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8.1 GEOLOGIC SEQUESTRATION OF CO_2 AND ENHANCED OIL RECOVERY

The Hydrogen Energy California (HECA) Project will utilize Integrated Gasification Combined Cycle technology to capture over 90 percent of potential CO_2 emissions from the synthesis gas that is produced during steady state operations (approximately 2.2 million tons per year). This CO_2 will be compressed and transported via buried pipeline to the custody transfer point at the adjacent Elk Hills Field, where it will be injected. The CO_2 enhanced oil recovery (EOR) process involves the injection and reinjection of CO_2 to improve oil recovery. During the process, the injected CO_2 becomes sequestered in a secure geologic formation. This process is referred to herein as CO_2 EOR and Sequestration. Elk Hills Field is considered an excellent long-term sequestration site and the CO_2 EOR and Sequestration process will employ existing, well-tested technology that is protective of human health and the environment to minimize potential risk. As a result, the Project will provide low-carbon power and additional oil reserves, while generating revenue for the state and creating hundreds of jobs.

CO_2 has been naturally sequestered in geologic formations for hundreds of millions of years. In 2005, the Intergovernmental Panel on Climate Change (IPCC) released a report, *Carbon Dioxide Capture and Storage*. This report was written by 125 contributing authors, and was extensively reviewed by over 200 others, including technical experts and government representatives from around the world. The IPCC report carefully weighs the technologies and the potential risk and concludes that with appropriately selected and managed sites, CO_2 may be permanently sequestered.

The U.S. Environmental Protection Agency (USEPA) has recognized that oil and gas reservoirs will play a valuable role in the geologic storage of CO_2. Two reasons cited by USEPA are: (1) oil and gas reservoirs have proven capable of containing water-buoyant fluids for millions of years; and (2) these reservoirs are well studied and they offer the best opportunity to kick-start large-scale geologic sequestration of CO_2, building on 100 years of oil and gas field operating experience. CO_2 EOR and Sequestration has the added benefit of increasing domestic energy supplies in the face of increasing demand, and extending the life of mature oil fields. The U.S. Department of Energy (DOE-NETL 2008) estimates that CO_2 EOR has the potential to increase total U.S. oil reserves by 45 to 85 billion barrels of oil (bbo), which is 2 to 4 times the current U.S. total proved reserve. A significant portion of these potential oil reserves are in California (5 to 6 bbo). Importantly, sequestration of CO_2 occurs during active EOR operations and continues after EOR operations cease.

8.2 OVERVIEW OF CO_2 EOR AND SEQUESTRATION

A CO_2 EOR and Sequestration project has a dual purpose – to use the CO_2 to permit the extraction of hydrocarbons (oil and gas) from the reservoir and, in the process, store injected CO_2, safely in the reservoir. During the EOR process, the volume of oil and gas produced from the reservoir is expected to offset the purchased volume of CO_2 injected into the reservoir. Therefore, the combination of EOR with sequestration not only eliminates any undesirable reservoir pressure increase, the pore space voided by the produced oil and hydrocarbons serves as the storage space for the injected CO_2. A detailed review of CO_2 EOR and Sequestration at Elk Hills is provided in Appendix F.

During EOR operations, CO_2 is injected into the reservoir, through wells specially designed for this purpose, at pressures that will not fracture the confining geologic zone. The CO_2 flows away from the injection well (see Figure 1), and as it does a portion of the CO_2 contacts and mixes with the oil to form a single-phase solution (i.e., the CO_2 and oil are miscible). The resulting solution has the favorable properties of lower viscosity, enhanced mobility and lower interfacial tension as compared to the oil alone. This helps to mobilize oil that might otherwise be trapped in the rock, and results in increased oil production. Often, water injection is used to sweep the miscible CO_2 and oil mixture to production wells.

