The Use of Salt Domes for the Strategic Petroleum Reserve

Michael E. Carosella
Management Division, Strategic Petroleum Reserve, U.S. Department of Energy, Washington, D.C. 20461

ABSTRACT

In response to the interruption of petroleum supplies during the winter of 1973–1974 and the threat of future disruptions, the United States Government has embarked upon an ambitious program to stockpile an emergency supply of oil. The Strategic Petroleum Reserve is being planned to contain 250 million barrels of crude oil by December 1978, 500 million by December 1980, and 1 billion barrels by the end of 1983. In selecting sites, the Department of Energy examined numerous methods and locations. Major criteria for selection of the initial storage sites are the following: technical feasibility, proximity to existing petroleum distribution system, environmental impacts, security, and costs. Five salt dome sites: four with solution caverns and one conventional salt mine were selected for the first 250 MMB of storage. A cavern testing and verification program was established for solution caverns and the mine. The West Hackberry caverns were acceptable and within 45 days of acquisition, the caverns were tested, a brine disposal well was drilled, an oil pipeline was laid and oil was placed in storage. Four caverns at Bryan Mound were converted, one is a dumbbell shaped cavern, holding 25 MMB. The first wells tested at Bayou Choctaw failed to pass and repair work was required. The caverns at sulphur mines will be converted to store 23 MMB. At Weeks Island mining continued during conversion and a temporary mine was established at an upper level to continue production. A permanent mine is planned adjacent to the oil storage. All sites will be connected to a major oil terminal by a 36-inch or larger pipeline. It is expected that the vast majority of the entire program will be stored in underground salt formations.

BACKGROUND

The interruption of petroleum supplies during the winter of 1973–74 demonstrated to the United States the need for an emergency storage program. The resulting petroleum shortage caused severe economic impacts on the United States economy and emphasized its vulnerability to interruptions in imports from major oil exporting nations. The supply denial and simultaneous price increase of the 1973–74 embargo resulted in a loss of $35 to $45 billion in gross national product (GNP) and an estimated 500,000 jobs.

A future petroleum cutoff could be more severe because of the increased dependence on foreign oil supplies and because many users have already restricted their use of energy. Many relatively easy steps to conserve energy have been taken and future improvements in energy efficiency will become more difficult.

LEGISLATION

As a result of this interruption, the United States Congress passed the Energy Policy and Conservation Act in December of 1975, which required that a Strategic Petroleum Reserve be established. At that time Congress set a goal of 150 million barrels of stored oil by the end of 1978, and what amounted to a goal of 500 million barrels by the end of 1983. The size of the reserve was expanded to one billion barrels based on the requirements of President Carter's National Energy Plan.

PURPOSE

The ultimate purpose of the Strategic Petroleum Reserve as envisioned by the Congress was to reduce the vulnerability of the United States to a severe petroleum supply interruption. This had to be done in the context of our continued reliance on imported oil, which increases even in the face of U.S. efforts to reduce consumption through other means. The reserve provides additional foreign policy flexibility, in that in the event of an embargo the reserve will provide additional negotiating time as well as ultimately reduce our military vulnerability, although this is a civilian reserve.

IMPLEMENTATION

Certain fundamental requirements were apparent at the outset. These requirements were translated into the criteria, which were used for storage technique selection and site selection. A paramount requirement was the need to implement the reserve by locating the storage facilities where they would be most accessible to tankers and major pipelines to allow rapid withdrawal of the oil from the reserve during an interruption and allow it to enter the normal crude oil distribution system of the country. The vast portion of all crude oil entering the United States enters through the Gulf of Mexico and is transferred inland via three major pipelines, the Seaway, the Texoma and the Capline pipelines. Thus, the most desirable locations appeared to be along the Gulf Coast, because it already receives a majority of crude oil imports and provides the necessary access to the primary crude oil distribution system of the country. Storage in this area can feed the three major market areas dependent upon oil imports that are likely to be interrupted, the interior of the country, the Gulf Coast refinery complexes, the East Coast and the Caribbean refineries.

