THE MAJOR SOURCES OF CO_2 AND THEIR DEVELOPMENT - 1985 UPDATE

Eugene F. Herbeck and Joe R. Hastings

Atlantic Richfield Company

ABSTRACT

Over the past few years, the oil industry has taken a very active interest in the use of CO_2 for enhanced oil recovery. Many CO_2 injection projects have been started. Other fields are being studied for CO_2 flooding with future projects being planned.

On the other side of the picture, making all this possible, has been the finding and developing of large sources of CO_2. Most of the CO_2 has been found in naturally occurring underground reservoirs which are capable of producing the quantities needed for oil field application. Although the CO_2 sources are often hundreds of miles from the prospective oil fields, major pipelines have already been constructed and others are being planned to transport the CO_2 to places where it will be applied.

This paper presents an overview of these major sources of CO_2 and the current status of their development.

INTRODUCTION

CO_2 injection for miscible displacement of oil is being initiated in an increasing number of reservoirs. This is possible only because of the development of large sources of CO_2, most of which are natural underground reservoirs. Three of these major CO_2 sources, Sheep Mountain, McElmo Dome and Bravo Dome are already on production with the delivery of CO_2 taking place. Other sources such as the LaBarge Area and N. E. Jackson Dome are actively being developed, and some such as Slawter-Brown Sunrise Field on the Escalante anticline are still in the planning or initial development stages. This paper reviews the current status of these natural CO_2 sources. Also discussed are two industrial CO_2 sources which were considered to be of general interest.

This paper does not discuss the Delaware-Val Verde Basin CO_2, which is removed as a contaminant from hydrocarbon gas produced from deep high pressure reservoirs. This CO_2 is delivered to long established projects such as SACROC, North Cross Unit, and Two Freds Field. These programs have been in operation over 10 years, and the status of the CO_2 sources has changed little in recent years. Also, the authors recognize that there are other recently utilized CO_2 sources not discussed here. These are generally industrial sources supplying limited quantities of CO_2. Although these sources are of interest, it was not within the intent of this paper to discuss every known source of CO_2.

In preparing this paper the authors relied on information that is generally available to the public. In many cases it came from articles and papers previously published, and in some instances the operating companies furnished the authors with brochures and news releases regarding their operations.

SHEEP MOUNTAIN

Delivery of CO_2 from Sheep Mountain Field, located in Huerfano County in southeastern Colorado, to Seminole Field in West Texas began in early 1983. Figure 1 shows the route taken by the CO_2 pipeline. The field and pipeline are operated by Atlantic Richfield.

CO_2 production at Sheep Mountain comes from the Dakota and Entrada sandstone formations. These zones and the producing operations were described in a paper by Huff and Tracey.[1] The Dakota measures from 125 to 250 ft. in thickness and has permeability varying from 20 to 4000 md. The Entrada lies 100 to 200 ft. below the Dakota. It ranges from 60 to 90 ft. in thickness and from 10 to 250 md. in permeability.

Because the field is in mountainous terrain, surface elevations vary from 7500 to 11,500 ft. The producing zones are situated at a depth of about 4500 ft. above sea level. The reservoir temperature averages 126°F and the initial pressure was 1465 psia. The 1984 NPC Report[2] states that reserves for Sheep Mountain are estimated to be 1 Tcf. This value would be for initial reserves prior to production.

The gas from Sheep Mountain is 97% pure CO_2 with impurities being nitrogen, methane and other hydrocarbons. Typical producing rates over the latter part of 1983 and first half of 1984 were around 80 MMcf/D. This is being increased and is expected to be about 200 MMcf/D in early 1985.

