1956

# A study of the prospective use of underground storage of crude oil in the next decade.

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# A STUDY OF THE PROSPECTIVE USE OF UNDERGROUND STORAGE OF CRUDE OIL IN THE NEXT DECADE

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# FOREWORD

The author wishes to express his appreciation to Professor Holbrook G. Botset, Head of the Petroleum Engineering Department, University of Pittsburgh, for his helpful suggestions in the preparation of this thesis.

# I. PURPOSE

The purpose of this study is twofold: (1) to determine from background factors and current trends, the storage requirements within the next decade for crude oil in the United States, and (2) to determine the practicability of underground storage of crude oil in those areas which offer the most favorable atmosphere in terms of economics and other considerations.

Crude oil has been chosen for study in lieu of the liquid petroleum products for several reasons: (1) crude oil as the raw material in essentially a manufacturing process requires storage space equal to the sum of storage space for the several products. Storage space considerations for crude oil thus quantitatively embraces approximately one-half the storage in the petroleum industry, not considering natural gasoline or liquids from natural gas, (2) the physical characteristics of low viscosity, low vapor pressure and specific gravity qualify crude oil as a likely candidate for underground storage, and (3) regardless of changing product demand brought about by improvements and design changes in equipment using petroleum products as energy, crude oil will still be the necessary raw material in the manufacture of the products.

## II. INTRODUCTION

In recent years technical and scientific developments throughout the world have accelerated the utilization of natural resources to an extent that increasing effort and money are being devoted to their development and exploitation.

Basic industries have been forced to probe further and further afield in search of new sources of raw materials with which to ensure their future, and have been forced to look further into the future in an attempt to prepare for those courses of action that appear sound in the conduct of free enterprise.

With the accelerated growth in mechanization of manufacturing processes throughout the world and the increased dependence of all types of industry on petroleum for energy and lubrication, more and more attention is being devoted to the analysis and prediction of the future status of the key petroleum industry.

In consonance with the responsibility for satisfying the ever growing market for petroleum products, the petroleum industry is obliged to take advantage of each development and opportunity that tends to improve the availability of the products.

Among other concurrent developments that have taken place affecting the petroleum industry is the use of underground storage for L.P.G. In terms of economics, the use of underground storage has contributed directly to the fantastic growth of this branch of the petroleum industry within the past decade.

The record is obscure, but it appears that the first underground storage project was developed in Sweden during World War II, when a

Mr. Harold Edholm developed an underground container[1] of a type now referred to as the Edholm container, in which to store fuel oil. The first attempt to use underground storage in the United States probably occurred in Texas in 1949, when the Texas Natural Gasoline Corporation dissolved and used a salt cavity of approximately 50,000 barrels in Upton County, west Texas.

Since that time the LPG branch of the petroleum industry has expanded the capacity of its underground storage to the extent that at the present time an estimated 258,000,000 gallons of LPG are housed in underground storage.

Until recently, when an abandoned open quarry in Wind Gap, Pennsylvania was converted to store fuel oil,[2] the use of underground storage was confined to the LPG branch and as far as can be determined, the storage in Wind Gap represents the only attempt to store a normally liquid hydrocarbon in underground storage in the United States.

The prime value of underground storage to the LPG branch of the petroleum industry is that such storage provides a larger, stronger pressure container for the fluid at a fraction of the cost, per unit stored, of the steel pressure tank.

This advantage does not apply to the remainder of the petroleum industry because in the storage of products the application of pressure to fluids that are liquid under normal conditions of pressure and temperature does not result in any significant reductions in volume; pressure tanks, therefore, are not a prerequisite to the storage of petroleum fluids that are liquid under normal conditions of temperature and pressure.

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[1]References are listed in the Bibliography.

It is believed that there may be certain conditions in which underground storage may be used advantageously to store crude oil.

This study will attempt to explore and isolate these conditions.

## A. Definitions

In order to achieve the purpose of this study, it will be necessary to examine factors which have marked the course of certain past economic relationships and predict the future course of those factors. The factors concerned are defined below and pertain to the United States only.

The total demand for all oils[2] is the yardstick by which the basic economics of supply and demand in the petroleum industry is measured. Total demand for all oils represents the total new supply of all oils in barrels for a stipulated period, usually one month, to which is added or subtracted the difference between the total stock on hand at the end of the current period, and the total stock on hand at the end of the previous period. If the ending stock for the current period is greater than that for the previous period, the total demand is reduced by that difference between the two figures. If the ending stock for the previous period is greater than the current period, the difference is added to the total demand.

Normally, the total demand for all oils is expressed as a daily average for the month or year concerned.

The indicated domestic demand is the total demand, less exports, expressed in barrels of refined products produced for the period concerned. This factor is under continuous scrutiny by the industry in order to prevent abnormal inventory conditions.

Crude runs to stills represent the number of barrels of crude oil that are refinery processed during a stipulated period.

Refined products are those various commercial types of petroleum products derived from crude oil, and include unfinished gasoline which may be processed through a catalytic unit at a later time.

Total refinery capacity represents the maximum productivity in barrels of all operable refinery units in the United States and is normally expressed in barrels capacity per day.

Primary storage includes stocks at refineries in tank farms, in bulk terminals and in pipelines. For this study all crude oil stocks will be considered to be at refineries, in tank farms, in pipelines and in bulk terminals. Where it is necessary to refer to refined products, the stocks likewise will be considered as being in primary storage.

## B. Assumptions

The year 1948 will be used as the initial time point in this study, primarily because it is far enough removed in time from the war years to be free of the artificial influences of a wartime economy and secondarily, because in 1948 the United States first became a net importer of petroleum. This fact heralded a new era of growing significance to the petroleum industry and to the United States and brought into focus new and challenging economic pressures that persist today in increasing intensity.

The following assumptions are also made:

(a) That peaceful conditions will influence the petroleum industry for the next decade.

(b) That crude petroleum stocks will not drop below a 30 day level, based on total demand, in the interest of national security and in order to maintain efficient operation of the petroleum industry.

(c) That the spirit of free trade in the free world marks the future of the United States petroleum industry for the next decade.

## III. TOTAL OIL DEMAND TREND

The first factors to be examined involve the total oil demand and average stock level of crude oil on-hand in the United States.

The average daily total oil demand[2] for the years 1948 through 1956 on a semi-log plot (Figure 1), and projected to the years 1960 and 1965 indicate a daily total oil demand rate of approximately 11,400,000 barrels by 1960 and approximately 14,800,000 barrels by 1965. These projections compare favorably with those published by authoritative sources.[3] Their use will permit the establishment of a fundamental relationship in the determination of storage space requirements for crude oil.

This fundamental relationship involves the average amount of crude oil stocks on-hand as a function of the daily total oil demand. The ratio of the on-hand crude oil stocks to the total daily demand is the number of days' stock of crude oil in the United States (Table 1).* It is noted that the ratio of average amount of crude oil in stock to the daily total oil demand is relatively stable with a slightly decreasing trend. A minimum 30 day level of crude oil on-hand is assumed necessary for efficient operation of the oil industry. Application of the 30 day supply factor to the projected daily total oil demand for 1960 and 1965 will result in an average crude oil stock of 342,000,000 barrels in 1960 and 444,000,000 barrels in 1965.

*All tables are found in Appendix I.

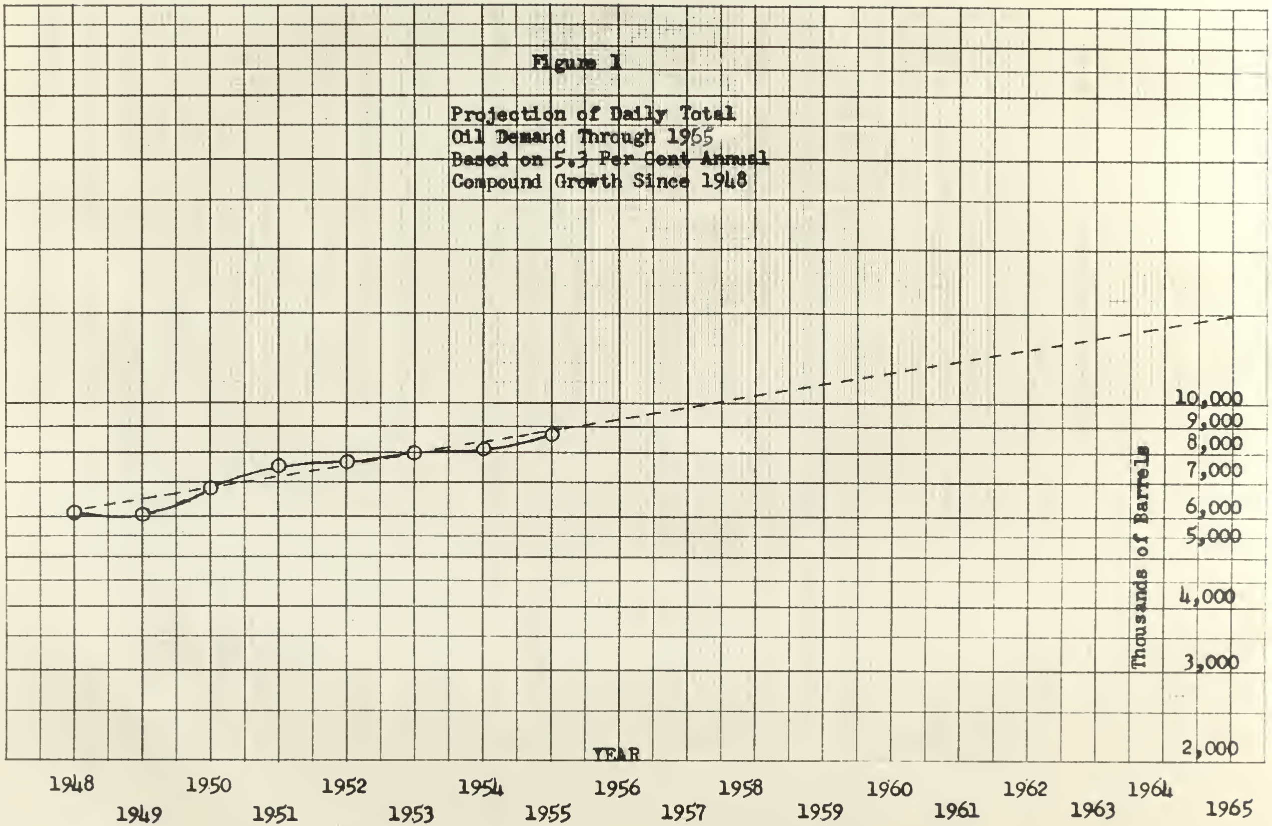


Figure 1

Projection of Daily Total
Oil Demand Through 1965
Based on 5.3 Per Cent Annual
Compound Growth Since 1948