Each one of the identified storage alternatives was evaluated in accordance with the following criteria:

Technical feasibility and suitability for storage. Potential storage sites must be structurally sound, i.e., the containment of the oil must be assured from available data.

Storage capacity availability. Storage facilities must have adequate existing capacity to meet the short term requirements (the 250 million barrel goal), and total potential capacity must contribute to the remaining program requirements. The current use of a candidate facility was considered in the context of how it might impact on the timely availability of the facility. Any space already committed to operational hydrocarbon product storage was ruled out due to the expanding industry needs for petroleum product storage, unless the current user indicated and agreed the space could be made available.

Proximity to existing petroleum distribution system. Distribution of stored petroleum is cost sensitive to distance from major crude oil pipelines or ports. Maximum use of the existing distribution systems in the United States is essential for the effective distribution of the reserve. Accordingly, all potential facilities were screened on the basis of the amount of new pipelines required to connect to major distribution terminals and the capabilities at seaports (docks) to handle the necessary oil distribution with minimum construction of new docks and piers. Included in this criterion is the requirement that the storage should be situated on the "upstream" side of refining centers. The limitation of the transportation infrastructure establishes the upper limit of useful storage capacity at a given storage site (or in the combination of storage sites served by the transportation system). It is desirable for a 500 MMB SPR to be able to deliver oil at 3.3 MMB/D, and the 1 billion barrel SPR to deliver 6–8 MMB/D. The 500 MMB system is designed to drawdown in 150 days.

Costs. Facility types were evaluated on the basis of their relative costs of acquisition, development and operation.

Environmental impacts. Each type of candidate storage structure and site was evaluated in terms of the potential environmental impact that would result if used for the storage program, and our ability to obtain necessary permits for the activity.

Economic impacts. Development of a particular facility should have no long-term negative economic impact including loss of employment.

Security and safety. Alternative facility types were evaluated for their security from fire, natural disaster, sabotage, and other factors which might affect their security and safety.

Numerous methods of storage were examined. The public was solicited to suggest locations and methods of storage. During the early stages of investigation, consideration was given to the more than 20,000 operating and abandoned mines and nearly 700 salt domes on shore and in the Gulf of Mexico, as well as the numerous salt beds throughout the United States, as well as other alternative storage techniques.

The first alternative examined was solution mined caverns in salt. That is, caverns that had been created in underground domes of salt through the injection of water and the removal of brine. Throughout the Gulf Coast area of the United States there exist, both onshore and offshore, approximately 700 salt domes. Solution mining has been taking place for a number of years in the Gulf Coast by petrochemical firms, in order to satisfy their brine requirements for feedstock for their plants. The caverns created as a result of brining are generally large, irregular and, in some instances, approach the 30 million barrel mark.

The second alternative storage technique evaluated was conventionally mined caverns. These are conventional room and pillar mines which can be created specifically for storage in some media such as hardrock, limestone or salt, or they can result from product mining of limestone and salt.

Evaluations were made of the use of conventional surface tanks, the use of laid up oil tankers, the use of lagoons and rubber bags, the use of depleted oil wells and also the alternative of simply shutting-in a fully-developed producing oil field.

As a result of our analysis, shut-in oil was dropped from consideration. Although technically feasible, the cost of fully developing a one billion barrel oil field would be significantly higher than any of the other reviewed alternatives. Additionally, if the field were developed to its maximum efficient recovery rate, it would take years rather than days to drawdown, assuming a one billion barrel reserve. Thus, from an effectiveness and cost standpoint a shut-in reserve was unacceptable. Similarly, re-injecting oil into depleted oil wells was rejected on the basis of high relative cost. The recovery rate and quantity of re-injected oil would be uncertain and at best be very low.

Although lagoons and rubber bags may be appropriate for smaller quantities of oil, the quantities considered for the SPR make this particular alternative unrealistic from both a cost and environmental point-of-view, as well as technically uncertain, given the size and magnitude of the requirements.