As of January 1985, 22 wells had been drilled at Sheep Mountain. All wells are being drilled from five drillsite locations with each location able to accommodate six or more directionally drilled wells. Figure 2 is a map of Sheep Mountain which shows the drillsites and current wells. A few of the wells were drilled before the drillsite idea was conceived. Therefore, these wells have their own drilling location but are connected to the nearest drillsite producing facility. A sixth drillsite will possibly be developed in the adjoining Dike Mountain Unit. The facilites for processing the CO_2 are located at each drillsite. The producing CO_2 streams are heated after leaving the wells to prevent hydrate formation and to vaporize any liquid CO_2 that may have formed. The CO_2 is next dehydrated and then compressed to 1500 psi for delivery to the pipeline.

The Sheep Mountain CO_2 pipeline design and operation are discussed in detail by Swink[3]. The north 183 miles of the 408-mile pipeline is 20-in. in diameter which makes it capable of delivering 330 MMcf/D of CO_2. At a point south of Bueyeros, New Mexico, as shown on Figure 1, the line diameter is expanded to 24-in., increasing the capacity of the south part of the pipeline to 500 MMcf/D. This is to accommodate Amerada Hess which uses this part of the line to transport CO_2 from Bravo Dome to the Seminole oil field. The 20-in. section of the pipeline is owned jointly by Atlantic Richfield and Exxon; Amerada Hess joins Atlantic Richfield and Exxon in the ownership of the south portion of the line.

The design and operation of the pipeline had to take into account a substantial variation in elevation along the pipeline route. It starts at about 8800 ft. above sea level at Sheep Mountain, drops to 6300 ft. in southern Colorado and then climbs to 8500 ft. on the Johnson Mesa where it enters New Mexico. From there it descends to about 3300 ft. at the Seminole terminal. These elevation differences cause operating pressures to vary from a high of

2780 psi to a low of 1200 psi at different places along the route. The line pressure at the delivery point is 2000 psi, which is higher than at the origin. The CO_2 moves through the line by gravity flow. At one point along the line it was necessary to install a pressure control station to reduce the downstream pressure to ensure the safety of the pipeline. At all points, however, the pressure is maintained above 1200 psi to make sure that the CO_2 stays in a super critical state and to prevent two-phase flow.

McELMO DOME FIELD - CORTEZ PIPELINE[4,5,6]

Another major pipeline recently built for the transportation of CO_2 is the Cortez Pipeline. This line originates in Montezuma County in southwestern Colorado near the town of Cortez where it picks up CO_2 from McElmo Dome Field for delivery to the Denver City area of West Texas. Figure 3 is a map showing the pipeline route. The pipeline is owned as a partnership with Shell, the operator, having a 50% interest, Mobil 37% and Continental Resources 13%.

McElmo Dome and the nearby Doe Canyon Field have initial CO_2 reserves estimated to be in excess of 10 Tcf. McElmo Dome, which is being developed first, is the larger of these two fields covering over 200,000 acres and having reserves of 8.4 Tcf. The reservoir gas is 97% pure CO_2 with the remainder being nitrogen and hydrocarbons. These reserves are in the Mississippian Leadville formation which occurs at depths ranging from 6600 to 9150 ft. The formation is composed of limestone and dolomite and varies in thickness from 250 to 300 ft.

The Colorado Oil and Gas Commission approved a field wide unitization plan for McElmo Dome in October 1982 with Shell Oil company being the designated unit operator. This unit is expected to result in reduced costs, increased ultimate recovery and minimized land disturbance.

Development plans for the field provided for wells to be drilled in clusters with a maximum of four wells in each cluster. Presently, there are about 28 wells at 11 cluster locations. These wells were expected to be able to deliver 350 MMcf/D initially. As additional capacity is needed, more wells and facilities will be added up to an anticipated 180 wells at 45 cluster sites. McElmo Dome, when fully developed, is expected to have a producing capacity of 1 Bcf/D of CO_2.

A paper presented by Weeter and Halstead[7] discusses the production of CO_2 from McElmo Dome wells by the use of downhole submersible multistage centrifugal pumps. The CO_2 in the reservoir is a super critical fluid which would separate into liquid and gas phases under natural flowing conditions in the wellbore. The submersible pumps maintain the pressure of the flowing stream in the wells above the critical value so that the CO_2 stays as a single phase fluid. This prevents many operational problems that would otherwise develop and also increases the production from the wells.