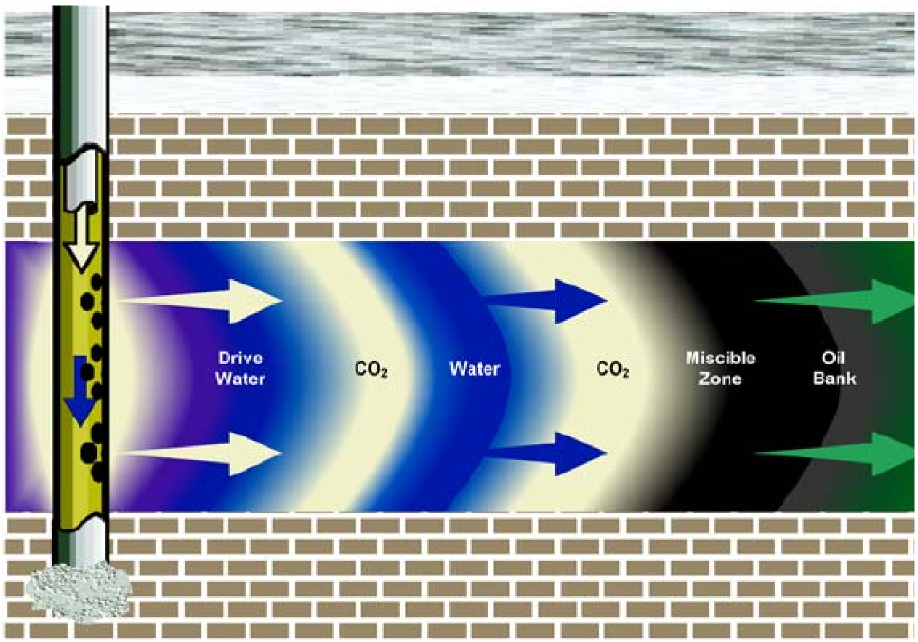

Figure 8-1: Schematic of Miscible CO_2 Flood (Courtesy of Occidental Petroleum)

In commercial scale EOR projects, CO_2 can represent a significant portion of the cost of the project and therefore, operations are designed to minimize CO_2 procurement and maximize oil production. This is accomplished by separating the CO_2 from the produced oil and recycling the CO_2 within an enclosed system back to the reservoir as part of the continuous EOR process. Injected CO_2 is monitored closely to ensure economic operation as CO_2 is a valuable commodity to EOR operators. However, sequestration of CO_2 within the pore spaces of the formation occurs with each injection cycle, necessitating the introduction of additional amounts of CO_2 to continue the EOR operation. For these well-selected, designed and managed geological storage sites, the CO_2 will be immobilized by various trapping mechanisms and be retained indefinitely without release to the atmosphere[1], as further discussed in Appendix F. A schematic of a typical miscible-CO_2 EOR operation is shown in Figure 2.

[1] Even where EOR operators have attempted to reproduce the CO_2 after production at a particular field is completed (for use in another field); approximately 30 percent to 50 percent of the injected CO_2 volume typically remains permanently stored in the oil or gas reservoir and is unrecoverable.