The use of idle oil tankers was rejected on the basis of potential high environmental impacts and the political unacceptability of the nesting of large numbers of inoperable, unmanned vessels close to shore.

The environmental impact of constructing large surface tanks as well as the cost of those tanks compared to the other alternatives, make tank farms unattractive.

Based on studies, it was determined that the most economical and environmentally acceptable means of storing oil is in existing caverns or newly created caverns contained in the underground formations, such as salt or limestone. Thus, the Strategic Petroleum Reserve can be described as a potential one billion barrel reserve of crude oil contained in underground storage in salt and rock caverns, located in the Gulf Coast, with a drawdown capability of

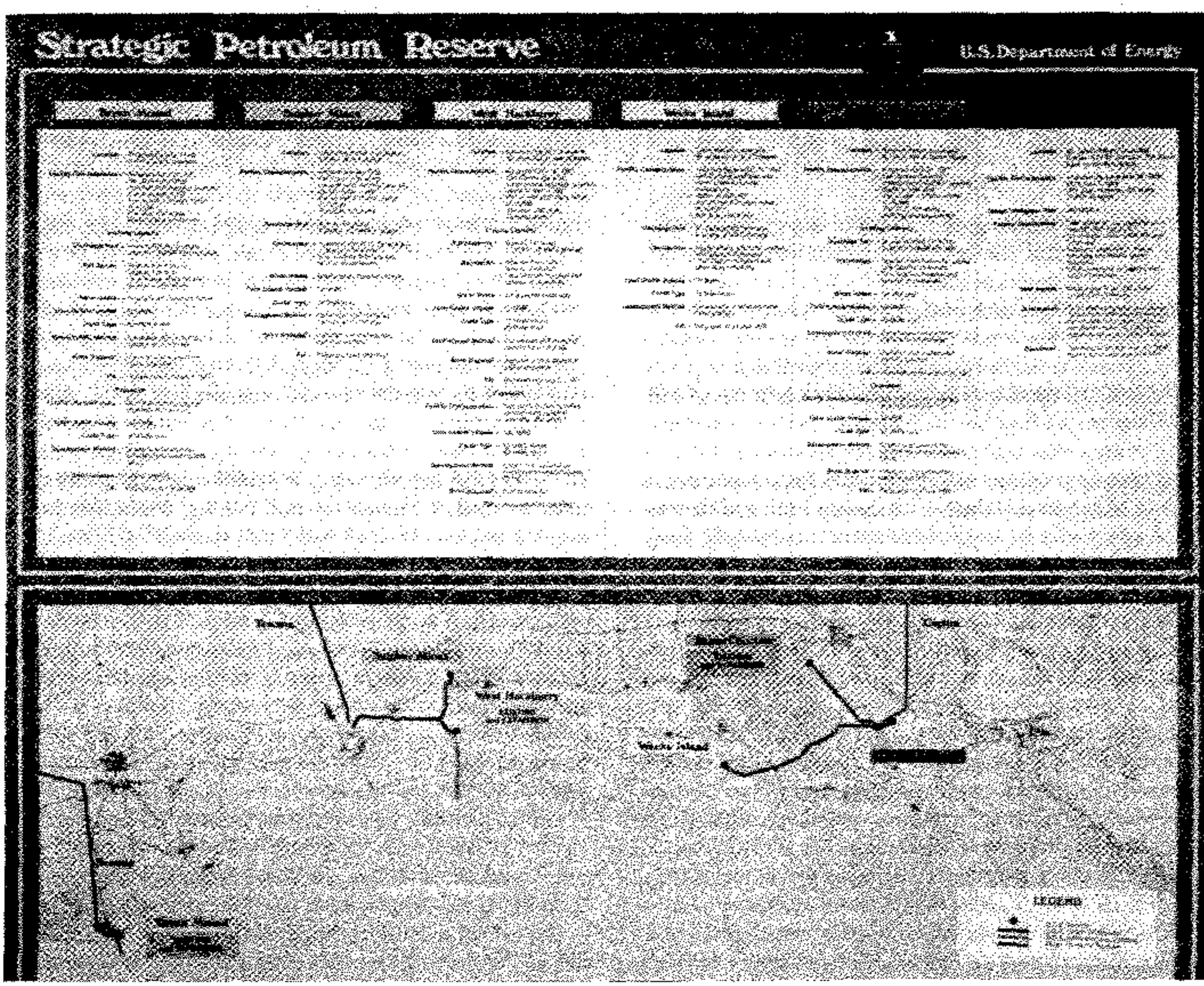

Figure 1. Strategic Petroleum Reserve.