A. Analysis of Reported On-Hand Stocks of Crude Oil

Analysis of the reporting system employed by the Bureau of Mines in compiling on-hand inventories of crude oil points out the significance of certain facts that bear on this study.

In the first place, crude oil stock inventories embrace all crude oil stocks in the hands of pipeline operators, in tank farms, in tanks and barges engaged in coastal shipping, in bulk terminals and in storage at the refineries.

Thus, of the reported amounts of crude oil on-hand and of the amounts predicted as average on-hand levels for the years 1960 and 1965, an appreciable quantity will represent the crude oil necessary to maintain normal operation of the vast transportation and manufacturing network of the oil industry and will be related only indirectly to the storage problem covered by this study.

Various estimates have been made of the amount of crude oil in the status of "pipeline fill," but no effective means has been devised for measuring and standardizing this variable and relating it to terms of normal operation. In addition, there is no means of effectively relating the crude oil in tank farms, in transit via ship etc., to factors that can be utilized.

Of the reported components that comprise the Bureau of Mines monthly crude oil stock reports[2] the refinery inventories are the most reliable for purposes of storage analysis. This is supported on the following grounds:

(1) The refinery is the focal point of a complex transportation system. Once oil has been committed to a transportation phase, accounting for that oil in an inventory system is difficult and inaccurate until the final terminal has been reached. Thus, refinery stocks reflect the receipts of crude oil from all sources.

(2) Refinery capacity may be expressed in terms of refinery storage space for crude oil on the basis of available data.

(3) Refinery storage space may be identified with the area designation applied to refineries (Table 5).

Refinery storage space thus may be used as the critical factor in the analysis and projection of crude oil storage space because:

(1) Crude oil storage space is related directly to the refinery capacity which in turn is a function of total oil demand.

(2) Refineries are located in areas of industrial concentration, which in turn implies that refinery storage facilities for crude oil will be concentrated in the same areas. Tank farms and bulk terminals are considered to be more closely associated with the petroleum transportation and will not be a part of this study.

The significance of the refinery-crude oil relationship lies in the fact that the influences which affect refinery growth and the location of refineries will directly affect the storage conditions for crude oil.

The primary influence on refinery growth is the factor of total oil demand. Other things being equal, the rate of change in refinery growth will parallel the rate of change in total oil demand.

Refinery locations are determined by the influence of basic economic factors, which involve the cheapest method of transportation of the raw material to the manufacturing center and a highly specialized distribution system of the manufactured products to consumer levels. It is axiomatic that the manufacturing activities of the petroleum industry are attracted to the large industrial areas for the same underlying reasons that other industries have gravitated to those sites.

## IV. RELATIONSHIP BETWEEN CRUDE OIL STOCKS AND REFINERY CAPACITY

Refinery crude oil stocks[2] may be expressed in terms of day's stock by the use of a ratio of the on-hand stock at refineries to the average daily refinery capacity (Table 2). It is noted that this ratio has declined steadily in the past eight years. Reduction in this ratio may be attributed to an increasing proportion of the total crude oil stock being in tank farms, pipelines, barges, etc. at any given time.

It is in the best interests of the petroleum industry to attempt to reverse this trend and increase the proportion of crude oil on-hand at refineries. A proportionate increase in the amount of crude oil on-hand at the refinery will have a strong influence on the refinery operations by providing greater stability in crude runs to stills. In addition the resulting greater amount of crude oil storage capacity will have a tendency to stabilize production by providing greater flexibility in delivery schedule and rates of crude oil to pipelines from producing area.

By means of the relationship stated above, the predicted crude oil stock level at refineries can be expressed in terms of predicted refinery capacities for the years 1960 and 1965. The basis for prediction of refinery capacities is a semi-log plot of refinery growth since 1948, through the years 1960 and 1965 (Figure 2). As a desirable refinement in pin-pointing prediction of crude oil storage requirements to geographical location, refinery capacities are analyzed individually by refinery district.[4] The projected refinery capacities and related crude oil stocks are shown in Table 3.

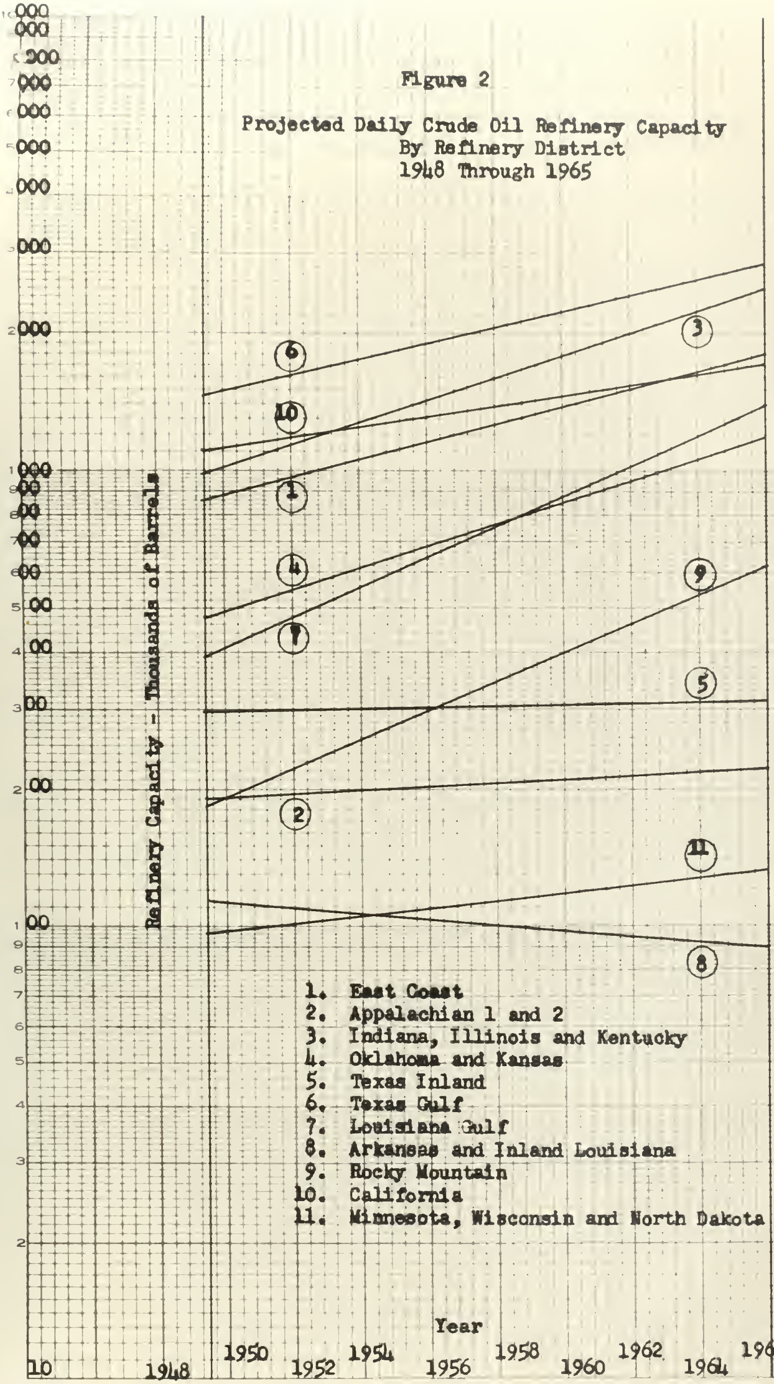


Figure 2

Projected Daily Crude Oil Refinery Capacity
By Refinery District
1948 Through 1965

To these subdivided stocks of crude oil, the application of a suitable storage tank utilization factor for crude oil will provide an estimate of the crude oil storage space required at refineries for the years 1960 and 1965.

## A. Storage Space Utilization

Analysis of reported inventories of gasoline, kerosene, distillate fuel and residual fuels, and of the reported total shell capacity for storage of these products[5] in October, 1955 indicates a 50.5% utilization of total available capacity. Personal correspondence with responsible individuals reveals that this low space utilization is a general condition for refined products in primary storage throughout the petroleum industry, but some doubt exists as to the probable utilization of tankage devoted to crude oil.