Construction of the 500-mile, 30-in. Cortez Pipeline started in the summer of 1982 and was about 53% completed that season. In 1983 construction resumed and the line was completed with the first production of CO_2 taking place in December 1983. Full scale production did not take place until 1984. Operating pressures along the line range from 1400 to 2000 psi as the elevation changes along the route.

The line is designed to carry up to 650 MMcf/D of CO_2, but by installing three pump stations along the route, its capacity can be increased to 1 Bcf/D. This increase in deliverability is not expected, however, before the late 1980's. The Denver Unit in Wasson Field will require about 330 MMcf/D of the CO_2 initially, and the remainder is available for injection in other West Texas or New Mexico oil fields.

BRAVO DOME[8,9]

Another large natural reserve of CO_2 that is under development and being produced is at Bravo Dome in northeastern New Mexico. Amoco is the principal developer of this field and is operator of the 1,036,034-acre Bravo Dome CO_2 Unit which covers portions of Union, Harding and Quay Counties. Figure 4 shows the location of the unit and the general route of the Bravo Pipeline which delivers this CO_2 to the Permian Basin in West Texas.

The CO_2 production comes from the Tubb formation, which is a Permian age sandstone found at a depth of about 2318 ft. The formation is about 103 ft. thick and has an average porosity of about 20%, permeability of 20 md. and temperature of 90°F. The deposit is 98% to 99% pure CO_2 and is in a gaseous state in the reservoir. The 1984 NPC Report[2] mentions estimated reserves for Bravo Dome Unit as being more than 6 Tcf.

About 288 producing wells had been drilled in the Unit as of July 1984. Development of the field and facilities has taken place to date in two phases. Phase I includes 50 wells and associated dehydration and compression facilities capable of processing 86 MMcf/D of CO_2. The compressors boost the CO_2 in three stages from about 100 psi gathering line pressure to the pipeline pressure of 2100 to 2400 psi. The plant facilities are tied to the Sheep Mountain Pipeline by the 16-mile, 14-in. Rosebud line. This phase supplies CO_2 for use by Amerada Hess in Seminole Field and began production in April 1984.

The Phase II project has 177 wells with its own dehydration and compression facilities and is capable of producing an additional 250 MMcf/D of CO_2. Most of this CO_2 from Phase II is transported to the Permian Basin of West Texas by the Bravo Pipeline.

Construction of the Bravo Pipeline started in July 1984 and was completed late in the same year. It is a 210-mile, 20-in. line capable of delivering 380 MMcf/D. The south terminal of the pipeline is approximately three miles north of Denver City in the Wasson Field area. The line is owned by Bravo Pipeline Company, Sun Gas Transmission Company, Inc. and Markland Pipeline Company.

Amoco Pipeline Company operates it under a contract with Bravo Pipeline. Initial delivery of CO_2 started in December 1984 and has been to Wasson and Slaughter Fields.

N. E. JACKSON DOME

The N. E. Jackson Dome in central Mississippi is another major natural source of CO_2 where some development has already taken place and further steps are being taken. Shell Oil Company is considered to be the most active developer of these reserves, as they have about 48,000 acres under lease in Rankin, Scott, and Madison Counties. Sufficient drilling has been done on this acreage to prove an estimated 1 Tcf of CO_2 reserves. Their undrilled acreage was thought to have a potential of an additional 2 Tcf of reserves.[10]

The CO_2 production comes from the Buchner, Smackover and Norphlet formations which are found at depths of 14,000 to 16,000 ft. There are a number of geologic structures in the N. E. Jackson Dome Area from which the CO_2 is produced. The largest of these is the South Pisgah structure.

Shell has 13 wells in the area capable of producing CO_2. Their plans are to transport it southward through the 91-mile, 20-in. Choctaw Pipeline, which is owned as a subsidiary by Shell Western E&P, Inc.