approximately 3–6 million barrels per day at a development cost of $21 billion.

SELECTED STORAGE SITES

Because of the large number of salt domes in the Gulf Coast area and their proximity to major distribution systems, major petrochemical firms over the past years had created caverns in these salt domes by solutioning with water in order to create brine as feedstock. Because of the short time available for the creation of the early part of the reserve, that is the first 250 million barrels, those salt domes with existing caverns were selected.

Five sites have been selected to date. Bryan Mound, which is in Texas, West Hackberry, Sulphur Mines, Bayou Choctaw and Weeks Island, which are located in Louisiana. These sites are grouped by proximity to major crude oil distribution centers. Thus, at Freeport, the Texas Seaway pipeline would be served by Bryan Mound; at Nederland, the Texas Texoma pipeline would be served by West Hackberry and Sulphur Mines, and at St. James, the Louisiana Capline pipeline would be served by Bayou Choctaw and Weeks Island. The combined total existing capacity of these sites is about 250 MMB.

DESCRIPTION

Each one of these sites has specific generic components. Each site contains caverns either created through solution mining or conventional mining.

Prior to storage, each of the caverns, whether a conventional mine or a solution mine, must be certified as to its integrity, that is its ability to contain the oil that is placed therein. With regard to solution mines, each of the caverns including the casings are individually tested to determine whether they can withstand the pressures associated with movement of brine and crude oil to and from the cavern as well as to determine whether the cavern itself and the casings that connect the wellhead to the cavern have the integrity necessary to assure that any adjacent caverns are not interconnected or that the caverns themselves are not connected to the overlying rock structure. Consequently, a cavern testing and verification program was necessary to establish the suitability of these caverns for the storage of crude oil.

Generally, the testing program consisted of a sonar log survey of each cavern, a cavern and casing pressure test and wellhead tests. Sonar logs were necessary to determine the cavern size and shape, to locate any chimneys and to locate re-entry wells that are necessary to achieve the flow rates in and out of the cavern required by the program. These logs may also be used to guide us in controlled leaching to modify the cavern roof shape and to identify actual or potential cavern coalescing, which could affect the type of crude oil to be put in adjacent caverns and possibly the method of operation. The cavern pressure testing was a crucial element of this certification program. The reserve has a system requirement to deliver oil at a rate equal to the total withdrawal in 150 days, therefore, these caverns would have to function at much higher pressures than they are currently being operated. All caverns were tested by injecting saturated brine.

For conventional mines a geotechnical evaluation and test of the mine was completed. The purpose of the evaluation is to determine the structural stability of the mine with and without oil, to verify its containment of oil and gas and to provide information for any reinforcement work that may be required and the identification of areas needing excavation work to ensure oil flow. The study includes complete examinations of all literature, mining data, and well records in the surrounding area, a complete mapping of the mine and testing program. The testing program consists of boring holes into the pillars and abutments to determine permeability. Laboratory testing of the cores was conducted for strength, permeability, sound velocity, reactivity of oil and salt and chemical composition.

At each oil storage site extensive control buildings must be constructed to house the instrumentation necessary to control the flow of oil, water and brine. Surge tankage of oil must be constructed, as well as brine surge ponds. Extensive pumping and electrical power systems must be installed. Offsite infrastructure is also required. The brine which results from fill of the caverns with oil must be disposed. This is not an insurmountable problem when brine is displaced from an existing cavern, since the volume of displacement is one for one. This problem becomes more acute and is, in fact, one of the biggest problems when new solution caverns are created for the program.