It may be argued that a higher percentage utilization for crude oil exists on the premise that the varieties in type of crude oil processed by a refinery are less in number than the types of refined products that require individual tankage and hence at any given time the total tankage allocated to a few types of crude oil will be more fully utilized than the separate tanks allocated to multiple products. On the other hand, there is no reason to assume that tighter control is exercised over the use of crude oil storage tanks than for product tanks. Accordingly, an over-all tankage utilization of 50 per cent will be used for crude oil.[23]

### B. Geographical Distribution of Refinery Capacity and Related Storage Space

On the basis of trends in increases in refinery capacity by refining district since 1948, predicted refinery capacities by 1960 and 1965 are shown in Table 4. Application of the crude oil storage factor from Table 2 and the tankage utilization factor of 50 per cent provides the estimated crude oil storage space required by 1960 and 1965 by refinery district. The geographical distributions by refinery districts are listed in Table 5.

Projections made on the basis of refinery trends between the years 1948 and 1956 have no compensation for new influences such as jet fuel requirements for the military and commercial aviation, and the prospective opening of the St. Lawrence Seaway in 1959, unless such influences have contributed a hidden and unmeasurable factor to the growth trends between 1948 - 1956.

## V. CRUDE OIL IMPORTS

Since 1948, when the nation became a net importer of petroleum, imports of crude oil have steadily increased (Table 6). Net crude imports have risen from 129 million barrels in that year to 273 million barrels in 1955. At the present rate of increase, net crude imports will rise to 428 million barrels by 1960. Whether this rate of growth will be sustained in competition with domestic production or be subject to curtailment in favor of other economic considerations is a matter of considerable speculation and controversy at the present time.[6] It is noted that 1955 imports were 10% of the total domestic production in the United States.

Despite strong opposition within the United States, the increasing growth and importance of crude oil imports is predicted. Some of the more salient facts supporting this prediction are:

(1) The heavy and increasing financial investment of American capital in foreign exploration, development and production.

(2) The increasing cost of exploration within the United States and the relative diminution of exploration incentive as compared with the lower costs and potential yield of effort on foreign soil.

(3) The increasing deficit between total demand and conservation-governed domestic crude oil production.

(4) The traditional position of the United States in the exploitation and use of available materials that can be obtained for the lowest cost consistent with national security and with the welfare of friendly nations.[7]

(5) The great amount of foreign reserves owned by American capital which will be available for production and distribution only under peacetime conditions.

Accordingly it is desired to examine further the dominant characteristics of imports to determine what bearing, if any, may be cast on the problem of crude oil storage.

A. Crude Oil Import Receipts by Refining Districts

By far the greatest portion of the crude oil imports since 1948 has been received by east coast refineries, (Table 7) although receipts by California and Chicago refineries are increasing.

East coast receipts of crude oil have been concentrated almost entirely in two localities, the Elizabeth-Woodbridge area and the Philadelphia-Marcus Hook area. Approximately 70% of the receipts of foreign crude in the east coast district are of Venezuelan origin, though the crude oil receipts from the middle east are increasing.

The St. Lawrence Seaway, scheduled to be completed in 1959, will open Chicago, Detroit, Toledo and Cleveland to ocean tanker traffic at shipping rates competitive with those to the east coast ports from the middle east. Such conditions promise to attract heavy investments in refinery installations, and will undoubtedly result in a proportionate increase in receipts of foreign crude oil in the Illinois and Indiana district.

The Texas gulf coast, though possessing the largest refinery capacity in the United States, traditionally has provided the east coast with bulk crude oil shipped via tanker. In addition, the Texas gulf coast has been the principal interstate shipper via pipeline of crude oil to Kansas, Illinois and Indiana. Excess production in Texas over refining capacity has likewise made Texas the principal exporter of crude oil to other countries.

As imports of crude to the east coast have increased, the intercoastal shipment of crude oil from the Texas gulf coast to the east coast has declined in proportion to the production growth. Transfer of crude oil to Kansas, Illinois and western Ohio, by pipeline from Texas, has increased in the last three years and in time will compete in the middle west with crude oil imports shipped via the St. Lawrence Seaway. The possibility that

the Texas gulf coast will receive increased shipments of foreign crude appears remote at this time because of the production excess over the refinery capacity.

Imports of crude oil received by the west coast have increased consistently to supplement the local production in meeting the total oil demand of a sharply increasing population. Production of crude oil in Canada promises to be a source of increasing importance to the west coast in meeting demand and comprises approximately 30% of the imports into the west coast at this time. The lack of pipeline communication to the west coast from other producing areas in the United States, coupled with a somewhat level production rate will create a strong market for imported crude oil on the west coast and receipts will undoubtedly increase.

## VI. EFFECT OF PREDICTED IMPORTS ON REFINERY CAPACITY AND CRUDE OIL STORAGE SPACE

The Elizabeth-Woodbridge, New Jersey and Philadelphia-Marcus Hook, Pennsylvania areas will absorb a large percentage of the increased imports into the east coast district, though both localities have a moderately low potential for heavy increase in refining and storage facilities. The low expansion potential in these two localities and the almost prohibitive cost of real estate for surface expansion will lead to refinery increases in the lower Delaware River and the Baltimore area. Because of the heavy industrial saturation, both of the former areas should be given prime consideration as sites for underground storage.

The St. Lawrence Seaway undoubtedly will exert a strong influence on the distribution pattern of foreign crude oil imports by opening Cleveland, Toledo, Detroit and Chicago directly to middle east production. The refinery growth rate in the Illinois-Indiana district will show the influence of foreign imports by 1960. Chicago refineries are in a heavily industrial location and are good prospects for underground storage on this basis.

Imports of foreign crude oil to the Texas and Louisiana gulf coast will not increase appreciably, although refinery capacity at Baton Rouge and Port Arthur will necessarily be increased to process domestic crude oil heretofore shipped to the east coast refineries for processing.

Though beyond the scope of this study, the influence of crude oil imports on production in the Texas gulf and Louisiana gulf coast will have a profound effect on the economic balance of the southwest and will require drastic changes in marketing technique to guarantee distribution of crude oil and its products produced under intelligent conditions of proration.

Imports of foreign crude oil to the west coast will necessarily be increased to a level that will balance the deficit between California production and west coast demand.[8] The bulk of the imports will be handled in Los Angeles and San Francisco and refinery capacity increases required to process crude imports will take place in those two areas, both of which have moderate to heavy saturation of industrial waterfront.

The over-all effect on crude oil storage space at refineries in those areas receiving imports will be to increase storage capacity requirements above the level dictated by normal storage tank utilization. In the interest of efficiency, the transfer of imported crude oil direct from tanker to refinery is desirable.

This will entail a high degree of flexibility in the crude oil storage space of refineries capable of receiving direct from tankers because of the enormous capacity and high pumping rates of the modern tanker. Current tanker capacity approaches 100,000 tons and pumping rates are as high as 10,000 barrels per hour. Receipt of such high volume within the normal dockside time of an oceangoing tanker will require an amount of ready tankage normally associated with low utilization.

The heaviest impact on refinery storage space, attributable to imports, will be in the east coast where by 1960 an estimated average of one million barrels daily will be discharged. In comparison to the estimated refinery crude oil stocks on hand in 1960, this will amount to a five per cent increase in stocks and additional required storage space of 1,670,000 barrels.

## VII. RECAPITULATION OF THE FUNDAMENTAL FACTORS

The foregoing analysis of fundamental factors in the petroleum industry has resulted in the following:

(1) Provided a basis for predicting average 30 day stock level of crude oil for the years 1960 and 1965.

(2) Provided a basis for determining probable locations of refinery expansion.

(3) Provided a basis for relating crude oil stocks at refineries to the refinery capacities.

(4) Provided the data for analysis of the effect of crude oil imports on refinery concentration and indirectly on refinery storage tank requirements.

(5) Provided a basis of evaluating the specific locations in which the general background and conditions for underground storage of crude oil appear to be the most favorable.

## VIII. LOCATIONS FOR UNDERGROUND STORAGE

Evaluation of the specific locations of refinery concentration which appear to be most promising sites for underground storage in light of the foregoing data are listed below in the order of decreasing incentive for such storage.

| | | |
|---|---|---|
| (1) | Elizabeth-Woodbridge, Bayonne, New Jersey | Quarry, mined storage |
| (2) | Philadelphia-Marcus Hook, Pennsylvania | Quarry, mined storage |
| (3) | Port Arthur, Texas | Salt Dome |
| (4) | Baton Rouge, Louisiana | Salt Dome |
| (5) | Chicago, Illinois | Mined Storage |
| (6) | Los Angeles, California | Mined Storage |
| (7) | San Francisco, California | Mined Storage |
| (8) | Toledo, Ohio | Mined Storage |
| (9) | Detroit, Michigan | Salt bed, mined storage |
| (10) | Cleveland, Ohio | Mined Storage |

## IX. DESCRIPTION OF TYPES OF UNDERGROUND STORAGE

The basic types of underground storage and their characteristics, considered to be most likely for the locations previously listed, are:

(a) Mined storage[9]

(b) Storage in dissolved salt bed

(c) Storage in dissolved salt dome

(d) Open pit quarry

<u>Mined Storage</u> is prepared from excavated caverns in rock formations specifically for storage purposes or it may be abandoned portions of rock mines or complete mines such as limestone mines. The excavation may be accessible either by means of a vertical shaft or in the case of an excavation into the side of a mountain, by means of a horizontal or sloping tunnel.