The laying of this line was essentially completed by the end of 1984. It passes southward through West Mallalieu Field and terminates near the town of McComb, Mississippi as shown on Figure 5.

The line will be capable of delivering up to 450 MMcf/D of CO_2, though initial rates are expected to be only about 100 MMcf/D. Plans are to have CO_2 enter the line at about 2100 psi which will provide a delivery pressure of 1200 psi. Full delivery of CO_2 is not expected to start until late 1985 or early 1986.

Initially, injection is to take place in Little Creek, Olive and West Mallalieu Fields. McComb and Brookhaven are future candidates for the CO_2 process. Also under consideration is the extension of this line to Weeks Island Field in south Louisiana.[11]

Another pipeline already taking CO_2 from the N. E. Jackson Dome Area, but on a smaller scale, is the 43-mile, 8-in. line which goes to the Perry Woodruff Waterflood Unit in Tinsley Field. This pipeline is owned by the Unit, and both the Unit and pipeline are operated by Pennzoil Producing Company.

CO_2 delivery to Tinsley Field started in November 1981 and has averaged around 13 or 14 MMcf/D. There are two supply wells from which the CO_2 is taken. The gas stream is 99% pure CO_2. It flows direct from the supply wells, through a dehydrator and into the pipeline, entering the line at about 2600 psi. Because of lower elevation at Tinsley Field, the pressure at that end of the line increases to about 2700 psi enabling the CO_2 to flow directly from the pipeline into the injection wells.

LA BARGE AREA

The LaBarge Area in Lincoln and Sublette Counties in southwestern Wyoming has large natural deposits of CO_2. Exxon is in the process of developing that part of these reserves which underlie three units which it operates.

The LaBarge Area CO_2 reserves are being found, for the most part, to the east of the overthrust belt along the Moxa Arch. The full areal extent of these deposits has yet to be delineated; however, sufficient wells have been drilled to show that the productive area is extensive and that this is probably the largest known CO_2 deposit in the United States.

The Mississippian Madison formation appears to be the most common CO_2 bearing horizon in the LaBarge Area, although the Big Horn of Ordovician Age also is productive. These zones are usually found at depths of 14,000 to 16,000 ft.

Composition of the reservoir gas varies, but a typical Madison gas may be 70% CO_2, 20% CH_4, 2.5% H_2S, 0.5% helium, and the remainder nitrogen. Big Horn gas may typically be 90% CO_2.

Exxon is the first company to undertake the development of the LaBarge reserves, which is being done on the Lake Ridge, Fogarty Creek, and Graphite Units. These units adjoin each other and together cover about 64 square miles. Their development program was discussed in two recent articles.[12,13] Exxon expects to start operations with 20 to 22 wells drilled to the Mississippian. This zone is 600 to 800 feet thick, and individual wells are expected to produce at rates of about 30 MMcf/D.

The gas stream will be dehydrated in the field and then transmitted by a 40-mile, 28-in. pipeline to a gas treatment plant Exxon is building at Schute Creek. There the gas stream will be separated into its constituents. The overall composition of this total gas stream is expected to be 66% CO_2, 22% methane, 4.5% hydrogen sulfide, 0.5% helium, and 7% nitrogen. The resulting methane gas stream is to be taken by Northwest Pipeline Corporation. The CO_2 will go southeast toward Rock Springs, Wyoming in a 49-mile, 24-in. pipeline.

At Rock Springs, the Chevron operated Rangley Unit will connect to the CO_2 pipeline with its own 127 miles of 16-in. line. Figure 6 shows the route of Exxon's CO_2 line to Rock Springs and the line which will carry CO_2 on to Rangley Unit. Gas sales to Rangley are expected to start by July 1, 1986, with the contract volume being 200 MMcf/D.

Exxon's LaBarge development is expected to furnish CO_2 to Amoco's Lost Soldier and Wertz Fields near Bairoil, Wyoming if Amoco decides to put these fields under EOR. Figure 6 also shows a possible CO_2 line to this vicinity.