If we assume that the first 250 million barrels of storage is satisfied through the use of existing storage in the Gulf Coast and that the remaining 750 million barrels of storage must be created through solution mining, this results in a requirement to dispose of over 5 billion barrels of brine. On each of the sites selected, other than the conventional mine sites, brine is being disposed of from the existing caverns as a result of displacement by injection into wells which have been drilled and completed to approximately 5,000 to 7,000 feet into saline acquifers. Each of the wells constructed to date has the ability to take approximately 10,000 to 20,000 barrels of brine per day. However, in order to accommodate future leaching of new storage, disposal of brine into the Gulf of Mexico is being studied. Brine disposal is probably the most sensitive environmental area in the program to date. The Department of Energy has spent over two years and $5 million in order to study and minimize the effects of such Gulf brine disposal and select suitable sites.

It goes without saying that any brine operation obviously requires water to solution mine. Accordingly, water intake locations are also a critical area in the program. The farther inland our site selection proceeds the more difficult freshwater availability becomes. Also, in some areas, freshwater intakes may cause local ecological damage if not placed or constructed properly. Furthermore, at each site barge docks are necessary in order to accommodate fill while permanent pipeline systems are constructed.

Certainly, the most important elements of each site are the oil distribution facilities. DOE attempted throughout the program to minimize cost by using, to the greatest extent possible, existing crude oil distribution systems. These include not only distribution system pipelines but also dock facilities. DOE has succeeded so far. At Bryan Mound, existing dock facilities for the Seaway pipeline are being used. At West Hackberry and Sulphur Mines, existing facilities of the Sun Terminal which feeds the Texoma pipeline are being used. Only at the Capline area in St. James, Louisiana, is a terminal, which includes a tank farm and docking facility, being constructed.

INITIAL STORAGE SITES

Bryan Mound. Bryan Mound, in Brazoria, Texas, has five existing caverns that were created by Dow Chemical to obtain brine for its petrochemical plant. Four of these caverns have a total useful storage volume of 60 MMB. The Bryan Mound salt dome is roughly circular in plan form, about 6,000 feet diameter, and is almost completely overlain by rock at a depth of approximately 680 feet. The caprock has a maximum thickness of 480 feet. Over 5 million tons of sulfur have been extracted from the caprock during the years 1912 to 1935. Several hundred test and producing wells were drilled into the caprock for this purpose. These wells do not affect the integrity of the solution caverns to be used for crude oil storage since they stop short or just contact with the salt. There is no subsidence apparent in the storage area and there is no evidence to indicate that any will occur in the future. Cavern #1 is approximately 6.5 million barrels in capacity. Cavern #2 is approximately 5.8 million barrels in capacity. Cavern #4 is of approximately 16.1 million barrels in capacity. Cavern #5 is approximately 31.9 million barrels.

Cavern #5 presented a unique problem. This cavern had been developed initially at a deep level to a size of about 20 MMB and then developed at an upper level to about 10 MMB size. Anhydride and insolubles blocked the areas between the upper and lower portions of the cavern. When DOE became serious about utilizing this site for storage, the salt plug was penetrated and communication reestablished between the upper and lower caverns.

Caverns #4 and #5 sidewalls are 300 feet apart at their nearest approach, and Caverns #1 and #4 sidewalls are 435 feet apart. The possibility that any of the caverns will coalesce with adjoining ones after application of the design criteria of five cycles of crude oil displaced with freshwater is generally considered remote. In the event future sonar surveys indicate coalescence is imminent, the caverns involved would be used to store the same type of crude.

The 36 inch brine disposal pipeline into the Gulf of Mexico is not scheduled for completion until mid-1979.

Consequently, until the permanent brine disposal pipeline is completed and operational, a chemical company will consume the brine and a portion will be disposed of by deep well injection. The oil handling system was designed to receive and discharge oil both to the Seaway Docks and to the Seaway Tank Farms. The oil pipelines were ready for operation in October of 1977.

