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Electricity Use of Enhanced Oil Recovery with Carbon Dioxide (CO_2-EOR)

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Introduction

CO_2 enhanced oil recovery (CO_2-EOR) offers the potential for storing significant volumes of carbon dioxide emissions while increasing domestic oil production. Additionally, revenues from the sale of captured CO_2 from coal-fired power plants to the EOR market can help offset the costs of installing CO_2 capture facilities and hasten the market penetration of capture technologies. As suggested in previous analyses of the domestic CO_2 storage potential of CO_2-EOR, this technology can be an important stepping stone toward greater penetration of Carbon Capture and Storage (CCS) technology[1].

In order to more fully address the potential of CO_2-EOR to reduce CO_2 emissions, it is important to understand the impacts of widespread CO_2-EOR implementation. Direct CO_2 emissions from CO_2-EOR operations, through fugitive emissions and flaring of produced gasses, have been minimized by current technologies and are effectively negligible. However, CO_2-EOR operations consume large amounts of electricity. Quantifying the electricity consumption of CO_2-EOR operations will allow for a better understanding of the additional electricity load required of the power sector.

Electricity usage by CO_2-EOR projects is highly variable. Myriad factors can affect project electricity demand, including, but not limited to: project length, reservoir depth, pressure, production levels, starting relative volumes of oil, gas, and water among others. Additionally, some CO_2-EOR fields use natural gas to power parts of their operations, though this is outside the scope of the current paper[*].

This white paper will address and attempt to quantify the electricity requirements of CO_2-EOR technology, with the intent to provide a representative

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1 Storing CO_2 with Enhanced Oil Recovery, Advanced Resources International, Inc. 2008. Available at: http://www.netl.doe.gov/energy-analyses/pubs/Storing%20CO2%20w%20EOR_FINAL.pdf

*Field operators contacted for this paper cited variable gas prices, more reliable electricity supply, and easier permitting as the main reasons for choosing electrical powered equipment. Electricity is the most common source of energy to power field operations.

range of estimates, expressed in kWh of electricity consumed per Bbl of incremental oil produced. Information for this report was gathered through informal operator communications, equipment specifications, reservoir modeling and empirical calculations.

In the first section of the paper, we will introduce the elements of a CO_2-EOR project and, where possible, provide information on the contribution of each element to the total project electricity use. The second section of this paper will use reservoir modeling data from ARI's analysis of CO_2-EOR favorable reservoirs and estimates from equipment providers to estimate three "sample" CO_2-EOR projects' electricity requirements on a per barrel of produced oil basis.

Section 1: Major Electricity Consuming Elements of a CO2-EOR Project

Artificial Lifting

Experts contacted during the writing of this paper estimate that artificial lifting is used at approximately 80% of all CO_2-EOR operations[2]. At these fields, the reservoir fluid at the base of the well bore is too heavy, viscous and/or deep to be brought to the surface by the pressure in the reservoir. Notable exceptions exist, such as Anadarko's Monell and Salt Creek fields and portions of Kinder Morgan's SACROC field, where operators have converted to free-flowing wells. However, the majority of CO_2-EOR projects employ artificial lifting to achieve economic production levels[3].

Electricity consumption by artificial lift equipment is highly dependent upon the depth of the well and the composition and volume of the produced fluids. Shallower wells with lighter oil may only require 2-4 kWh/Bbl to lift the produced fluids, but this number may reach 25 kWh/Bbl in deep wells or in reservoirs with heavy oil and/or water-laden reservoir fluids[4]. Operators contacted for this paper estimate that, when used, lifting power consumption makes up between 10 to 30 percent of the electricity use by a CO_2-EOR project[5,6].

Additionally, the amount of power required to lift the produced fluids in a CO_2-EOR reservoir is likely to change over time. In the beginning years of the project, before the CO_2-mobilized oil bank has reached the production wells, lift power consumption is likely to be quite high. In this beginning stage of the project, reservoir pressure has likely been depleted by primary and secondary production and wells may produce high volumes of water.

As injected CO_2 and water (in the case of water alternating gas (WAG) floods) increase reservoir pressure, lifting electricity requirements will decrease.

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[2] Personal Communication with industry representatives from Anadarko
[3] Personal communication with industry representatives from Anadarko and Kinder Morgan
[4] QRod Rod Pumping Design Application. Available at: http://www.echometer.net/qrod/. ARI Reservoir Modeling, see Section 2, below.
[5] Personal communication with a representative of Wilson Field Services Company.
[6] QRod

High concentrations of CO_2 in the produced oil stream will also decrease lifting power consumption by reducing the density of the produced fluid. At the end of the project, if the operator injects a large slug of water to flush the reservoir, lifting power requirements could rise again.

Under favorable circumstances, it is possible for wells that begin a CO_2 flood using artificial lift to be converted to free flowing wells later in the project. Indeed, whenever feasible, reservoir operators will attempt to minimize the electricity and mechanical operating costs of a project by converting wells to flow freely. This decision is made on a reservoir by reservoir basis, and is dependent on site-specific operational and economic factors.