Exxon is looking for CO_2 markets in the Wind River, Big Horn, Powder River, and Williston Basins. If these are found, the pipeline could be extended from Bairoil.

Phase I development, as it is being designated, will have capacity to handle about 550 MMcf/D of raw gas, and to deliver a daily rate of 300 MMcf of CO_2. Exxon's LaBarge CO_2 reserves may exceed 5 Tcf.

UTAH BASINS

At least four areas in the state of Utah have produced CO_2 on tests. One of these, the Escalante Anticline, is getting considerable attention, but little is being said about the other sources at this time. The four areas which are mentioned in the report by Mike Hare, et al.[14], are the following.

Paradox Basin in southeast Utah in San Juan County has produced CO_2 from the Mississippian Leadville, which is the same horizon which produces in McElmo Dome in Colorado. This information is based on six wells drilled in the 1950's to depths of 6900 to 8100 ft.

Escalante Anticline is in south central Utah in Garfield County on the north edge of the Kaiparowitz Basin. Knowledge of CO_2 in this area goes back to 1961 when Phillips Petroleum produced CO_2 from an exploratory well. Mid-Continent Oil Company has drilled three recent wells on this structure and have designated this area as the Slawter-Brown Sunrise Field.

Gordon Creek in central Utah in Carbon County tested a high purity CO_2 from Sinbad and Coconino horizons at depths of about 12,000 ft.

Farnham Dome, also in Carbon County but about 25 miles east of Gordon Creek, tested CO_2 from the same formations plus the Navajo and Kaibab but at shallower depths of only 3000 to 5000 ft.

ENID-VELMA/PURDY[15]

The Enid-Velma/Purdy system is an example of using CO_2 from an industrial source for EOR. Atlantic Richfield and Cities Service built the 140-mile pipeline to take CO_2 from Farmland Industries fertilizer plant near Enid, Oklahoma, and deliver it to the Cities operated Northeast Purdy Springer "A" Sand Unit in Golden Trend Field and to the Atlantic Richfield operated East Velma West Block Sims Sand Unit in Sho-Vel-Tum Field. This line is capable of transporting 33 MMcf/D and started CO_2 delivery in September 1982.

The gas stream taken from the fertilizer plant is about 80% water vapor and 20% CO_2. The water is removed, and the CO_2 is compressed to about 2000 psi for delivery into the system. For the first 120 miles the pipeline transports the CO_2 through 8-in. pipe. At that point the stream splits, half going to Northeast Purdy and the other half continuing southward for approximately 20 miles to East Velma. Figure 7 shows the pipeline route from near Enid to the Northeast Purdy and East Velma projects. To the end of 1984, this system had transported nearly 11 Bcf of CO_2 and was then delivering about 15 MMcf/D to each of the two fields. Atlantic Richfield is the operator of the pipeline and the dehydration and compression facility which processes the CO_2 for delivery.

GREAT PLAINS COAL GASIFICATION PLANT

The Great Plains Coal Gasification Plant located about 11 miles west of the town of Hazen in Mercer County in west central North Dakota is expected to be an industrial source of CO_2. This plant was completed in late 1983 and is in the final stages of start-up at this time. This plant will use lignite from nearby mines for gasificaton and will produce about 125 MMcf/D of high BTU gas and approximately 200 MMcf/D acid gas which is 97% pure CO_2. Steps are being taken to further purify the CO_2 and making it available for use.