To provide a satisfactory storage the following conditions must prevail:

(a) The rock formation in which the excavation is made must have low porosity and be impervious, or if it is porous, must be capable of being sealed economically.

(b) The rock formation in which the storage exists must be competent. Further, the rock above the formation containing the excavation must be competent.

(c) The rock formation must be large in terms of thickness and horizontal cross-sectional area.

(d) The rock formation must not be fractured or faulted to the extent that it will not hold liquids or to the extent that it cannot be sealed.

(e) The rock formation must be within 500 feet of the surface.

DISSOLVED SALT BED STORAGE

Dissolved salt bed storage is prepared by pumping fresh water into salt deposits and pumping the resulting salt saturated solution to the surface.

To provide a satisfactory storage the following conditions must prevail:

(a) The salt formation must be free of continuous stringers of anhydrite or similar rock.

(b) The salt formation must have a competent integral cap rock.

(c) The salt deposit must be large in cross-section and be at least fifty feet in thickness.

(d) The salt deposit should not be more than 1000 feet below the surface.

DISSOLVED SALT DOME STORAGE

Dissolved salt dome storage is formed by pumping fresh water into shallow intrusive salt domes and pumping the resulting salt saturated solution to the surface.

To provide satisfactory storage the following conditions must prevail:

(a) The salt dome must have a competent, integral cap rock above it.

(b) The top of the salt dome should be within 1000 feet of the surface, and

(c) The salt dome must be relatively free from impurities and should have no continuous anhydrite stringers.

QUARRY STORAGE[18]

Quarry storage is prepared from abandoned or operating quarries of slate, phyllite or marble, selected with regard to necessary utilities and transportation facilities to make the site operable. The quarry storage is

similar to the salt cavity in that both are in place geographically and can be developed only after due consideration of the economics of utilities and transportation features.

To provide satisfactory storage the following conditions must prevail:

(a) It must have low secondary or "cleavage" permeability.

(b) The ground water must be at a high enough level that the tendency always will be for it to seep into the storage at levels that are closer to the surface than the anticipated level of the stored oil to prevent contamination of potable water.

(c) It must have large capacity, with great depth and relatively small cross-sectional area to minimize roof costs.

(d) It must be situated in low level ground.

(e) It must have an adequate water supply.

## X. PRINCIPAL COSTS IN CONSTRUCTION OF UNDERGROUND STORAGE

The principal costs in the construction of underground storage will vary over wide ranges, both by type of construction and within type of construction.

Construction of the mined cavern involves essentially mining technique and equipment, and hence costs are estimated on the basis of mining engineering criteria. Preparation of a salt dome or salt bed cavity, on the other hand, is more akin to petroleum engineering and costs are more readily estimated in terms of normal drilling costs.

The following passages will deal with the principal costs in the construction of the types of underground storage space considered to be most likely in meeting the requirements of the next decade.

## A. Discussion of the Principal Costs in Construction of a Mined Storage

Under normal conditions the principal costs in excavation of a mined storage are:

(1) Shaft sinking

(2) Excavation of drifts or tunnels

(3) Sealing the shaft from storage tunnels after completion of project

(4) Sealant for fractured and porous sections

The most expensive portion in the excavation of a mined storage is the shaft sinking operation.

New techniques and new equipment developments used in shaft sinking continue to reduce the costs of excavation and shoring, but the basic processes required in vertical excavation of rock are not particularly adaptable to changes involving speed.

Shaft sinking is always handicapped by the presence of ground water and, depending on its occurrence, shaft sinking costs will vary widely. Ordinarily a significant flow of ground water into a shaft pit will bring the digging process to a complete standstill until the water is excluded or drawn off by pumps. Though expensive, the most satisfactory means of combatting ground water is by low pressure grouting[10] into the water bearing formation. A thumb rule cost for grouting is approximately $30.00 per cubic yard of grout.[11]

Considerable variation in shaft costs will also be experienced depending on whether shaft facings are finished with concrete or timber. Despite the higher initial cost of concrete shaft facing, it may be more economical in the long run than timbered facing because of its permanent

strength and resistance to ground squeezing action.

Costs of the storage tunnels will vary with a number of factors including the strength of the rock, its drillibility and the size and shape of the tunnel.

Obviously, the stronger the rock the larger the tunnels will be in both width and height. As a rule, increase in tunnel height and width will result in a lower cost per cubic yard excavated, although the limit in size at which this ceases to be true has not been determined. In connection with the tunnel height, the roof of the tunnel should always be arched. The arched roof has two principal advantages over the flat roof. It is stronger and it will create less roof pockets in which storage losses of the crude oil will be experienced. The additional cost of an arched roof as compared to a flat roof varies with the width of the tunnel; the wider the tunnel the greater the cost of the arched roof. For a tunnel 40 feet wide, the cost of an arched roof is approximately 23 per cent greater[12] than for a flat roof, while for a tunnel 60 feet wide the cost of an arched roof is approximately 35 per cent greater than for a flat roof.

The nature of the rock formation in which the storage tunnel is being driven will influence the costs over a wide range. For example, excavation in shale will be more expensive than in limestone[13] because of the additional protection required for workers against spalling of the shale formation. Metamorphosed rock will be harder to drill than sedimentary rock, though there is reason to believe that in tunnels ranging 50 to 60 feet in width the unit costs will approach the excavation costs in sedimentary rock.

The ideal rock formation in which to excavate the storage cavity is an impermeable rock with negligible porosity. Unfractured crystalline rock more nearly approaches the ideal than other rock types, but it is rarely

found in unfractured state. All other rock types suitable for underground storage of liquid petroleums have some porosity, which will lead to varying percentages of "cushion" loss of the oil in storage - dependent on the porosity.

In rock that exhibits low primary porosity and is to be used as a storage for liquid petroleum, sealants are available for plugging the rock pores.[14] Such sealant will be practical in nonporous crystalline rock that has light fracturing, but caverns excavated in fractured rock to which sealant has been applied must be thoroughly tested hydrostatically before being placed into operation. Use of these sealants will increase cost at the rate of approximately ten cents per square foot of ceiling and sidewall.

Great care must be exercised in establishing a gradient of $2^{\circ}$-$3^{\circ}$ in the roof along the tunnel axis with the high side toward the tunnel end at which the oil will be introduced and withdrawn from the storage. This gradient will serve to reduce the "cushion" loss of crude oil when the storage is emptied by salt water displacement.

The same slope along the axis of the tunnel floor will provide a natural sump in the opposite end of the tunnel from the high point. The oil casing should be introduced into the cavern at the high point and at the opposite end of the tunnel; at the low point, the water casing should be introduced. No particular caution must be exercised in eliminating surface irregularities in the tunnel floor.

## B. Discussion of Principal Costs in Developing A Salt Dome Cavity

The principal costs in developing a salt dome cavity under normal conditions are: (a) drilling expense, (b) fresh water supply, (c) casing, tubing, circulatory pumps, and (d) brine storage facilities.

Drilling expense will include test drillings necessary to explore the dimensions of the salt dome or deposit, to determine the nature and occurrence of stringers in the salt, to determine the nature and characteristics of the roof rock above the salt, and finally to determine the thickness in depth of the salt dome. Core drilling with a diamond bit through the cap rock will be approximately $5.50 - $7.00 per foot up to a 700 foot depth.[15] Dry drilling with an air coolant has the advantage of cleaning the hole continuously, which permits easy detection of anhydrite particles when stringers in the salt are encountered.

Test holes drilled into the salt formation to determine whether or not a false cap rock exists, to determine the depth and thickness of the cap rock, and to determine the thickness of the salt body, may be plugged after serving their purposes without adversely affecting the operation of the storage cavity.

Drilling and setting the surface casing and drilling of the casing string are routine operations and subject to routine costs. However, setting of the casing string in the anhydrite roof rock is a very delicate operation upon which the eventual utility of the storage cavity will depend. Any weakness in the seal of the casing string to the cap rock through which oil may leak is virtually impossible to detect and equally difficult and very expensive to repair. With a thin cap rock (five feet or less) topped by an

unconsolidated formation, a practical means of providing a trustworthy setting of the casing string is difficult. If the depth to the thin cap rock is shallow, surface cementing of the surface string to lessen the load on the cap rock may be tried. Even so, with thin cap rock the possibility exists that vibration of the casing string after the cavity has been formed may lead to eventual fracture of the cap rock. This portion of the drilling operation is slow and expensive.

After the casing string is cemented into the cap rock, drilling into the salt dome is routine. In accordance with individual practices, one, two, or even three additional strings may be added before the solution process starts. The additional casing strings added and the placement of the tubing are governed by the size and shape of the cavity desired.

The speed of dissolving the salt is dependent on the rate of water circulation and the size of the casing and tubing. Ordinarily, the greater the circulation rate, the more expensive the operation because of reduced salt concentration in the water pumped out.

If the salt cavity is designed to receive crude oil directly from tankers, a high flow rate of both displacement brine and crude oil will be necessary. High flow rates will require the drilling of an additional offset hole into the cavity to handle either the brine or the crude oil. If the casing in the additional hole is designed to carry the brine, it will be lowered to the bottom of the hole, and the brine tubing in the original casing may be withdrawn or merely closed.

This type of installation is known as the U-tube installation,[16] with each of the casings forming a leg of the U and the salt cavity forming the bottom. Such an arrangement permits higher flow rates and permits temporary emulsions to settle out. Obviously, the cost of additional drilling and

casing will influence the unit cost of construction.