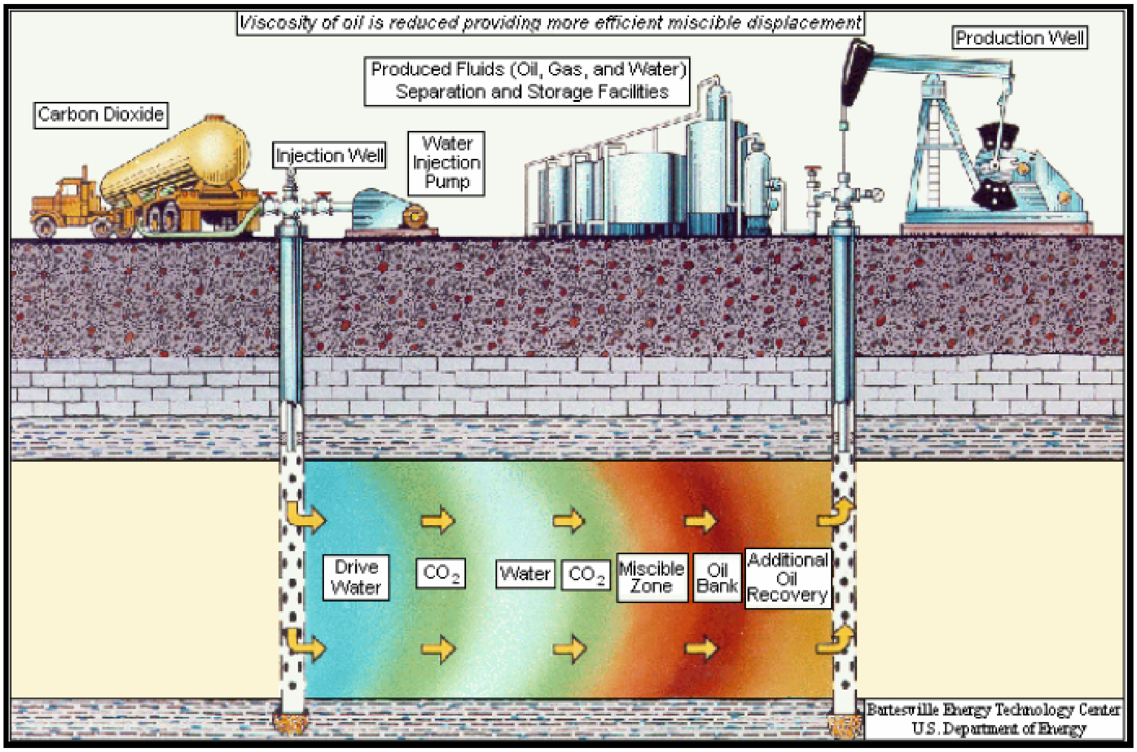
CO_2 Compression

CO_2 compression is the most electricity intensive component of any CO_2-EOR operation. Field operators estimate that compression uses about 60-80% of the electricity demanded by CO_2-EOR operations[7].

Figure 1 illustrates the typical dynamics of a CO_2-EOR flood. After some time, typically 1 to 5 years after first injection, the portion of the residual oil bank that has contacted and mixed with the injected CO_2 reaches the production wells. During this phase of the project, produced oil contains a gaseous mix of CO_2 and lighter hydrocarbons such as methane, ethane, and propane. Typically, the operator will separate the produced oil from the CO_2 and light hydrocarbons mix before sale. In the majority of cases, the combined gaseous mix is compressed to field injection pressure and recycled back into the reservoir. The next section will discuss separating the CO_2 and lighter hydrocarbon gases.

[7] Personal communication with representatives of Kinder Morgan, Anadarko, Chevron and other industry experts.

Figure 1: Simplified Diagram of a CO_2-EOR Flood[8]



CO_2 compression power requirements depend on the differential between the pressure of the produced CO_2 and the field injection pressure. While these pressures vary depending on reservoir characteristics, operators estimate that, though CO_2 needs to be injected at a minimum of 1,800 psi, it is typically produced at around 50psi – an implied compression ratio of 36[9]. Additionally, the CO_2 stream needs to be dehydrated before compression, a process that also requires some electricity.

Using CO_2 compression power consumption equations compiled by McCollum and Odgen[10], we calculate that 65 kWh are needed to compress one ton of CO_2 for the range of pressures mentioned above; per the authors'

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[8] Image Source: U.S. Department of Energy
[9] Personal communication with representative of Anadarko Corporation
[10] McCollum, D., Ogden, J. *Techno-Economic Models for Carbon Dioxide Compression, Transport and Storage*. Institute of Transportation Studies, University of California, Davis

guidelines, this range of pressures would require four stage compression. Assuming that the average CO_2-EOR field injects about 0.3 to 0.4 tonnes of recycled CO_2 to produce a barrel of oil, compression alone requires 20-26 kWh per barrel of oil produced.

In the field, compression performance is likely to be less optimal than what is predicted using lab-based equations. In an average example field discussed by Steve Melzer, an industry expert, the CO_2 compression requires 40kWh per barrel of oil produced. At Chevron's Vacuum Field, CO_2 is compressed from under 100 psi to 1,800 psi using four 3,000 HP compressors (Picture 1). The compression is performed in three phases, both before and after the Ryan Holmes process. Total electricity usage is equivalent to 35 kWh per barrel.