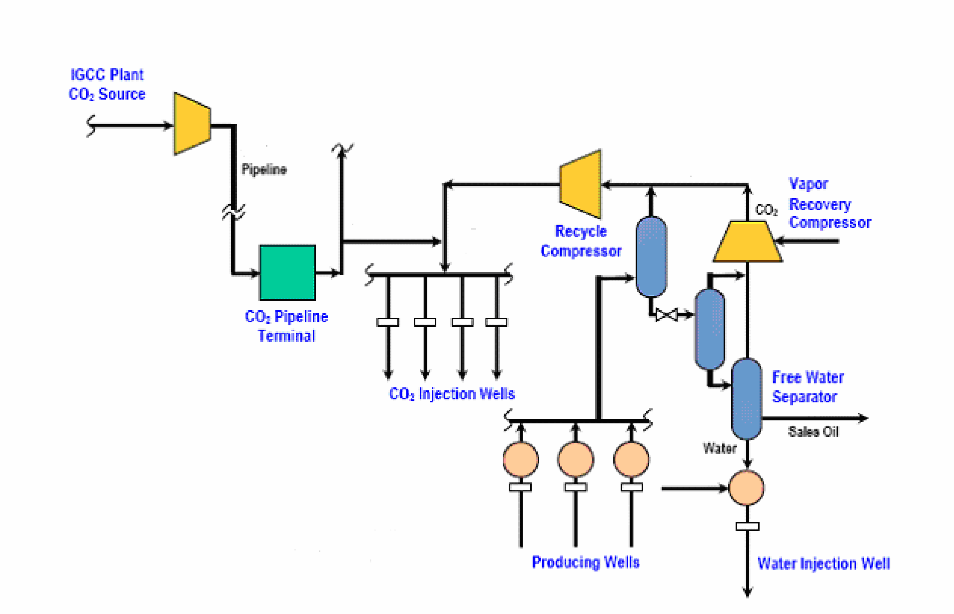

Figure 8-2: CO_2 EOR Surface Process Schematic

8.3 CO_2 EOR AND SEQUESTRATION PROJECT REQUIREMENTS

CO_2 EOR and Sequestration will require the review and approval of the California Division of Oil, Gas, and Geothermal Resources (DOGGR). The Project must satisfy the requirements of SB 1368 including confirmation of, (1) capacity; (2) containment; and (3) economic feasibility. This section focuses on the capacity and containment aspects of CO_2 EOR and Sequestration and explains the basis for the Project's decision to sell its captured CO_2 to Occidental of Elk Hills, Inc. (OEHI). The California Energy Commission (CEC) has advised that it will rely on DOGGR for the regulation of CO_2 EOR and Sequestration.

CO_2 EOR and Sequestration will utilize injection, production and separation technology employed in the petroleum industry for many decades. The technology, metallurgical qualities and operational and emergency procedures are well defined and documented in American Petroleum Institute standards and recommended practices. These technologies include: well-drilling, geologic formation analysis, seismicity analysis, computer simulation of static and dynamic reservoir injection and production, injection and storage of natural gas and industrial waste and, monitoring of subsurface fluid movement.

In general, CO_2 EOR and Sequestration demonstrates capacity and containment by the following activities:

- Site characterization that validates the geological model of the storage site and potential leakage pathways;
- Risk assessment that builds upon a practical understanding of the CO_2 in the reservoir over time and confirms that the potential for leakage has been evaluated; and

- A monitoring, measurement and verification plan that assesses the performance of the sequestration site (geology and technology) and validates or updates anticipated behavior.

The appropriate implementation of these key areas will ensure the safe and secure operation of CO_2 EOR and Sequestration. The various phases of such a project are as follows:

1. Site Selection;
2. Operations; and
3. Closure.

8.4 SITE SELECTION

8.4.1 Preliminary Sequestration Assessment

The Project conducted a scoping/screening study to assess potential sites for CO_2 sequestration. Two well-studied, geologic basin areas, the Ventura Basin on the west coast of California, and the southern end of the San Joaquin Basin located in and around Kern County, were targeted based on their sequestration and EOR potential. The study evaluated capacity, containment, and other specific criteria generally deemed important by current industry and scientific standards in sequestration projects and deemed necessary to satisfy Project Objectives. Based on this scoping/screening study, the focus of the subsurface effort was then directed to the Elk Hills Field in Kern County.

8.4.2 Elk Hills Structure and Geology

The structure and stratigraphy of Elk Hills Field is ideally suited for the injection and long-term sequestration of CO_2. The primary injection targets are within the Miocene age Stevens reservoir. The Stevens sands are porous, permeable and can be very thick, providing an excellent CO_2 EOR target and ample pore space for long-term CO_2 sequestration. The overlying shales are excellent seals and have proven capable of containing water-buoyant fluids and gasses for millions of years. While faults are present within the Elk Hills Field, evidence indicates that these faults are non-transmissive. In addition, there are several shallower productive sands at Elk Hills Field that are also capped with impermeable shales above the proposed injection zone. Consequently, there is a very minimal risk of CO_2 leakage to the surface or to the atmosphere from the targeted CO_2 injection zones at Elk Hills Field.