Circulating pump capacities used in dissolving the cavity will not necessarily be dependent on the casing sizes involved. If large casings are installed to handle the high volume of displacing brine and crude oil when the storage is placed in operation, circulating pump sizes may be kept low by using relatively small floating liners or tubing for introducing fresh water into the cavity. If, however, it is desired to enlarge the storage capacity after it has been placed in operation, large capacity pumps will be required for the displacement water.

WATER COSTS

Essential to the development of a dissolved salt cavity storage is an adequate supply of fresh water. It has been computed that 5.97 barrels of fresh water are required for every barrel of storage cavity formed, assuming 100 per cent saturation of the fresh water and assuming that Sodium Chloride is the salt involved. In practice the saturation level does not reach 100 per cent concentration, but is considerably lower. One salt cavity dissolved in Kansas[19] required 16.3 barrels of fresh water per barrel of dissolved storage. In some sections of the Texas gulf coast, procurement of an ample supply of fresh water for washing purposes may be prohibitive in cost, though on the coast proper it may be feasible to circulate sea water.

BRINE STORAGE FACILITIES

A supply of saturated brine will be essential to the operation of a dissolved salt cavity used for storage of crude oil, particularly if further enlargement of the cavity is not desired.

Open pit storage of brine, and brine storage wells are the two methods developed to date for ensuring a brine supply.

One company reported development of a lined brine pit on the surface at a cost of five cents per barrel,[17] at a capacity of 900,000 barrels. No reported costs are available for the construction of a brine storage, but depending upon the depth at which an aquifer is found, the costs of development will vary over a wide range.

In some cases it may be possible to construct a brine storage in either the same salt dome that is being adapted for storage of crude oil or in an adjacent salt dome. In order to control the size of the brine storage cavity after it has been enlarged to the size necessary to contain the maximum displacement brine from the crude oil storage, the brine circulation will have to be in a closed system.

The cost of construction together with the preliminary cost of developing this type brine storage well, where feasible, will undoubtedly be lower than the costs in developing a brine storage well in an aquifer.

SIZE AS A FUNCTION OF UNIT COST IN SALT CAVERN STORAGE

Once a salt cavern has been developed and placed in operation, if conditions of size of the dome, depth, etc. are favorable, the cavern may be continuously enlarged by displacing with fresh water in lieu of brine during regular operation.

The eventual size to which a salt cavern may be developed under such procedure is limited only by the prevailing geologic conditions. A salt cavity of two to three million barrels capacity is not beyond possibility in the Texas-Louisiana gulf where the size of salt domes will provide such a cavern under safe circumstances.

## C. Discussion of the Principal Costs of Preparing A Quarry Storage

The principal costs in preparing a quarry storage are:

(a) The ground water survey

(b) Necessary grading of quarry lip and trimming quarry contours to house the roof

(c) Fabrication and erection of the quarry roof

A ground water survey must be made to determine the characteristics of the water table, the drawdown and whatever seasonal fluctuations occur in the ground water. Because of its location at the surface, the quarry must always be in a cone of depression with the water seeping into the quarry. Otherwise contamination of potable ground water by the stored product will occur.

In order to provide an accurate determination of ground water conditions, a great number of test holes are required to house piezometers. Depending on terrain, the cost of this type hole will vary with the type equipment used. Pneumatic percussion drilling may be done for $2.00 - $3.00 per foot up to 600 feet, while diamond drilling will vary from $3.00 - $4.00 per foot at 400 feet, up to $7.50 - $9.00 per foot at 1000 feet.

After the quarry has been selected, the lip must be graded on all sides and sealed with a surfacing compound to prevent alluvium from washing down on the quarry roof. These costs are indeterminate, owing to the variables in terrain, the nature and extent of the overhang and the size of the areas to be worked.

By far the greatest cost will be for the fabrication and erection of the roof with attendent vapor seal. In the one quarry constructed to

date[18] a floating, steel pontoon type of roof, engineered to fit the contours of the cavity, was installed at a cost that comprised approximately 90 per cent of the total cost of the storage.

Vapor loss from crude oil will be less if a floating roof is installed, though fixed roofs are feasible in a narrow opening, deep type of quarry.

The known location and size of quarries makes this the easiest of underground types to explore in terms of economics. Except for the test holes drilled to house piezometers there is no elaborate program of test-holing, as with other types, necessary to determine the physical characteristics of the potential storage site.

The availability of required information on which to base decisions regarding construction makes the quarry type storage less of a speculative risk than the mined storage or dissolved salt cavity.

# XI. COMPARISON OF COSTS OF MINED AND DISSOLVED SALT DOME CAVITY WITH CONVENTIONAL STEEL TANK STORAGE

Figure 3 represents a comparison of the costs of mined and salt cavity types of underground storage with the cost of conventional steel tank storage.

The curve representing mined storage is based on a 400 foot, 9' x 13' shaft, drilled at an average cost of $2.124 per cubic foot as shown in Table 8. The cost of excavation for the storage tunnels is likewise based on an average cost of 64.3¢ per cubic foot as shown in Table 9.

The selected shaft depth of 400 feet is considered to be an average depth at which suitable rock formations will be found for practical operation of a mined petroleum storage. Below 400 to 500 feet the shaft sinking and grouting become more difficult. Formations suitable for excavation at a lesser depth than 400-500 feet are considered to be rare and should they appear at shallower depths, excavation will be hampered by rules governing protection of potable water. The curve indicating mined storage cost in Figure 3, therefore, represents the average in estimated shaft sinking costs. Less depth of shaft will reduce unit costs in the lower capacity ranges, but will have little effect in the unit cost of large capacity tunnels.

The unit cost of mined storage includes the sealant necessary for low porosity rock and minor fracturing, but does not include operating equipment.

The curve representing unit costs for dissolved salt dome storage in Figure 3[25] includes costs of drilling to 1000 feet, installation of casing string and tubing and salt storage pit. The costs do not include pumps or the separator required for operation.

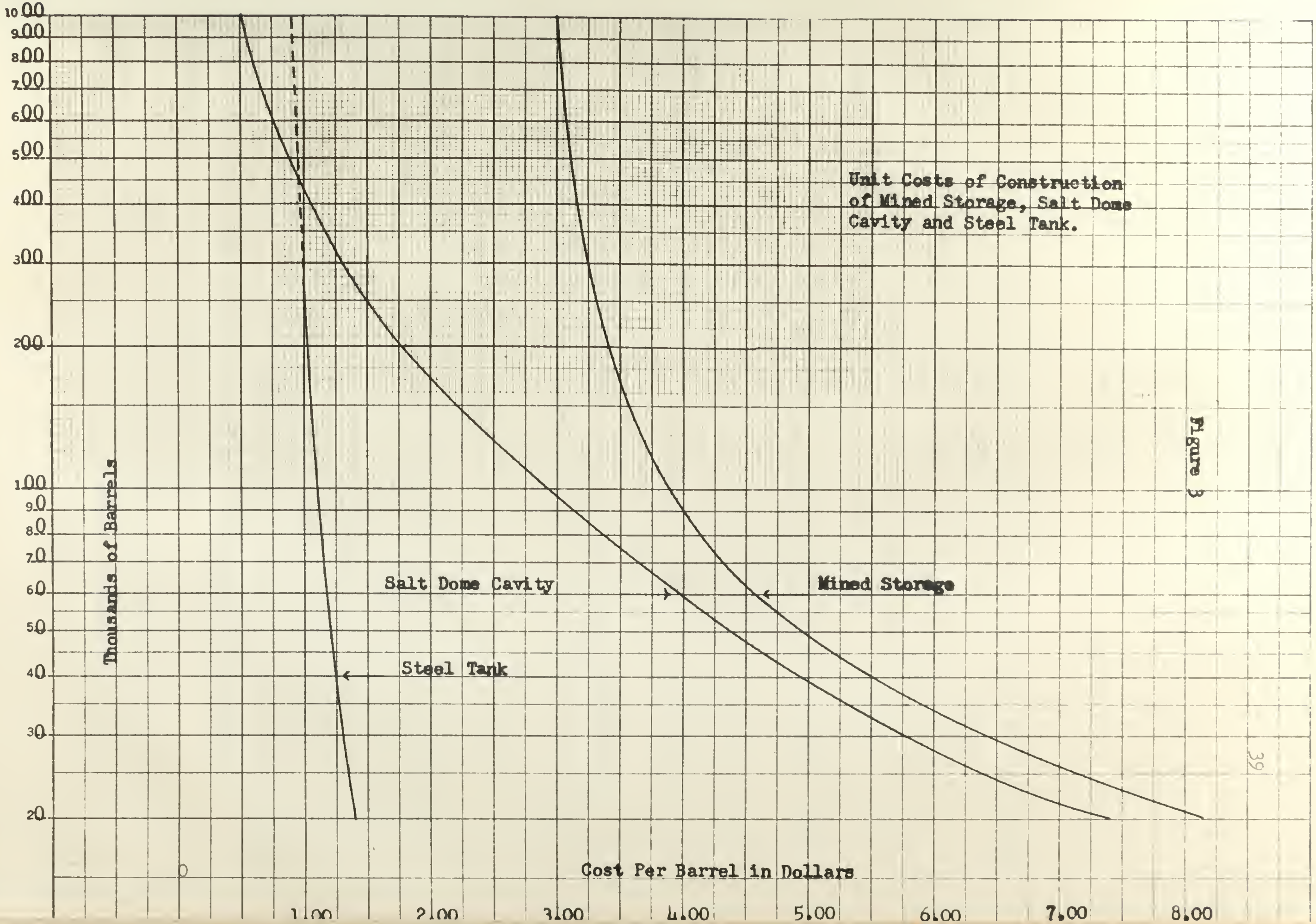
Unit Costs of Construction of Mined Storage, Salt Dome Cavity and Steel Tank.
Thousands of Barrels
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
Salt Dome Cavity
Mined Storage
Steel Tank
Cost Per Barrel in Dollars
0
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00

Figure 3

Under equivalent conditions of depth, the preparation of a dissolved salt cavity in a salt bed will be slightly lower in cost for the lower capacity ranges, but probably will be higher in cost in the larger capacity ranges.