Picture 1: 3,000 HP Compressor at Chevron's Buckeye Plant

When expressed in kWh/barrel of oil produced, an important determinant of compression power consumption is the amount of CO_2 injected per barrel of incremental oil produced. As the CO_2-EOR industry has evolved, operators have steadily increased the amount of CO_2 they inject into the reservoir, helping increase the volume of oil recovered. Forward-looking operators are now injecting anywhere from 0.4-1 hydrocarbon pore volumes (HCPV) of CO_2 into their floods[*]. Previously, volumes ranging from 0.3-0.4 HCPV were the industry standard[11]. Not surprisingly, these much larger volumes of injected CO_2 increase the compression power consumption requirements of a project. An operator contacted for this paper noted that, on a kWh/Bbl of produced oil basis, their electricity consumption had risen 41% over the past several years due to increased injection of CO_2[12].

Hydrocarbon Separation

In fields that produce considerable volumes of hydrocarbon gases in their CO_2 streams, operators may choose to install equipment to separate and capture some of these valuable hydrocarbons for sale. Hydrocarbon separation can be performed using a Ryan Holmes process or membrane separation.

Ryan Holmes

Ryan Holmes facilities separate natural gas liquids (NGLs) from the produced CO_2 stream by exploiting the dew point differential of different types of hydrocarbons. Produced gas is pumped through a vertical, temperature-polarized column and NGLs are separated as they condense out of the gaseous stream. Ryan Holmes facilities can be scaled to separate all of the produced hydrocarbons from a produced stream, or a selected few, depending on project economics. At the Seminole Gas Processing Plant, for example, ethane, NGLs, and sulfur are all separated from the produced stream, requiring four separation columns.

Ryan Holmes facilities require additional compression of refrigerant liquids to maintain the temperature differential of the separation column. This additional

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[*] Hydrocarbon Pore Volume (HCPV) is a measure of the volume of pore space in a reservoir available for hydrocarbon intrusion.

[11] Advanced Resources International. "Storing CO2 and Producing Domestic Crude Oil with Next-Generation CO2-EOR Technology" http://www.netl.doe.gov/energy-analyses/pubs/Storing%20CO2%20w%20Next%20Generation%20CO2-EOR.pdf.

[12] Personal communication with anonymous industry representative.

refrigerant compression adds to the electricity consumption of the plant. In the propane recovery column at Chevron's Buckeye Processing Plant at the Vacuum Field, the top of the column is chilled to -5 degrees F and the bottom of the column is heated to 410 degrees F (Picture 2)[13]. Though significant amounts of CO_2 compression are required to drive the low pressure produced CO_2 stream through the separation process, the CO_2 compression requirements are no larger than those of a CO_2-EOR operation of similar size.

Picture 2: Propane Recovery Column at Chevron's Buckeye Plant[14]

In the Buckeye Plant, two 1,750 HP compressors are used to cool the separation tower. Together, these compressors use approximately 63,000 kWh per day, or 10 kWh per produced barrel of oil. To compress the produced CO_2 stream, Chevron uses four 3,000 HP compressors, which use approximately

[13] Informational material provided to attendees of the 2008 CO2-EOR flooding conference in Midland, TX.
[14] Image Credit: Robert Ferguson, ARI.

215,000 kWh per day, or 35 kWh per produced barrel of oil[15].

Membranes

Membranes are another form of hydrocarbon separation used as an alternative to or in conjunction with Ryan Holmes. Membrane permeation systems separate various fraction of CO_2-EOR produced gas based on molecular size. A carbon dioxide molecule permeates a filter-like material more quickly and with less force than a hydrocarbon molecule. As a result, membranes create a permeate stream (CO_2 rich) and a non-permeate stream (hydrocarbon rich).

During the process the permeate stream loses more pressure than the non-permeate stream and additional compression is required to recompress this stream to its initial pressure. The electricity consumption from membrane separation systems comes from this additional CO_2 compression requirement. The compression and resulting electricity requirements can vary widely, depending not only on the volume of throughput in the process, but also the starting and desired finishing CO_2 concentrations.

Other Electricity Use

In addition to the major sources of electricity consumption discussed above, there are other smaller, but non trivial, components that contribute to CO_2-EOR electricity demand.

The majority of remaining CO_2-EOR electricity use is for injecting water into disposal wells and as part of the CO_2-WAG[*] process, where applicable. Water injection electricity requirements are dependent on the injection pressure and volume of fluid being injected. The standard equation to calculate the

[15] Personal communication with Chevron Representatives, and tour of Vacuum/Buckeye operation

[*] Water alternating Gas (WAG) floods alternate between injecting CO_2 and water to ensure more efficient flood sweep efficiency.

electricity requirement of water injection equipment is given below*.

In the sample CO_2-EOR fields discussed below, we find that water injection electricity requirements range from 4-8 kWh/barrel of oil produced. At Cheveron's Vacuum field, this process consumes 0.5 to 1 kWh/barrel of produced oil due to low volumes of reinjected water relative to oil production[16].

Finally, very small amounts of electricity are used by field automation and CO_2 dehydration equipment. Operators contacted for this paper did not monitor the electricity consumption of these processes separately from the overall operation, so exact numbers are not available. We assume that these components would require no more than 2 kWh/barrel of oil produced. At Cheveron's Buckeye plant, Tri-Ethylene Glycol Dehydration is employed to remove the moisture from the produced gas stream before it is sent to the Ryan Holmes facility. Field operators were not able to give specific estimates on this component's electricity use. However, an equipment provider contacted for the writing of this paper confirmed that the major electricity consumer in a dehydration unit is the pumps needed to recycle the desiccant fluid. As these units are built to be very efficient, electricity use on a per barrel of produced oil basis is assumed to be minimal[17].