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Figure 1 - Sheep Mountain Pipeline delivers CO_2 from Colorado to West Texas

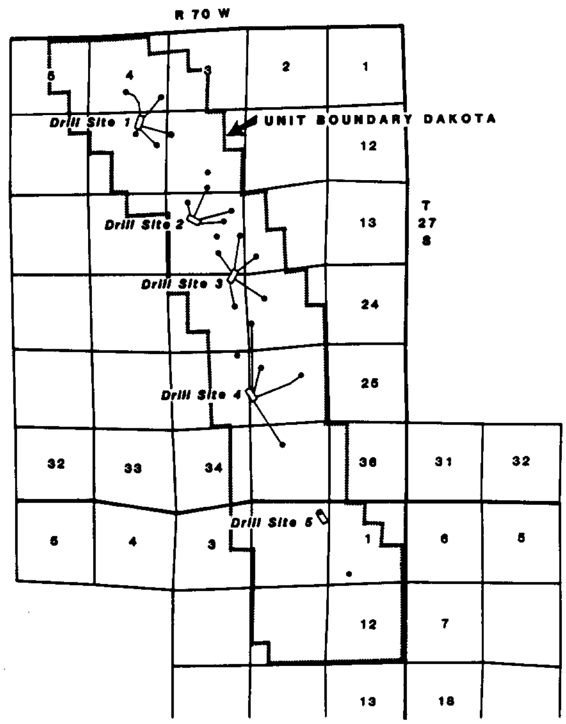

Figure 2 - Sheep Mountain drill site and well locations

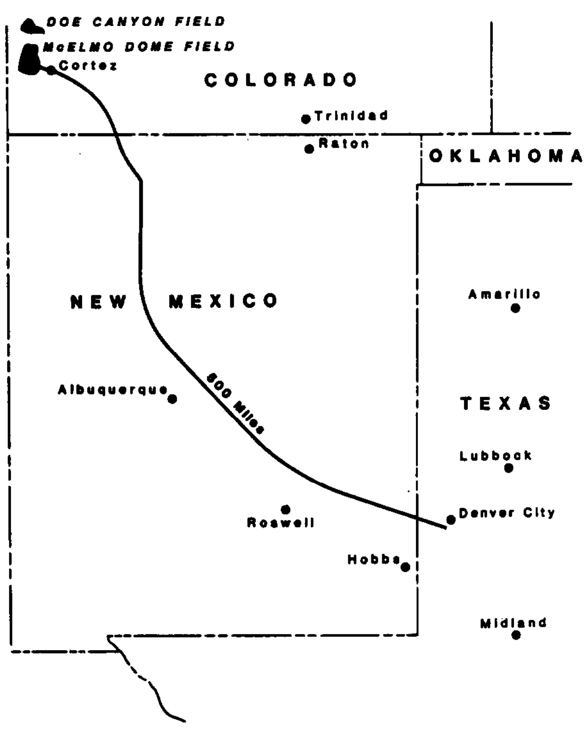

Figure 3 - Cortez Pipeline delivers CO_2 from McElmo Dome to West Texas

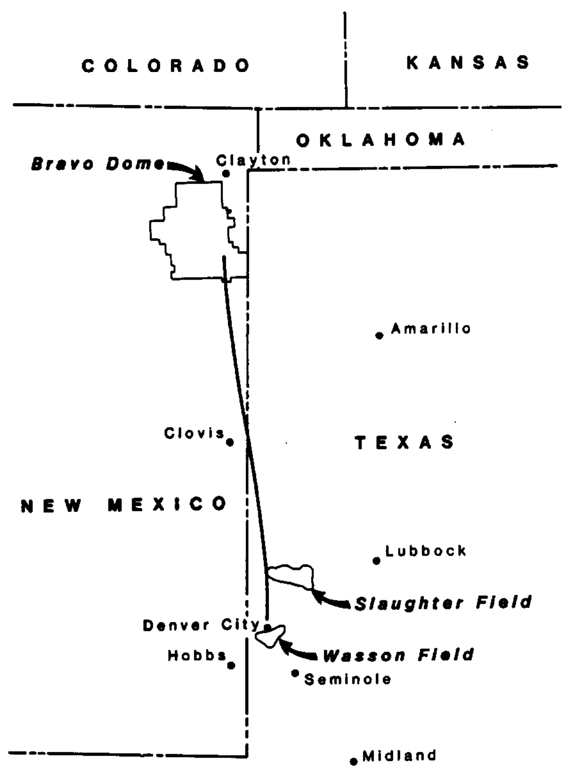

Figure 4 - Route of the Bravo Pipeline which takes CO_2 from Bravo Dome Unit to the Permian Basin