The lower cost in the smaller capacities is postulated on the premise that the density of salt in a bed is less than that in a salt dome and, therefore, will go into solution faster. The higher cost in the larger capacities is based on the premise that the washing operation in a salt bed becomes inefficient in large cavities where the vertical distance between the brine tubing and the fresh water casing, limited by the thickness of the salt bed, is far less than such distance in a salt dome.

The unit costs for steel tank storage[24] in Figure 3 are for in-place tanks with average foundation costs added. These figures are average and will vary, dependent upon the location and the terrain.

Unit costs are not available for steel tanks above 268,000 barrel capacity, since these are the largest commercial, above ground steel tanks in use at this time.

It may be noted that the unit cost for mined storage becomes asymptotic to $3.00 per barrel. The cost figures derived from mining operations are influenced by small precise tunnel excavations and cramped working conditions. It is probable that excavation of long, high vaulted, wide tunnels in an integral formation will reduce the minimum cost per barrel by a significant amount. With no background experience in this sort of excavation, the reduction in unit cost as a function of increased size is based on a general rule applying to other related work.

In summary, the mined storage cannot compete with the steel tank on the basis of direct construction costs. However, other considerations, to

be covered later, may favor mined storage to the extent that the economics of construction are minimized.

The construction costs of dissolved salt dome storage are relatively more favorable than the mined storage, in comparison with conventional steel tank. At capacities up to approximately 400,000 barrels, the direct costs of construction of the salt cavity exceed those for steel tanks.

Comparative costs for quarry type storage are not represented for a lack of data. In the one case of quarry utilization, the construction costs amounted to 50¢ per barrel for one million barrel storage.

The variation of this unit cost cannot be predicted without specific knowledge of quarry depths, the size of the quarry opening and the local ground water conditions.

A comparison of the unit costs of construction of dissolved cavities in salt beds has not been made, though the unit costs should closely approximate the costs for cavities in salt domes. The maximum size cavity in the salt bed will be limited by the thickness of the bed and except under unusual conditions where a thick salt bed is available, a safe capacity probably will not exceed 200,000 barrels.

Other sources[26,27] indicate considerably lower construction costs for mined and salt dome storage, (as well as salt bed storage) than are indicated in this study and in general anticipate a more favorable future for underground types of storage than the cost figures in Figure 3 imply.

## XII. OTHER CONSIDERATIONS AFFECTING UNDERGROUND TYPES

CONSERVATION OF STEEL

The approximate amount of steel that will be required to construct additional storage for 70,450,000 barrels of crude oil at refineries within the next nine years (Table 4) (assuming the average tank will be the A.P.I. 55,000 barrel capacity) will be 256,000 tons. While this appears small in comparison with the annual steel production, the steel requirements for this aspect of storage in turn represent approximately 10% of the steel used by the petroleum industry for line pipe in 1955.[20] Nonetheless, conservation of steel where indicated by economics may be a form of self-discipline required within the petroleum industry to protect availability of supply for more critical needs.[21]

REAL ESTATE SAVINGS

Inflated values characterize industrial real estate in areas that are highly developed such as the locations of refinery sites. In some locations the entire area is heavily built up and congested to the extent that further expansion by property acquisition is made at almost prohibitive price. Two of the largest refinery complexes on the east coast, the Elizabeth-Drawbridge area and the Philadelphia-Marcus Hook area on the Delaware River are in highly developed industrial locations. Expansion of refinery facilities and associated storage in either of these locations will be difficult at any price.

Refinery and conventional storage sites in the areas which are predicted to bear a heavy portion of refinery expansion will be increasingly expensive because of the tendency for industry to concentrate in direct ratio with population growth.

The self-sustaining cycle of industry being attracted to locations experiencing population growth, and population being attracted to locations experiencing industrial growth, tends to insure that refinery expansion will occur in locations at which previous investment has been made. Increasing competition for limited property in industrial areas may lead to conditions that favor the adoption of mined, underground storage at costs that normally will exceed conventional steel tank storage costs.

EVAPORATION LOSSES

Evaporation losses of crude oil and high vapor pressure refined products from conventional tanks are a matter of constant concern to the industry. Some operators place their over-all vapor losses of crude oil and refined products as high as 10 per cent of the total throughput in storage tanks. Accurate means of evaluating vapor losses under general storage conditions have not been devised, but vapor losses of crude oil in conventional storage tanks with vapor saving systems are still significant. For example, a 100,000 barrel tank that experiences one-tenth of one per cent vapor loss per filling cycle will lose approximately 1500 barrels of oil per year based on fifteen filling cycles per year. The use of either mined storage or dissolved salt cavity with a brine displacing system will eliminate this type of vapor losses.

MAINTENANCE COSTS

In addition to the direct savings in maintenance and repair of underground storage are the intangible savings in time otherwise spent in the inspection of conventional steel tank facilities. Routine maintenance of steel-type tanks requires a rigid, frequent inspection of the flame arresters, vents, the fire protection system, and the cathodic protection system. Inspected less frequently, but nonetheless requiring considerable

man hours in a large installation, are the tank groundings, the tank fittings such as the filling and outlet lines, drain lines, valves, ladders, platforms, etc. and the floating roofs. As opposed to conventional tanks, underground excavations should not require sludge cleaning, because such deposits may be drawn off by "skimming" the displacement brine.

REPLACEMENT COSTS

The depreciation rates established by the Commissioner of Internal Revenue lists the life expectancy of conventional steel storage tanks as 20 years. The life expectancy of a properly prepared underground cavern, whether excavated in rock, or salt beds or salt dome, is limited only by the life of the casing string which is difficult to replace. With the proper preservation and care, the surface string may reasonably be expected to last at least 50 - 60 years. A contingency depreciation rate extended over a period of 50 - 60 years in lieu of 20 years will account for a significant change in the net income of a firm, even though modern day practice seeks faster depreciation of facilities as a tax saving device.

The best opportunity for savings in replacement costs will be realized in the Texas-Louisiana gulf coast area where "sour crude oil" is processed. The resistivity of the salt cavity, or any type of underground storage for that matter, to the corrosive components of crude oil will result in significant savings.

FIRE INSURANCE

Fire insurance rates for refineries and conventional steel tank storage in localities protected by fire fighting systems and in zones served by organized full duty fire departments vary with the locality.

In Pennsylvania, for example,[22] the prevailing rate is 65¢ per $100 property valuation, including equipment and oil.

The prospective quoted rate for underground storage is 12¢ per $100 property valuation, which amounts to a difference of 53¢ per $100 property valuation per year.

Under anticipated operating conditions it is considered that the fire risk with crude oil in underground storage is negligible and the justification for premium payment cannot be visualized. Fire insurance on the surface operating equipment such as the pumps, strainers, etc., can be absorbed in the quoted rate for the above ground portion of the refinery.

SAFETY

Concentrations of hazardous materials in populated areas are always a matter of concern in the interests of public safety, and normally zoning laws are designed to restrict the concentration of dangerous materials to a minimum.

In the case of refineries, massive concentrations of inflammable materials (crude oil) are essential to the manufacturing processes, to an extent beyond that of any other industry. In addition to the crude oil are the refined products such as gasoline, kerosene and fuel oil that augment the danger of fire and explosion in refinery areas.

It is recognized that most of the fires in refinery storage are caused by conditions that are difficult to control or correct. Undetected explosive collections of escaping vapor may be set off by static electricity induced by lightning discharges in the vicinity, or by the difference in potential between the roof of a storage tank and the shell when imperfectly bonded.

Crude oil in underground storage, in any quantity, is free from the hazard of explosion or fire. Massive concentration of crude oil in refinery storage in underground storage thus removes a significant proportion of the

danger to public safety that is inherent in a refinery operation.

STRATEGIC CONSIDERATIONS

Refinery complexes, by their association with heavy industrial concentration, are found in areas considered to be prime military targets, particularly in the east coast. The importance of the refineries in relation to other types of targets within an area is speculative, but the larger the concentration of facilities, including storage, the more important it becomes as a target within a target area.

Underground storage of crude oil in areas of heavy refinery concentration will have the effect of centralization of the facilities and will tend to reduce the value of refineries as targets, particularly if product storage is not contiguous.

In the highly congested areas of Philadelphia, Pennsylvania; Elizabeth, New Jersey; Baltimore, Maryland; Detroit, Michigan, etc., which are prime military target areas, the use of underground storage for crude oil appears to be desirable in the interest of national security.

Another strategic consideration concerns the possibility of stockpiling imports of crude oil. As the rate of crude oil imports increases, it may become necessary to stockpile a working supply of crude oil designed to offset for a short time the possible disruption of imports. Such stockpiling would entail enormous quantities of crude oil, substantially beyond the limit for which the steel industry could provide tankage. As indicated in Figure 3, the larger size salt cavity and mined storage are the most economical to construct, and are susceptible to massive construction without creating pressure on the availability of essential materials.