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* The equation is: $BHP = \frac{Q \times (P_d - P_s)}{1714 \times ME}$ Where: BHP is the horsepower of the pump, Q is the amount of fluid compressed in gallons/minute, P_d is the discharge pressure, P_s is the initial pressure and ME is the mechanical efficiency of the pump (typically between 65-75%). Horsepower can be converted into kilowatts by multiplying by .747. Source: http://www.pumpcalcs.com/calculators/view/81/

[16] Personal Communication with representative of Cheveron.

[17] Personal communication with representative of Q.B Johnson Manufacturing, Inc.

Summary

Electricity use by CO_2-EOR projects is highly variable. Differing geology of oil reservoirs suitable for CO_2 floods creates unique project infrastructure demands, with correspondingly varied levels of electricity consumption. Even among geologically similar reservoirs, operators can influence the electricity demand profile by how they choose to manage their flood.

CO_2 compression is the largest contributor to CO_2-EOR project electricity use. The normally high differential between produced CO_2 and necessary injection pressure requires many stages of power intensive compression. Reservoir characteristics such as pressure, permeability, porosity and net formation thickness influence compression power consumption because they affect both the pressure of the produced CO_2 and help determine the CO_2 injection pressure. We calculated the compression electricity requirements under a typical reservoir pressure differential at 26 kWh/Bbl, but this should be considered an optimal, low bound. Low produced CO_2 pressures or increased volumes of recycled CO_2 per barrel of oil could double this electricity requirement.

Artificial lifting requirements also significantly contribute to electricity demand from CO_2-EOR projects. Depending on the native pressure of the reservoir, average electricity requirements could be 0 (for free flowing wells) or as high as 10 kWh/Bbl, depending on reservoir depth and composition of the produced fluid. Artificial lifting power consumption is likely to decrease after several years of CO_2 flooding as the injected gas (and water, in WAG floods) act to re-pressurize the field and decrease the density of the produced fluids.

Advanced NGL separation facilities can also add to the electricity consumption of a field. Available data from field operators shows that the additional refrigeration compression requirements of a Ryan Holmes facility can add 10kWh/Bbl to overall project electricity consumption. Data were not available on additional electricity consumption of projects using membrane capture.

Finally, there are number of other minor processes involved in CO_2-EOR floods, such as injection automation equipment, CO_2 stream dehydration, water injection equipment and others that, together, contribute moderately to electricity demand. Consistent data were not available on each of these activities, but we estimate “other” electricity requirements range from 2 to 8 kWh per barrel, depending on the size of the flood.

Together, the above discussed elements will require between 35 to 98 kWh/Bbl of incremental oil produced over the life of the project. Based on field operator guidance, we estimate typical reservoir conditions for lifting and CO_2 compression around 60 kWh/Bbl. Table 1, below, displays the composition of these figures.

Table 1: Range of Electricity Use at CO_2-EOR Fields by Source

Project Component	Low Bound Electricity Consumption*	Mid Range Electricity Consumption**	High Bound Electricity Consumption***
Compression	26 kWh/Bbl	40 kWh/Bbl	70 kWh/Bbl
Artificial Lifting	0 kWh/Bbl	5 kWh/Bbl	10 kWh/Bbl
NGL Separation	0 kWh/Bbl	0 kWh/Bbl	10 kWh/Bbl
Other	1 kWh/Bbl	5 kWh/Bbl	8 kWh/Bbl
Total	35 kWh/Bbl	60 kWh/Bbl	98 kWh/Bbl
* This estimate represents a field with optimized compression equipment, free flowing wells, no additional hydrocarbon separation equipment and that injects straight CO_2.			
** A Mid range field injects additional CO_2 into the reservoir , or has somewhat inefficient compression equipment. It requires artificial lift equipment to produce its oil and injects some of its produced water in a WAG flood.			
*** A High electricity use field injects large amounts of CO_2 into its reservoir. This flood is likely producing large amounts of oil from a deep reservoir which requires powerful, somewhat inefficient artificial lifting equipment. This field also employs an hydrocarbon separation facility which requires additional energy to compress the refrigerant used in the Ryan Holmes process. Finally, it injects its produced water in a WAG process.			

Section 2: Electricity Usage from Three Model Reservoirs

In this section, we use reservoir models and equipment provider specifications to calculate the project-specific electricity demand of three sample CO_2-EOR floods. The reservoirs investigated are not currently undergoing CO2-EOR flooding. They are part of Advanced Resources database of large domestic oil reservoirs that are favorable for CO2-EOR[*]. To provide a representative geographic sample, we chose reservoirs with typical attributes from West Texas, Gulf Coast (Mississippi) and Californian basins. Advanced Resources' analysis of CO_2-EOR potential throughout the US indicated that these areas have significant CO_2-EOR development potential. Table 2 below, displays some of the relevant characteristics of the selected reservoirs.

Data on the CO_2-EOR performance of these reservoirs was developed in previous work ARI performed for the *Storing CO_2 with Enhanced Oil Recovery* report, cited above. Detailed discussion of the modeling methodology can be found in the appendix of that report[**]. Estimates of lifting electricity consumption were provided by equipment manufacturers, and were tailored to the specific characteristics of the reservoirs investigated. For ease of comparison, we did not assume that any hydrocarbon separation would be performed at these projects.

