oil in solution cavities in salt domes in such a manner that the stored oil can be used to replace imported oil for a relatively long period of time while a replacement source for the imported energy is developed.

THE COST OF STORAGE SPACE

If stored above ground, petroleum requires expensive steel tanks for safety and special fire protection provisions such as berms, dispersal, and fire fighting equipment. Above ground steel storage tanks cost up to 100 dollars per barrel of capacity (Proceeding 1967 Symposium on the Geology and Technology of Gulf Coast Salt). Large concrete tanks such as those to be used in the North Sea cost 50 dollars per barrel of capacity (Kennedy, 1972). Costs for construction of salt dome solution cavities have been reported to range from a low of $0.15 to a high of $2.50 per barrel of capacity (Hawkins and Jirik, 1966). The most economical storage method based on these data is a solution cavity in a salt body. Hawkins and Jirik listed liquified petroleum gas (LPG) storage projects in 24 domes having a total capacity of over 57 million barrels. By 1971 the capacity had reached 125 million barrels (Allen, 1971). Salt dome storage was expanded in 1970 to include natural gas with the completion of the Transcontinental Gas Pipeline Corporation's 2 million barrel project in the Eminence dome in Mississippi (Ibid). Mobil Oil A.G. will complete two 940,000 barrel crude oil storage cavities at Lesum, Germany, in 1972 (Oil and Gas Journal, 1970). The question remains, is it feasible to store as large a quantity as one billion barrels in salt dome cavities in such a manner that it will be readily available for use?

SALT DOME SELECTION

Salt domes are found in Arizona, Alabama, Mississippi, Texas and Louisiana. Arizona has only one identified salt dome, Alabama has two, Mississippi has 60, Texas has 82, and Louisiana has 183. Of these 328 domes, 71 are located offshore in the Gulf of Mexico. Four are off the Texas coast and the remaining 67 off the Louisiana coast (Hawkins and Jirik, 1966; Halbouty, 1967). In selecting a dome for use as a storage structure several criteria must be considered.

Depth to top of salt

Cavities can be maintained full of liquid at all times by floating the oil on salt water and in the case of storage of LPG or natural gas the stored material is under pressure approaching that of the overburden. This type of facility is a working storage and can be filled and emptied several times during a year. The case under study is a long-term storage facility with the possibility that it will be filled and emptied only once. In the interest of simplicity and economy it is assumed that the cavity will not be pressurized or filled with liquid at all times. Empty cavities with overburden pressures greater than 3,000 psi. and temperatures of 400 degrees Fahrenheit will start to close (Brown, 1959). The amount of closure increases with depth because of increasing pressure and temperature since the viscoplastic property of salt is dependent on both pressure and temperature. At depths up to 5,000 feet the temperature will most likely not exceed 180–190° F., and with such temperatures, stable cavities can be constructed. A maximum depth to top of salt was chosen as 3,000 feet. Out of the 328 known domes, 159 meet this requirement.

Availability of water

Fresh water wells have been the primary source for solution water used in cavities constructed to date. Rivers are considered as a viable source in this report although it should be noted that since construction periods of one, two, or three years and quantities of water in the range of 10 to 600 million barrels are contemplated for any one site, only rivers having a large reliable flow have been considered. Using salt water from the Gulf of Mexico or a salt water embayment along the Gulf Coast is feasible and has the advantage of low cost and unlimited supply. Of the 71 offshore domes, 23 meet the 3,000 foot depth to top of salt requirement. In addition, 34 of the onshore domes are within 10 miles of the Gulf or an embayment and hence in realistic reach of salt water.

Disposal of brine

Ideally the dissolved salt could be reclaimed and sold. This was done in 1953 by the Cities Service Company in a storage project in Reno County, Kansas (Interstate Oil Compact Commission, 1956). Such a method is feasible for small scale projects as construction rates are controlled by salt extraction plant capacities.

The next, and most widely used, method of brine disposal is injection of the brine into a salt water aquifer. The Transcontinental Gas Pipeline Corporation constructed two 1,000,000 barrel cavities for natural gas storage in the Eminence Dome in Mississippi using this method (Allen, 1971). Disadvantages of this method are the cost of drilling the injection well and the injection of the brine. Also cavity construction rates are dependent on the injectivity of the salt water aquifer and the quality of the brine injected may be restricted by governmental regulations or chemical limitations to prevent plugging the aquifer.

The third method is to dump the brine into a saline body of water, which affords an unlimited disposal rate and few or no restrictions on the quality of the water dumped.

Disposal of brine in rivers was considered as feasible if well controlled and limited to large rivers, however, in view of the current concern over protection of the environment, it is doubtful that any dumping of brine in the quantities that would result from the proposed construction would be allowed by the state or federal governments.