West Hackberry. West Hackberry is a very large, roughly sausage-shaped salt dome and is about 1½ miles long and ½ mile wide at the 2000′ level. The depth to the caprock is 1300′, the depth to the salt is 1800′. The site is located in Cameron Parish, Louisiana, about 20 miles south of the town of Lake Charles. Portions of the salt dome are under a lake. The five caverns that had been developed by Olin Chemical for brine for their chemical plants were acquired for storage. They total approximately 51 MMB useable storage volume.

Cavern #6 is approximately 12.1 million barrels. Cavern #7 is approximately 12.0 million barrels. Cavern #8 is approximately 9.9 million barrels. Cavern #9 is approximately 8.5 million barrels, and Cavern #11 is approximately 8.1 million barrels. Sufficient distances exist between Caverns #9 and #6 and #8 and #9 to preclude coalescence based on the planned five cyclings. To the extent that lateral growth through cycling of #8 and #9 do cause coalescence, no problem in stability is anticipated based on analysis. In addition, both caverns would contain identical crude oil so any mixing would not cause contamination.

At West Hackberry, brine is disposed of by injection into saline acquifers, located about one mile to the south of the dome. Oil will be delivered via a newly constructed pipeline from Nederland, Texas. This pipeline is scheduled for completion in September 1978, some months after the scheduled completion of the first brine wells. Therefore, for interim fill a temporary pipeline was constructed from the site to an existing barge dock. West Hackberry was the first site to become operational. On July 23, 1977, the first barge load of oil was injected into Caverns #6 and #11.

Sulphur Mines. Sulphur Mines is located in Calcasieu Parish, Louisiana. This site is approximately 20 miles north of the West Hackberry site. The dome is roughly circular in shape and about 2000 feet in diameter at the 2000′ contour. The depth in the caprock is 315 feet and the depth of the salt is 1460 feet. Five caverns will be used to store oil at Sulphur Mines, three of which have coalesced. Caverns #2, #4 and #5, which have coalesced are approximately 12.3 million barrels total. Cavern #6 is approximately 5.1 million barrels and Cavern #7 is approximately 5.6 million barrels.

Caverns of interest are #6 and #7, which are separated by only 100 feet. It has been estimated that these caverns will coalesce after 3 to 4 cycles of oil fill and withdrawal, however, this coalescence will not affect cavern stability. The wall of Cavern #6, which is 433 feet from the salt dome boundary and that of Cavern #7, which is 235 feet from the dome boundary, will approach but will not reach the dome boundary at the completion of 5 cycles. To the extent that cavern growth exceeds or does not conform to theoretical calculations, the caverns could be cycled with brine. Brine from the Sulphur Mines caverns will be disposed of during oil fill through deep well injection. This site is being developed as a satellite to West Hackberry and will tie-in to the West Hackberry 42-inch pipeline by a 16-mile spur line.

Bayou Choctaw. Bayou Choctaw is located in Iberville Parish, Louisiana, approximately 20 miles southwest of Baton Rouge, and about 35 miles northeast of St. James terminal on the Mississippi River. The dome is roughly oval shaped, 3600 feet by 4600 feet at the 2000 foot contour. The depth of the caprock is 237 feet and the depth of the salt is 629 feet.

Allied Chemical has developed a total of 19 caverns, six of which are being used for hydrocarbon storage. DOE has acquired ten of the caverns. These ten caverns have a total volume of about 70 million barrels. Current useable capacity is 36 million barrels. Bayou Choctaw was the second site to become operational, about one week after West Hackberry. Oil is being barged into docks at Bull Bay, approximately one mile distance from the site and injected into Cavern #1. Bayou Choctaw is connected by a 36-mile pipeline to the St. James terminal, being constructed by the DOE on the Mississippi River.