Salt dome cavities particularly are adaptable to use for strategic stockpiling because of the relative speed with which they can be dissolved,

coupled with the fact that the cavity may be continuously enlarged while in use.

## XIII. SUMMARY

The vast expansion facing the petroleum industry in the next decade will be reflected in the equivalent growth of storage space committed to crude oil.

Because of the basic relationship of crude oil storage to the refinery, the essential problem in the consideration of crude oil storage space is in the acquisition of sufficient space at refinery site for erection of tankage.

As refinery concentrations increase in metropolitan areas, and such concentration appears to be the trend, not only will the problem of providing storage become acute, but other complex problems will arise, stemming from over-all congestion of industry and facilities.

In relief of such congestion, at least that part of the congestion attributable to refinery operations, full consideration of the possible exploitation of underground storage for crude oil will be almost mandatory in the future.

Such course of action appears imminent in review of the potential growth and trends in crude oil storage capacity, which this study has attempted to evaluate in terms of future application of underground storage.

On the basis of this study it appears that the construction costs of mined storage are not competitive with the costs of erecting steel tanks. Likewise it appears that the construction costs of a salt dome cavity are not competitive with steel tank costs, below approximately 400,000 barrel capacity. Despite the cost disadvantage of the underground types of storage, however, other desirable features may outweigh this disadvantage. The table on the following pages lists the considerations appropriate to the various storage types.

| | STEEL TANK | SALT DOME CAVITY AND SALT BED CAVITY | MINED STORAGE |
|---|---|---|---|
| COST | Erection costs range from $1.50 to $1.00 per barrel | Construction costs for salt dome cavity range from $7.40 to 50¢ per barrel. Costs for salt bed less at small size, slightly more at large size | Construction costs range from $8.15 to $3.00 per bbl. |
| SIZE | Tanks range up to 268,000 barrels. Little change in unit cost as size increases | Cavities in salt dome may range upward of 2,000,000 barrels. Unit cost reduced as size increases, becoming asympototic at 50¢ per barrel. Salt bed cavities estimated to range to 200,000 barrels | Excavations may range up to 2,000,000 barrels. Unit cost reduced as size increases becoming asymptotic at $3.00 per barrel |
| LOCATION | May be erected at any site | Salt dome cavities applicable at this time to Texas and La. gulf coast only. Salt bed cavities in west Texas, N.Mex., western N.Y., Mich., and western Ohio | May be excavated at any point where local geology is suitable |
| VAPOR LOSS | Subject to vapor loss | None | None |
| FIRE RISK | High | None | None |
| REAL ESTATE REQUIREMENTS | Extensive - varys with size of tanks and spacing | Negligible surface space required | Negligible surface space required |
| MAINTENANCE | Varies with location and size of storage areas, includes painting, inspection of fittings, bondings, connections, etc. | None except surface fittings | None, except surface fittings |

| | STEEL TANK | SALT DOME CAVITY AND SALT BED CAVITY | MINED STORAGE |
|---|---|---|---|
| DETERIORATION | 20 year life expectancy. Deterioration accelerated by sour crude | None, except for fittings. Not affected by sour crude oil | None, except for fittings. Not affected by sour crude oil |
| CONSTRUCTION TIME | May be erected rapidly and easily | Both types three to six months until operable. May be expanded continuously while in operation | $1\frac{1}{2}$ years and up |
| INSURANCE | Rated at 65¢ per $100 valuation | Estimated at 12¢ per $100 valuation | Same as for salt dome and salt bed |

## XIV. CONCLUSIONS

1. Planning and providing adequate crude oil storage space to accommodate the sharp growth in the demand for petroleum products within the next decade will require careful attention on the part of the petroleum industry.

2. The major problem in providing storage space for crude oil will center in the locations of heavy refinery concentration in industrial areas.

3. The cost of constructing mined underground storage does not compare with the cost of conventional steel tank storage, per se, but other considerations favorable to underground storage conditions may minimize the disadvantage of construction costs.

4. The cost of constructing a dissolved cavity in salt domes compares favorably with the cost of conventional steel tank storage at capacities approaching 200,000 barrels and stands in an advantageous position at capacities above 400,000 barrels.

5. The investment required in the construction of either a mined underground storage or a dissolved salt dome storage precludes the use of such storage for other than major size corporations.

6. The use of underground storage in the form of dissolved dome cavities, where they occur in the Texas-Louisiana gulf does not modify the economic problems in the distribution of petroleum, because the market centers are concentrated in the eastern part of the United States.

7. In the interests of national security, partial subsidization of underground storage construction costs in the congested areas of the Eastern Seaboard is indicated. The most obvious subsidization with the greatest immediate attraction lies in the issuance of certificates of necessity which will entitle firms a fast tax write-off on construction costs.

# A P P E N D I X

TABLE 1

Projection of Average Daily Stocks of Crude Oil in Terms of Estimated Daily Total Oil Demand in the United States For 1960 and 1965

(Thousands of Barrels)

| Year | Total Daily Demand | Ave. Crude Oil on Hand | Number of Days Stock | Daily Refinery Capacity* | Number of Days Stock in Terms of Refinery Capacity |
|---|---|---|---|---|---|
| 1948 | 6143 | 228,958 | 37.3 | 5758 | 39.6 |
| 1949 | 6130 | 262,870 | 42.9 | 6121 | 43 |
| 1950 | 6812 | 243,566 | 35.7 | 6351 | 38.3 |
| 1951 | 7475 | 253,420 | 33.9 | 6520 | 38.8 |
| 1952 | 7717 | 269,259 | 34.9 | 6962 | 38.7 |
| 1953 | 8005 | 279,659 | 34.9 | 7261 | 38.5 |
| 1954 | 8108 | 272,260 | 33.6 | 7620 | 35.8 |
| 1955 | 8781 | 264,100 | 30.1 | 8020 | 33 |
| 1956 | 9340** | est.280,200 | 30 | | |
| 1960 | 11,400 | est.342,000 | 30 | | |
| 1965 | 14,800 | est.444,000 | 30 | | |

*Capacities listed are 95% of total capacity. 5% considered in process of modification, enlargement or shutdown for maintenance.

**Based on demand experienced through May 30, 1956.

TABLE 2

Relationship of Average Refinery Crude Oil to Total Crude Oil Stock and Crude Oil in Pipelines, Tank Farms, and Being Transported Via Tanker, Barge (Coastal) Etc.

| Year | Ave. Crude On Hand Refineries (000 Barrels) | Ave. Crude On Hand at Refineries No. of Days | Ave. % of Total Crude Stock in Storage at Refineries | Ratio - Refinery Stock to Pipeline Tank Farm Stock** |
|---|---|---|---|---|
| 1948 | 61,290 | 10.1 | 26.8% | 1:2.551 |
| 1949 | -- | -- | -- | -- |
| 1950 | 62,140 | 9.4 | 25.5% | 1:2.655 |
| 1951 | 64,040 | 9.4 | 25.3% | 1:2.488 |
| 1952 | 67,007 | 9.3 | 24.9% | 1:2.580 |
| 1953 | 68,580 | 9.3 | 24.6% | 1:2.566 |
| 1954 | 72,390 | 9.2 | 26.5% | 1:2.555 |
| 1955 | 69,012 | 8.3 | 26.1% | 1:2.596 |
| 1956* | 70,100 | 8.3 | 26.1% | 1:2.530 |

*Based on data through April, 1956.

**Does not include crude in producers lease tanks.

TABLE 3

Projected Crude Oil Stocks at Refineries by Refining District, 1960 and 1965 (Based on Factor of 8.3 Days' Stock of Crude Oil On Hand in Terms of Refinery Capacity) Refinery Capacity Projected on the Basis of Growth Trends From 1948 Through 1955.

| | 1960 | (Thousands of Barrels) | 1965 | |
|---|---|---|---|---|
| | Projected Refinery Capacity Daily | Crude Oil in Refinery Stock | Projected Refinery Capacity Daily | Crude Oil in Refinery Stock |
| East Coast | 1,440 | 12,040 | 1,805 | 15,090 |
| Appalachian 1 & 2 | 209 | 1,742 | 222 | 1,850 |
| Ind., Ill., Kentucky | 1,918 | 16,000 | 2,520 | 21,200 |
| Okla., Kansas | 940 | 7,850 | 1,180 | 9,850 |
| Texas Inland | 309 | 2,580 | 313 | 2,610 |
| Texas Gulf | 2,300 | 19,200 | 2,840 | 23,700 |
| La. Gulf | 950 | 7,930 | 1,400 | 11,680 |
| Ark., No. La. | 96 | 802 | 90 | 752 |
| Rocky Mt. (Including New Mexico) | 420 | 3,500 | 609 | 5,080 |
| California | 1,510 | 12,600 | 1,730 | 14,430 |
| Minn., N. Dak. S. Dakota | 97 | 809 | 130 | 1,083 |
| | 10,189 | 85,053 | 12,839 | 106,025 |

TABLE 4

Additional Storage Space for Crude Oil Required at Refineries By District in 1960 and 1965. (Based on Storage Factor of 8.3 Days) Crude Oil Stock in Terms of Refinery Capacity and Tankage Utilization of 50 Per Cent Through 1955.