For the purpose of this study, the cavity shape was assumed to be cylindrical and the total quantity of crude oil to be stored to be one billion barrels which will replace approximately 77 percent of the United States' imported petroleum for one year based on 1970 rates (Independent Petroleum Association of America, loc. cit.).

SITE SELECTION

The optimum cavity site as far as costs are concerned would be one large cavity. Such a cavity would be unstable but more importantly it would be vulnerable to accidental or intentional destruction and it would be impractical to remove and transport large quantities of crude at rates sufficient to compensate for import losses up to three million barrels a day. Thirty cavities would yield a total of three million barrels a day supplying 100,000 barrels per day each. Such rates are feasible if the cavities are properly located in relation to a means of transport.

The refining centers most likely to suffer from the supposed import loss are those on the East and West Coasts. Unfortunately there are no salt domes near these centers. Three transportation media, pipelines, tankers, and barges were considered as capable of moving significant quantities of crude oil. Trucks and railroads were not considered as prime transportation media based on the small quantity of crude oil they now transport in the United States.

It would be feasible to construct cavities and store crude oil in any of the salt domes with tops of 3,000 feet or less in depth. The problem is to select the most advantageous domes. It is impossible in most cases to say that a certain characteristic is definitely a disadvantage or an advantage. For instance, deep water over an offshore dome is an advantage if the storage cavity is to be serviced by supertankers but is a disadvantage when considering the cost of constructing a service platform. The location of an offshore dome near a developed refining complex is advantageous from a transportation point of view but again from the cost view it is a disadvantage when considering acquisition of land. The cheapest land is usually furthest from developed areas. A location serviceable only by tanker might be useless if all sea traffic were halted. On the other hand a site serviceable only by pipeline may be disadvantageous if the lines are operating at maximum capacity when the reserve of oil is needed.

SALT DOME AREA

The salt dome areas were divided into regions based on location on or offshore, proximity to refining centers and ocean ports, and/or proximity to large rivers offering potential solution water sources and transportation media (Figure 3). All the salt domes meeting the depth to top of salt requirement were considered using the following criteria:

1. Depth relative to the other domes in the group.
2. Volume in relation to potential expansion of storage and in relation to the volume of the other domes in the group. (No size was considered disqualifying.)
3. Distance to large rivers. This includes intercoastal waterways.
4. Location in respect to land acquisition cost and construction difficulties.
5. Possible conflicts with other commercial operations such as LPG storage, commercial salt mining operations, or sulphur production.

The best domes were then used to develop a program for construction of the proposed one billion barrel storage capacity. It was assumed that dispersal would be beneficial for physical security reasons, transportation availability and flexibility.

From the ten regions thirty-two domes were chosen as being the best for storage sites and are summarized below:

Region	*Dome*
Arizona	Luke
North East Texas	Oakwood, Brooks, and Steen
South Texas	Gyp Hill
Texas Coastal	Boling, Damon Mound, Hawkinsville, Moss Bluff, South Liberty, and Davis Hill
Texas Offshore	Block 144—Galveston
North Louisiana	Rayburns, Crowville, Bruinsburg
Louisiana Coastal	Vinton, Avery Island, Weeks Island, Cote Blanche Island, and Napoleonville
Louisiana Offshore	Blocks 386 West Cameron, 164 Vermillion area, 115 East Cameron, 175 Eugene Island, 126 Eugene Island and Rabbit Island
Mississippi	McBride, Leedo, Lampton, and Richton
Alabama	McIntosh

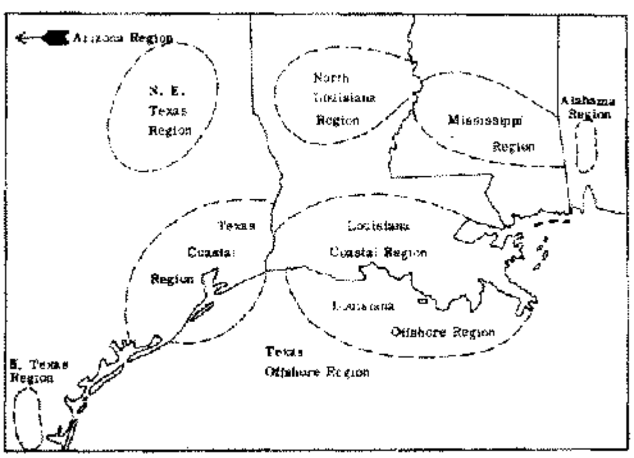

Figure 3. Salt Dome Regions.

CONSTRUCTION PROGRAM

Details regarding a possible time schedule for the proposed storage space construction program are given by Corcoran (1972) and will not be presented here. The program emphasizes construction in the coastal region and off-shore during the first five years. This was done for the following three major reasons:

1. These areas allow the highest possible construction rates because water is readily available and disposed of.
2. Supertanker offload facilities can be constructed at the same time. They may then be used to fill the caverns and thus afford an emergency supply of crude petroleum at the earliest possible time.
3. The vicinity of existing pipeline systems will facilitate the distribution of crude from the caverns if and whenever it is needed.