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[*] This database is used to provide estimates of the national potential for CO_2-EOR provided in the above cited *Storing CO_2 with Enhanced Oil Recovery.*

[**] It is important to note that the reservoir modeling for these fields assumes a larger volume of CO_2 is injected into the reservoirs than is typically employed in current CO_2-EOR operations. We assume 1 hydrocarbon pore volume (HCPV) of CO_2 is injected in our models, field operators typically inject anywhere from .1-1 HCPV. As such CO_2 compression/barrel of oil reported from our analysis represents the mid-high side of estimates.

Table 2: Characteristics of Sample Reservoirs Analyzed[18]

Reservoir	Location	Depth (feet)	Oil Gravity (API)	Porosity	Current Reservoir Pressure (psi)	% of OOIP Remaining
1	**W. Texas**	6,791	40	9%	1,500	55%
2	**California**	7,500	31	15%	2,000	55%
3	**Gulf Coast Mississippi**	4,974	24	29%	1,100	85%

West Texas Sample Reservoir:

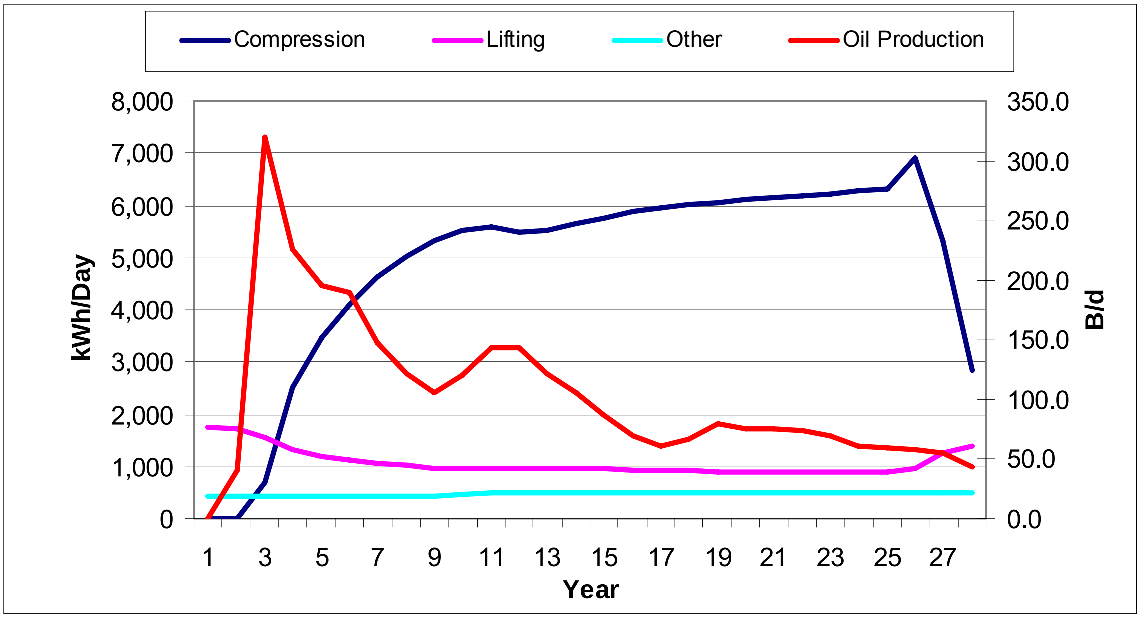
The sample West Texas reservoir used in this analysis is a moderately deep reservoir, with a formation top at 6,791 feet. The oil gravity in this reservoir is 40°, favorable for miscible CO_2 flooding. Typical of the region, this reservoir's porosity is 9%, with a pressure of 1,500 psi. Approximately 55% of the OOIP in this reservoir has been produced.

The figures below show the electricity demand this reservoir would display during full scale CO_2-EOR flood. Figure 2 displays the amount of electricity that would be demanded from lifting, compression, and other field equipment during the life of the flood. This data is displayed on the pattern scale*.

[18] ARI internally produced database on CO_2-EOR-favorable reservoir characteristics

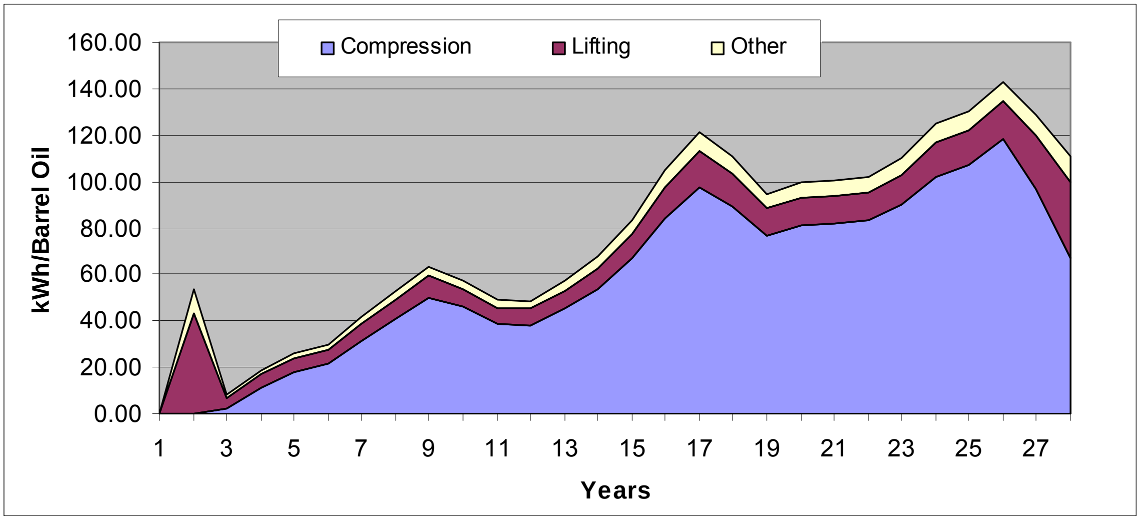
* A "pattern" is a uniform fraction of a field on which an arrangement of injection and production wells are located. The size of a pattern and arrangement of injection and production wells are determined on a reservoir-specific basis.