Weeks Island. Weeks Island is located on Vermillion Bay in Iberia Parish, Louisiana. The Weeks Island salt dome is roughly circular in shape and approximately two miles in diameter at the 400 foot contour. Salt occurs at the depth of about 90 feet. Morton Salt has operated a mine there since 1903. Salt was mined underground by the room and pillar method at a depth of approximately 700 feet. An upper level mine at elevation 536 feet has been abandoned. The mine produced 1 to 1½ million tons of rock salt per year. Useable storage capacity is 75 million barrels.

The mine has generally level floors and excellent structural stability despite normal amounts of spalling. No roof falls have occurred. The salt is 99% pure sodium chloride. Rock bolting is used on the lower level, the main thoroughfare areas, to reduce maintenance requirements. Continuous wall and pillar spalling does occur which requires mechanical removing every few months in the active portions of the mine. The 10-foot service shaft will be used for the pump shaft. Oil filling will be through lines in the shaft. Oil will be withdrawn by submersible pumps located at the base of the service shaft. These pumps can be removed for maintenance and repair. Due to the constrained shaft size and high withdrawal rate an underground manifold chambers are planned.

Other facilities to be installed in the shaft include vent lines, sensing systems and a service elevator. All openings will be sealed by concrete plugs designed to withstand the operating pressures of two atmospheres and explosion over-pressure of ten atmospheres. To prevent undue vapor pressure buildup during filling, or normal operations, ventilation must be provided. Current plans call for a vapor recovery system and a flare stack as well as inerting prior to fill. Floor excavation will be required to ensure that there is oil flow from all areas of the mine to the sumps. In many cases this floor excavation will consist of a three foot wide channel. Several small shafts will be bored to establish communications between upper and lower mines. The location of these bore holes will be chosen at the low spots in the upper mine area. The 36-inch, 67 mile long pipeline from St. James to Weeks Island is scheduled for completion by mid-1979. Fill of Weeks Island is scheduled to commence in late 1979. All conversion activities must be completed and the system tested by that time.

St. James Terminal. A 2 million barrel tank farm and 2 docks are being constructed on the Mississippi River in order to service both Bayou Choctaw and Weeks Island, and any other site selected in the area.

SPR sites. The five sites selected to date are for the first 250 million barrels. The potential expansion capacity of two of these sites, Bryan Mound and West Hackberry, is sufficient to meet the program requirement of the first 500 MMB. Additional sites for the remainder of the program are being examined. The current plan provides for storage of 750 MMB of petroleum by the DOE in underground storage facilities. Decisions have not been made regarding the type of storage facilities for the fourth 250 MMB, or the extent of Government and industry involvement in such storage. The feasibility and environmental impacts of developing new sites has been examined by DOE for three groups of sites associated with each of the major crude oil pipelines. In the Seaway pipeline group the potential expansion of Bryan Mound as well as new facilities in the alternative at Allen Dome, Damon Mound, West Columbia and Nash salt domes were examined. In the Texoma pipeline group the possible expansion of West Hackberry and new development at Vinton, Black Bayou, and Big Hill salt domes in the alternative were examined. In the Capline group the expansion by solution mining of Weeks Island, some expansion at Bayou Choctaw, and the development of Napoleonville, Chacahoula and Iberia salt domes in the alternative were also examined. The Cote Blanche mine, which is located along the pipeline route from Weeks Island to St. James, is also a candidate for the expanded program as well as a limestone mine in Ironton, Ohio. Because of the vast potential for development in any one of these three areas, serious consideration has to be given to the limitations of the oil distribution infrastructure and the need for flexibility in distributing the oil during an oil interruption. Additionally, industry is being solicited to propose the sale, lease or rental of completed "storage package" on a "turnkey" basis to the DOE.

Selection, design and construction of the additional sites for the Strategic Petroleum Reserve will continue through 1979 and 1980.

Status. 65 million barrels were in storage as of December 1978, in sites that have been selected, which can ultimately contain 250 million barrels in existing caverns. Although, the program is not on the schedule originally contemplated, the capability exists to inject at a rate of 10 million barrels a month for the first 250 MMB. The future activities for the next 500 MMB have been charted.