Figure 4 gives construction time for a billion barrels of storage at rates of 100 million and 200 million barrels a year. Figure 5 represents a summary of a time schedule for a 10-year 680 million barrel construction program.

Actual construction rates for individual cavities have varied from 1,235 barrels per day at the Sour Lake dome to 8,430 barrels per day at the Barbers Hill dome (Dommers et al., 1963). At a rate of 1,000 barrels per day to meet the 200 million barrel per year construction rate, 548 individual projects would have to be in operation at a time. This would be impractical from a cost standpoint. Even at 10,000 barrels a day, 55 individual solution projects would have to be operating at one time and increasing the construction rate to 20,000 bbl. per day, 28 projects would be required.

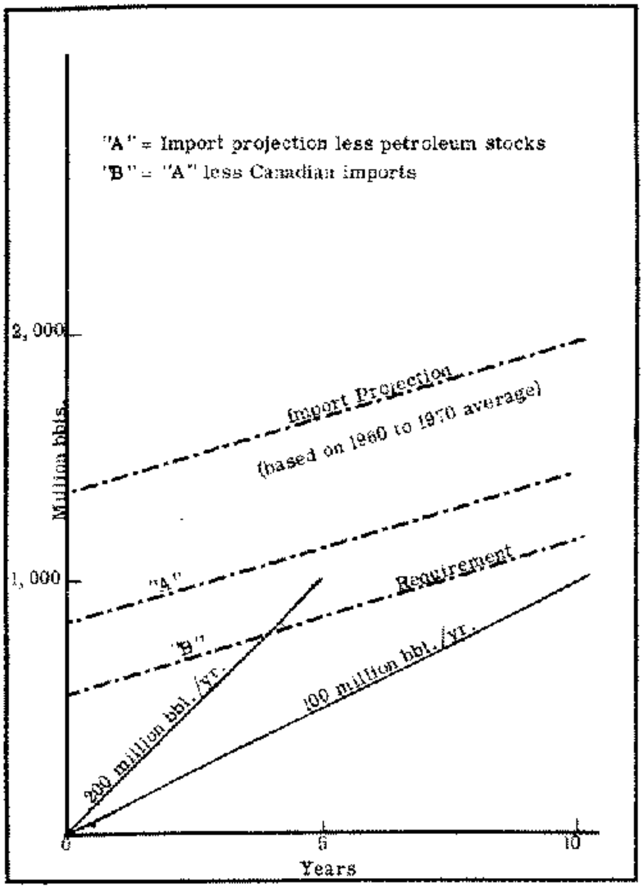

Figure 4. Storage Requirements vs. Construction Rates.

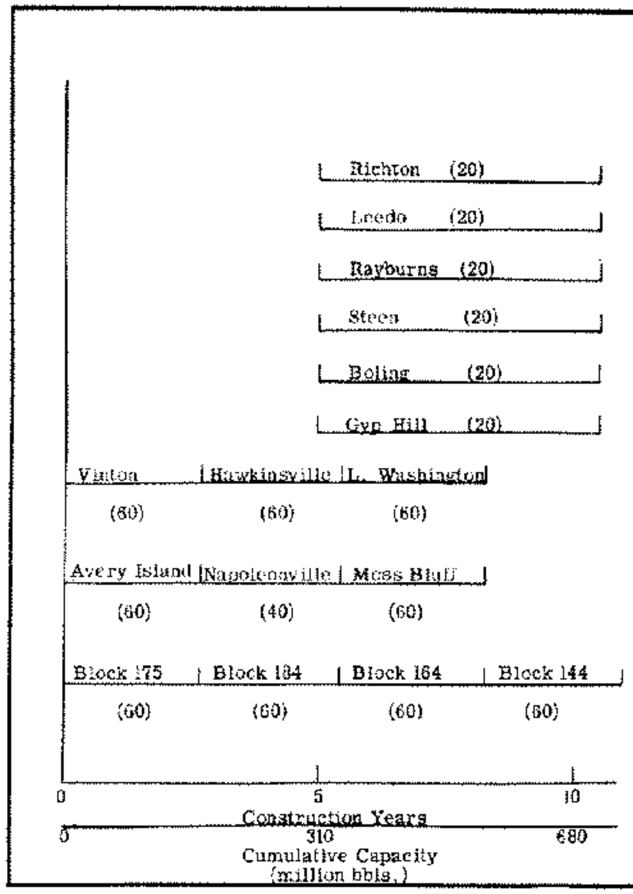

Figure 5. Cavity Construction Program.