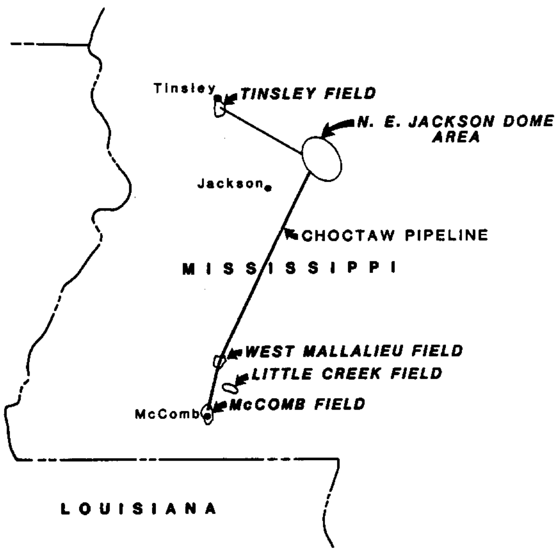

Figure 5 - CO_2 from the N.E. Jackson Dome area has been going to Tinsley since 1981 and will soon be delivered to other fields by the Choctaw Pipeline

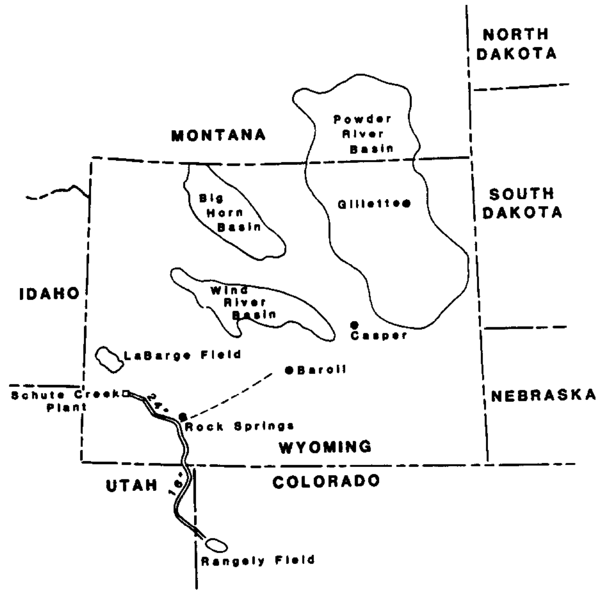

Figure 6 - Proposed pipelines to take CO_2 from LaBarge Field

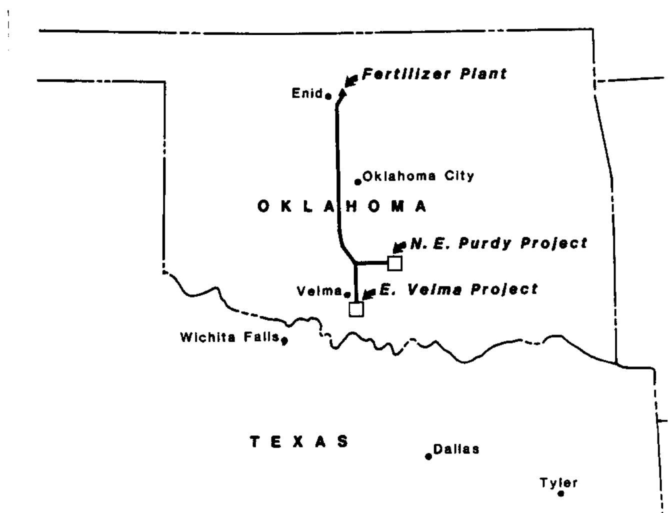

Figure 7 - CO_2 from plant near Enid is delivered to N.E. Purdy and E. Velma projects