(Thousands of Barrels)

| | Estimated Tankage Required | | Tankage Available | Additional Tankage to be Constructed By | |
|---|---|---|---|---|---|
| | 1960 | 1965 | 1956 | 1960 | 1965 |
| East Coast | 24,100 | 30,200 | 20,200 | 3,900 | 10,000 |
| Appalachian 1 & 2 | 3,492 | 3,700 | 3,380 | 112 | 320 |
| Ind., Ill., Kentucky | 32,000 | 42,100 | 25,600 | 6,300 | 16,500 |
| Okla., Kansas | 15,700 | 19,700 | 12,250 | 3,450 | 7,450 |
| Texas Inland | 5,160 | 5,225 | 5,030 | 130 | 195 |
| Texas Gulf | 38,420 | 47,500 | 34,200 | 4,220 | 13,300 |
| La. Gulf | 15,880 | 23,310 | 11,720 | 4,160 | 11,590 |
| Ark., No. La. | 1,602 | 1,500 | 1,710 | -108 | -210 |
| Rocky Mt. | 7,000 | 10,200 | 5,400 | 1,600 | 4,800 |
| California | 25,200 | 28,900 | 22,800 | 2,400 | 6,100 |
| Wis., N. Dak., S. Dak., Minn. | 1,618 | 2,025 | 1,620 | -- | 405 |
| | 160,172 | 214,360 | 143,910 | 26,272 | 70,450 |

TABLE 5

Bureau of Mines Petroleum Refining Districts and PAW Districts

Refining
District

EAST COAST - District of Columbia and the States of Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New Jersey, Delaware, Maryland, Virginia, North Carolina, South Carolina, Georgia, Florida, and the following counties of the States of New York: Cayuga, Tompkins, Chemung and all counties east and north thereof. Also the following counties in the State of Pennsylvania: Bradford, Sullivan, Columbia, Montour, Northumberland, Dauphin, York, and all counties east thereof.

APPALACHIAN #1 - The State of West Virginia, those parts of the States of Pennsylvania and New York not included in the East Coast District.

APPALACHIAN #2 - The following counties of the State of Ohio: Erie, Huron, Crawford, Marion, Delaware, Franklin, Pickaway, Ross, Pike, Scioto, and all counties east thereof.

INDIANA - ILLINOIS - KENTUCKY - The States of Indiana, Illinois, Kentucky, Tennessee, Michigan, and that part of the State of Ohio not included in the Appalachian District.

MINNESOTA - WISCONSIN - NORTH AND SOUTH DAKOTA - The States of Minnesota, Wisconsin, North Dakota, and South Dakota.

OKLAHOMA - KANSAS - MISSOURI - The States of Oklahoma, Kansas, Missouri, Nebraska, and Iowa.

TEXAS INLAND - The State of Texas except the Texas Gulf Coast District.

TEXAS GULF COAST - The following counties of the State of Texas: Newton, Orange, Jefferson, Jasper, Tyler, Hardin, Liberty, Chambers, Polk, San Jacinto, Montgomery, Harris, Galveston, Waller, Fort Bend, Brazoria, Wharton, Matagorda, Jackson, Victoria, Calhoun, Refugio, Aransas, San Particio, Nueces, Kleberg, Kenedy, Willacy, and Cameron.

LOUISIANA GULF COAST - The following Parishes of the State of Louisiana: Vernon Rapides, Avoyelles, Pointe Coupee, W. Feliciana, E. Feliciana, Tangipahoa, Washington, and all Parishes south thereof. Also the following counties of the State of Mississippi: Pearl River, Stone, George, Hancock, Harrison, and Jackson. Also the following Counties of the State of Alabama: Mobile and Baldwin.

NORTH LOUISIANA - ARKANSAS - The State of Arkansas and those parts of the States of Louisiana, Mississippi and Alabama not included in the Louisiana Gulf Coast District.

NEW MEXICO - The State of New Mexico.

TABLE 5 (Continued)

ROCKY MOUNTAIN - The States of Montana, Idaho, Wyoming, Utah, and Colorado.

CALIFORNIA - Etc. - To include the States of Washington, Oregon, California, Nevada, and Arizona.

TABLE 6

Growth of Annual Crude Oil Imports With Associated Data

Since 1948 When U. S. Became a Net Importer of Petroleum Products

| | Total Imports | Exports | Net Imports | Total Production | Net Imports To Total Prod. |
|---|---|---|---|---|---|
| | Crude (Thousands of Barrels) | | | | |
| 1948 | 129,093 | 39,736 | 89,357 | 2,018,960 | 4.3% |
| 1949 | 153,686 | 33,069 | 120,617 | 1,837,620 | 6.66% |
| 1950 | 177,714 | 34,823 | 142,891 | 1,970,000 | 7.25% |
| 1951 | 179,073 | 28,604 | 150,469 | 2,452,676 | 6.14% |
| 1952 | 209,591 | 27,729 | 182,862 | 2,513,733 | 7.26% |
| 1953 | 236,445 | 19,931 | 216,514 | 2,596,166 | 8.35% |
| 1954 | 239,479 | 13,564 | 225,915 | 2,567,628 | 8.8% |
| 1955 | 285,421 | 11,471 | 273,950 | 2,725,675 | 10.02% |
| 1956 EST. | 294,000 | 9,760 | 284,240 | | |

TABLE 7

Annual Crude Oil Imports into U. S. By Refining

Districts on the Basis of Available Data

(Thousands of Barrels)

| | 1948 | 1949 | 1950 | 1951 |
|---|---|---|---|---|
| East Coast | 123,625 | 136,483 | 168,843 | 171,894 |
| Ind.,Ill.,Ky. | --** | --** | --** | 426 |
| Texas Gulf | 3,328* | 5,828* | 1,703* | 857* |
| La. Gulf | -- | -- | -- | -- |
| California | 1,468 | 6,560 | 7,168 | 5,914 |

| | 1952 | 1953 | 1954 | 1955 |
|---|---|---|---|---|
| East Coast | 192,349 | 206,611 | 213,413 | 232,850 |
| Ind.,Ill., Ky. | 1,116 | --** | 2,772 | 7,425 |
| Texas Gulf | 4,423* | 711 | 4,553* | 11,098* |
| La. Gulf | -- | 722 | -- | -- |
| California | 11,703 | 28,411 | 18,741 | 34,048 |

*Total Receipts - Texas and Louisiana Gulf Coast

**Not Available

## TABLE 8

### Labor and Material Costs in Shaft Sinking in Dollars

| Shaft Size Feet | Rock Formation | Labor and Supervision | Cost of Shaft per Foot: Explosives | Cost of Shaft per Foot: Support | Power, Supplies | Total Sinking Cost | Cost per Cubic Ft. |
|---|---|---|---|---|---|---|---|
| 6.6 x 20 | Schist Met. Granite | 260.10 | 8.90 | 18.00 | * | 286.90 | 2.14 |
| 8 x 21 | Granite | 289.20 | 7.05 | 25.30 | 18.30 | 339.85 | 2.02 |
| 6.5 x 16 | Greenstone (Grouted) | 89.16 | 14.15 | 17.80 | 132.60** | 253.71 | 2.43 |
| 6.2 x 17 | Basalt (Grouted) | 167.35 | 10.25 | 24.65 | 105.20 | 307.45 | 2.91 |
| 9 x 16 | Limestone | 147.50 | 15.10 | 14.30 | 13.30 | 291.20 | 2.02 |
| 8 x 17.33 | Graywacke | 155.30 | 10.15 | 32.80 | | 198.25 | 1.44 |
| 19' DIA. | Sandstone & Shale - Heavy Grouting*** | 349.00 | -- | 57.40 | 108.00 | 516.40 | 1.91 |
| | | | | | | | AVE. 2.124 |

* Not Available
** Includes Supervision
*** Concrete shaft support
All other timber

Conversion Factors: US Dept. Labor Abstracts

| Labor | | Materials | |
|---|---|---|---|
| 1921-1955 | 4.06 | 1921-1955 | 1.46 |
| 1929-1955 | 3.78 | 1929-1955 | 1.66 |
| 1930-1955 | 3.78 | 1930-1955 | 1.75 |
| 1931-1955 | 3.78 | 1931-1955 | 1.87 |
| 1932-1955 | 4.25 | 1932-1955 | 2.23 |

TABLE 9

Labor and Material Costs in Excavation of Storage Tunnels in Dollars

| Size Tunnel Feet | Rock Formation | Labor and Supervision | Costs per Foot: Drilling Costs | Explosives | Misc. Supplies, Power | Total** per Foot | Cost per Cubic Foot |
|---|---|---|---|---|---|---|---|
| 15 x 10 | Gneiss Met. Granite | 37.40 | 3.40 | 3.99 | 2.37 | 55.56 | .371 |
| 7 x 7 | Limestone and Chert | 27.90 | 2.36 | 4.12 | 4.35 | 44.93 | .916 |
| 7 x 8 | Limestone | 18.50 | 1.93 | 2.46 | 3.16 | 30.12 | .538 |
| 7 x 7 | Dolemite Limestone | 15.40 | 1.93 | 3.85 | 1.48 | 26.08 | .533 |
| 7 x 8 | Quartzite | 18.95 | 2.00 | 4.28 | 1.408 | 30.83 | .55 |
| 8 x 8 | Grandiorite Greenstone | 37.50 | 2.35 | 5.55 | 1.85 | 55.55 | .87 |
| 7 x 8.5 | Schist | 27.50 | 3.40 | 4.75 | 1.55 | 43.40 | .721 |

**Arched Roof
Approx. 10,000 bbls. capacity

Reduction in Cost as Function of Size
10 - 50,000 bbls. 10% less .578
50 - up 20% less .515

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Thesis 28863
M278 Malcolm
A study of the prospective use of underground storage of crude oil in the next decade.