Onshore construction at rates of 10,000 to 12,000 barrels per day are feasible but would probably require multiple fresh water wells and possibly multiple disposal wells (Fenix and Scisson). If large cavities and high construction rates are required, it will be more feasible to use sites near the Gulf Coast or offshore.

There are other advantages to such a location in addition to those mentioned earlier. The oil to be stored will be imported oil and will come to the United States by tanker. Assuming an average transportation cost of even $1.00 per barrel for standard tanker rates, as much as $500 million could be saved if the one billion barrels of crude were shipped by supertanker because of 50% lower unit transportation cost. One of the areas where unit costs of industrial products can be lowered effectively in the future lies in the field of transport and distribution savings of up to 50% are feasible (Smith and Marcus, 1973). However, at the end of 1971 there were no port facilities capable of handling supertankers on the East or Gulf Coasts (National Petroleum Council, loc. cit.). Major efforts to create supertanker facilities offshore Louisiana and Texas are now under way (Oil and Gas Journal, 1973; Oil Daily, 1973). There is a possibility of combining an offshore system to serve a salt dome cavity with a commercial offload facility for supertankers, by using a floating platform costing $80 million, a fixed platform costing $50 million or a single point moor system costing $35 million (Kinney, 1971).

This concept of joint use can be carried even further. So as not to restrict tanker offloading by pipeline capacity, refinery requirements, or limited storage the tankers could be offloaded directly into the cavities which could be constructed with excess capacity to handle tanker shipments. Faster turn-around times for tankers would decrease import costs and the large storage capacity would allow firmer shipping schedules.

Also use of an offshore dome will reduce or eliminate the cost of land the acquisition of salt and/or storage rights in these areas controlled by the states or the federal government.

If one studies the crude transmission pipeline system of the United States, it becomes apparent very quickly that East Coast refineries are isolated from the domestic crude supplies except by ocean routes. There are a number of gas transmission lines to the East but converting these to crude lines, if it were feasible, could result in a natural gas shortage in lieu of a crude shortage. Product transmission lines, however, may be idle without a flow of crude to refineries and do offer a possible means of assisting in transporting crude to the East. No matter how unpredictable the availability of ocean transportation may be, it will have to be the means of supplying the East Coast with the bulk of its crude requirements.

The program as outlined to this point will not reach the previously projected one billion barrel capacity (Figure 5). At the end of five years the capacity will be 310 million barrels and at the end of ten years it will be 680 million barrels with a final capacity of 700 million barrels at the end of the eleventh year of the program.

The bases of this program are assumptions, projections and possibilities. If such a program were instituted, it would have to be reviewed after each five years of construction to account for changes in these uncertainties and revisions made accordingly. The reviews should be made to include not only changed supply, demand, and political conditions, but more importantly the availability of useable storage space in commercial salt mine cavities. Hawkins and Jirik (1966) reported that in 1964 10 million short tons of salt were produced by solution mining in Texas, Louisiana, and Alabama. This represents about 23 million barrels of storage capacity. Since salt solution mining cavities must ultimately be abandoned, the potential storage space is highly significant as shown by the 1964 rate of salt removal. If the cavities are also near crude oil transport media, they could be used for storage. It is entirely feasible that the remaining 300 million barrels of storage capacity could be obtained from existing salt mine solution cavities. The approximate total volume thus obtainable may suffice to complete the one billion barrel originally conceived.

Providing the West Coast refineries with crude oil is a problem in itself. The closest storage site is the Luke dome in Arizona. To completely offset California's import losses for a year would require over 100 million barrels of oil. The Luke dome could accommodate this quantity of storage space but construction may be quite difficult in this water scarce state. Even at the maximum construction rate and forming eight cavities simultaneously, it would take almost three years to construct a 100 million barrel capacity.

Considering the availability of Alaskan North Slope Oil three to five years away, the development of import sources on the west coast of South America, the probable construction difficulties in Arizona, and the paucity of large bulk transportation media to California from Arizona it is considered impractical and unwarranted to undertake a storage project for the West Coast at this time.

SUMMARY AND CONCLUSIONS

The question as to the feasibility of storing a large quantity of crude oil in salt dome solution cavities so as to be useable in case a restriction in imported oil should occur has been answered in the affirmative. Sixteen sites were selected for storage totalling 700 million barrels assuming that the remaining 300 million barrels of storage capacity can be found in solution salt mine cavities. Four of the selected sites are offshore and are intended to function also as supertanker offload facilities not only to fill the storage cavities but to also offload tankers on a regular basis. The proposed construction program will require ten to fifteen years to accomplish; ten years if 300 million barrels of useable storage space can be obtained in salt mine solution cavities and fifteen years if all of the proposed one billion barrel storage volume has to be constructed. The cost of such a project would probably not exceed $2 billion of which $185 million would be for offshore tanker offload facilities. The actual storage construction costs would be approximately $1.75 per barrel (for a billion barrel program assuming 300 million bbl. existing storage).

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