Figure 2: Electricity Use at West Texas CO_2-EOR Flood



Some trends are evident here that appear in the other sample reservoirs analyzed. As more of the injected CO_2 reaches the producing well, the amount of electricity demanded to compress recycled CO_2 increases over the remaining life of the project. Lifting electricity use falls after the first few years, and remains low as large amounts of CO_2 are present in the produced oil stream. Toward the end of the project, during the final large water flush, lifting electricity use once again rises. Figure 3 shows the estimated electricity use of this sample project per barrel of incremental oil produced.

Figure 3: West Texas Sample EOR-Flood Electricity Consumption



In the later years of the sample project, oil production falls while CO_2 production increases, resulting in very high electricity consumption per barrel of oil produced. Over the life of the project, compression amounts to 63 kWh/barrel of oil produced, 80% of the project total. Lifting costs remain relatively constant, at about 16% of the total (13 kWh/Bbl). In the last few years, however, during the final water flush, lifting electricity use rises somewhat. Other electricity consumption is predominantly driven by the amount of water that is reinjected into the reservoir. Though the amount of injected water remains relatively constant throughout the life of the flood, it increases on a barrel of produced oil basis as oil production decreases.

Table 3: Electricity Consumption at W. Texas Reservoir Sample CO_2-EOR Flood

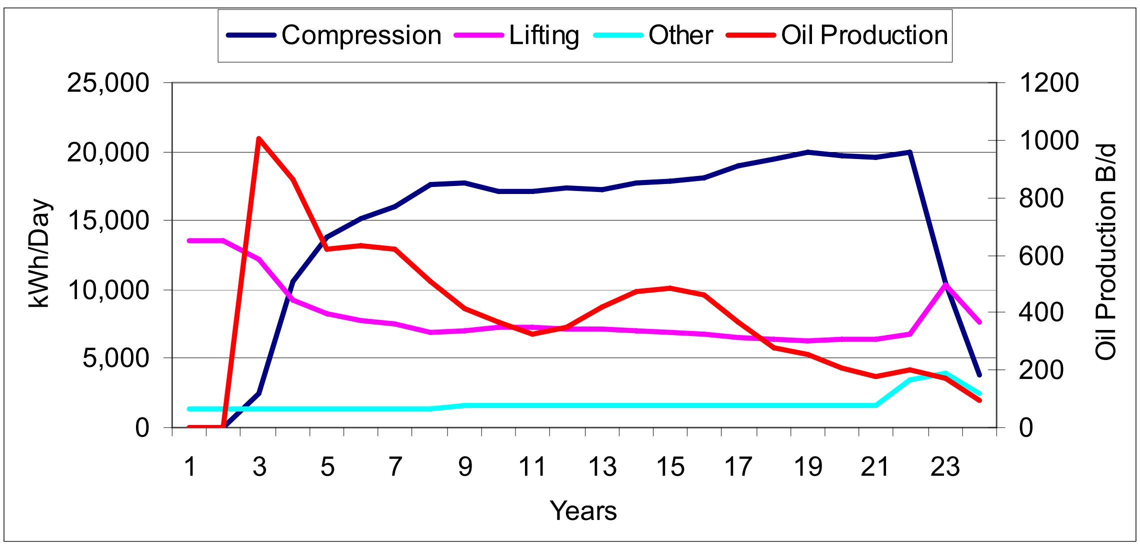
Power Consumption (kWh/Barrel)	Year 5	Year 10	Year 15	Year 20	Project Lifetime	
					Average	% of Total
Lifting	6	9	9	12	13	16%
Compression	11	50	54	82	63	80%
Other	2	4	6	7	6	7%
Total	19	63	69	100	79	100%

California Sample Reservoir

The California reservoir used in this analysis is a deep coastal reservoir with moderately light oil and average porosity. The reservoir is 7,500 feet deep, at a pressure of 2,000 psi and contains oil with an API gravity of 31°. The reservoir's porosity is 15% and it still contains approximately 55% of its OOIP.

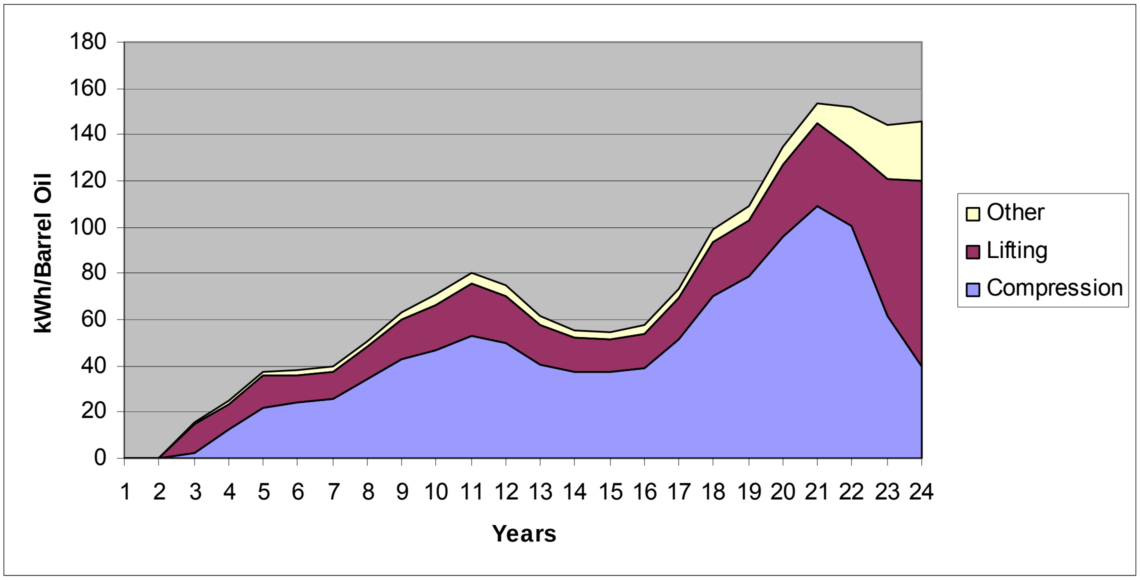
The graphs below show the electricity demand this sample reservoir would display during full scale CO_2-EOR flood. Figure 4 displays the amount of electricity that would be demanded from lifting, compression, and other field equipment during the life of the flood. This data is displayed on the pattern scale.

Figure 4: Electricity Use at Sample California CO_2-EOR Flood



Due to its depth and high water content, lifting electricity use in this reservoir is higher than in the West Texas example. As in the previous example, as the amount of produced CO_2 increases, lifting electricity use decreases. After the first 3 years of operation, once the initial oil bank has reached the production wells, CO_2 compression electricity use surpasses what is required for lifting. Figure 5 shows the amount of electricity use per barrel of oil produced over the life of the flood.

Figure 5: California Sample EOR-Flood Unitized Electricity Consumption



Though average electricity use per barrel of oil produced is relatively high in this field, at 79 kWh/Bbl, electricity use is actually quite low throughout most of its life. As shown in Table 4, electricity use in year 15 is only 55 kWh/Bbl. However, high amounts of produced water in the later years of the flood increase lifting costs while oil production is declining, markedly increasing the electricity usage per barrel of oil produced. By year 20, electricity consumption has increased to 135 kWh/barrel.

As a percentage of the total, electricity use for compression in the California reservoir is lower than normally reported (62%). The increased lifting demands in this reservoir account for 30% of the total electricity use.

Table 4: Electricity Consumption at California Reservoir Sample CO_2-EOR Flood

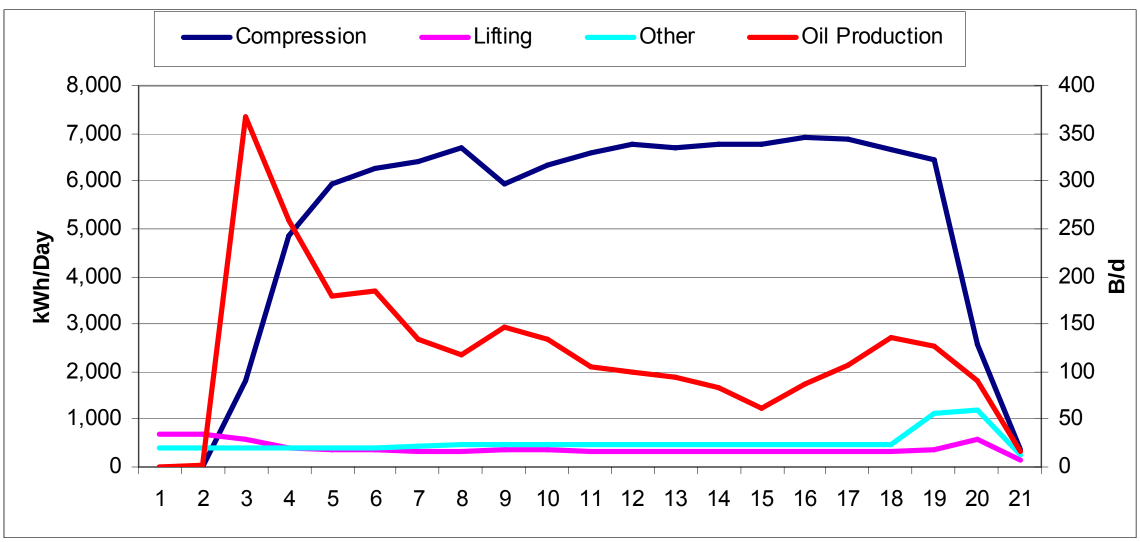
Power Consumption (kWh/Barrel)	Year 5	Year 10	Year 15	Year 20	Project Lifetime	
					Average	% of Total
Lifting	13	20	14	31	24	30%
Compression	22	47	37	96	49	62%
Other	2	5	3	8	6	8%
Total	38	71	55	135	79	100%

Gulf Coast Mississippi Sample Reservoir

The Mississippi reservoir used in this analysis is a homogeneous carbonate reservoir with excellent porosity and moderate depth. The reservoir is at a depth of 4,974 feet and contains moderately heavy oil with an API gravity of 24°. The porosity of this reservoir is 29%. Due to its favorable characteristics, a large portion of its OOIP (85%) was produced during primary and secondary recovery.

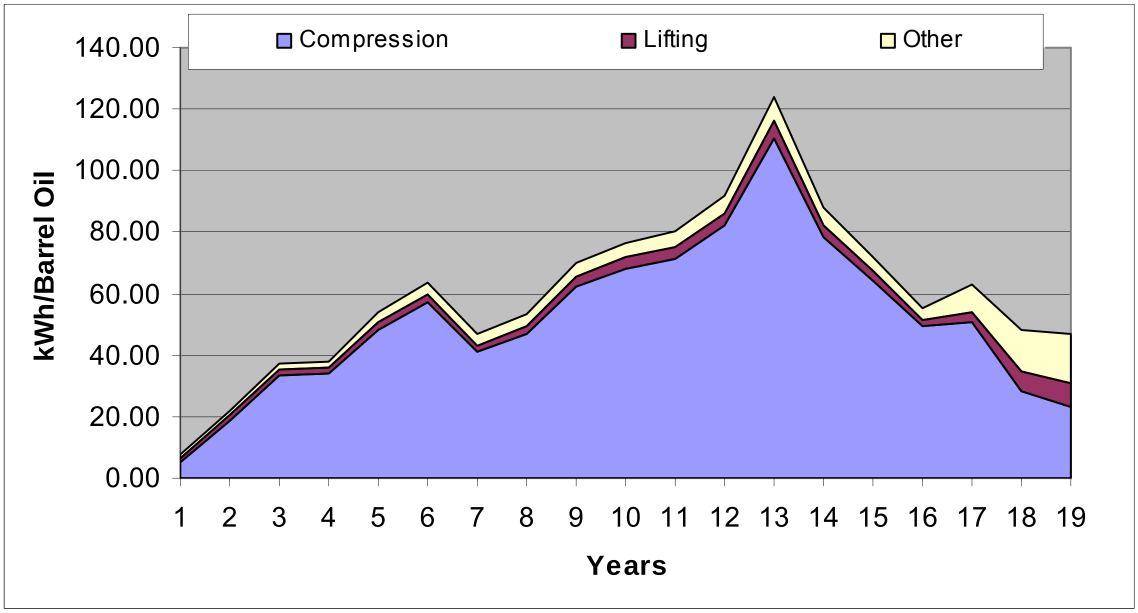
The graphs below show the electricity demand this reservoir would display during full scale CO_2-EOR flood. Figure 6 displays the amount of electricity that would be demanded from lifting, compression, and other field equipment during the life of the flood. This data is displayed on the pattern scale.

Figure 6: Electricity Use at Sample Mississippi CO_2-EOR Flood



The reservoir's shallow depth and smaller volumes of produced water make lifting a minor contributor to the overall flood electricity use. Figure 5 shows the amount of electricity use per barrel of oil produced over the life of the flood.

Figure 5: Mississippi Sample EOR-Flood Unitized Electricity Consumption



Electricity use stays low throughout the life of this flood. However, beginning in year 12, oil production decreases for a period of several years while CO_2 recycle volumes remain constant. This causes a spike in electricity use per barrel of oil produced, which subsides in later years.

As a percentage of the total, lifting electricity consumption at this flood is very low relative to the other two reservoirs analyzed. Only 6% of total electricity used was demanded by the lifting equipment. Compression electricity use is somewhat higher, at 85% of the total, though its gross average of 51 kWh/Bbl is relatively low in comparison to the other examples.

Table 5: Electricity Consumption at Mississippi Reservoir Sample CO_2-EOR Flood

Power Consumption (kWh/Barrel)	Year 5	Year 10	Year 15	Year 20	Project Lifetime	
					Average	% of Total
Lifting	2	3	5	6	3	6%
Compression	33	47	111	29	51	85%
Other	2	5	6	13	5	9%
Total	37	54	122	48	60	100%

Summary

This section is intended to demonstrate how variability between different types of CO_2-EOR projects can affect their electricity consumption profiles. Using reservoir simulation data from Advanced Resources previous work and electricity consumption estimates from field equipment providers, we calculated the electricity consumption of three sample CO_2-EOR fields in California, Mississippi and West Texas. Table 6 summarizes the results from these fields at various time periods throughout the flood.

Table 6: Total Electricity Consumption of Three Sample CO_2-EOR Floods

Power Consumption (kWh/Barrel)	Year 5	Year 10	Year 15	Year 20	Average
W. Texas	19	63	69	100	79
California	38	71	55	135	79
Mississippi	37	54	122	48	60

As the results show, differences in field performance can cause large deviations in overall electricity use. The Mississippi CO_2-EOR project analyzed requires 20 kWh less electricity per barrel of oil produced than the other two fields investigated. Much of the difference is caused by low amounts of produced water, which reduces lifting electricity costs.

Additionally, large variations exist throughout the lives of the projects. Fluctuations in oil and/or water production in later years of the projects caused varying levels of electricity consumption. In year 15, electricity consumption in the

Mississippi CO_2-EOR flood is more than double that in California, due to a period of decreased oil production. This variation is apparent in Figure 6, below.

Figure 6: Total Electricity Use by Three Sample CO_2-EOR projects