8.4.3 CO_2 EOR and Sequestration at the Elk Hills Field

The Stevens sands are also considered the best CO_2 EOR targets within Elk Hills Field. Studies indicate the Main Body B (MBB) Stevens sand is an ideal candidate for miscible-$CO_{2,}$ EOR. By analog, documented West Texas miscible-$CO_{2,}$ EOR projects have produced an incremental 10 to 20 percent oil, on average (Holtz et al. 2005). This range is also consistent with a CO_2 EOR pilot study in the Stevens sand at North Coles Levee field 2 miles east of Elk Hills Field conducted by ARCO (MacAllister, 1989). In addition, there is adequate capacity within the Stevens reservoirs to support the volume of CO_2 that will be generated by the Project.

8.5 SEISMICITY

An important aspect of site selection, particularly in California, is to understand the potential risks due to seismicity. These potential risks are twofold: (1) induced seismicity from injection activities, and (2) potential for CO_2 leakage due to natural seismic activity. The Project studied and evaluated both of these concerns with respect to the Elk Hills Field.

The risk of induced seismicity from the injection of CO_2 for CO_2 EOR and Sequestration is remote. In the unlikely event of induced seismicity, the magnitude would be no greater than 4.0. This 4.0 magnitude is comparable to the existing naturally occurring seismicity in the Elk Hills Field area and would not cause structural damage to nearby surface facilities. With respect to natural seismic events, there is abundant historic data and information demonstrating that a rather significant seismic event (on the order of magnitude 6), even if located in the immediate area of the Elk Hills Field, should not cause significant damage to wells or lead to leakage of CO_2. Finally, due to the numerous shale-sealed sand formations above the target injection zone, any vertical gas migration that might occur from the injection interval would most likely be contained and not reach the surface. A detailed review of seismicity and potential impacts at Elk Hills is included in Appendix F.

8.5.1 Elk Hills Field Development History

Part of the site selection analysis involved a detailed review of the development history of the potential site to determine if the reservoir will provide secure containment. The Elk Hills Field was officially discovered in 1919, and was part of the U.S. Naval Petroleum Reserve system until 1998 when OEHI acquired the United States Government’s interest and became its operator.

Active development of the Stevens reservoir was not begun until 1976, resulting in a relatively modern well stock and a detailed and thorough data set of injection zone well penetrations. Due to the limited number of owners/operators at Elk Hills and the relatively recent field development in accordance with modern industry standards, OEHI has a complete database of injection zone well penetrations and completions. This information greatly reduces the risk of leakage due to unknown or improperly completed well penetrations, which are generally recognized as the main risk associated with utilization of oil and gas fields for CO_2 sequestration, and helps confirm the secure containment of the field.

8.6 OPERATIONS

8.6.1 Operator Qualifications

One of the critical components in a successful CO_2 EOR and Sequestration project is effective field operation. Occidental Petroleum Corporation (Occidental) is one of the largest and most respected CO_2 EOR operators in the world and the largest oil producer in the West Texas Permian Basin, where they participate in over 20 CO_2 EOR projects. Occidental has proven operational competence and a stated focus on enhancing recovery in mature fields.

8.6.2 Field Development and Injection Operations

CO_2 EOR and Sequestration will focus on the Stevens reservoirs. These reservoirs have been under peripheral and pattern waterflood for more than 35 years. Much of the injected CO_2 will circulate through the reservoir and be produced from offset production wells along with oil and gas. The produced CO_2 will be separated from the sales streams and re-injected into the reservoir. This recycled CO_2 volume will be utilized to expand the pattern EOR development across the field.

Field development will consist of a pattern flood, operated under a water-alternating-gas/CO_2 injection design. Injection wells will be equipped to switch between water and CO_2 injection at any time. Alternating between water and CO_2 (gas) injection will improve sweep performance of the EOR operation and help California fully develop its natural hydrocarbon resources. The equipment used within the CO_2 EOR and Sequestration facility will form an enclosed system designed to inject, separate and reinject CO_2. The CO_2 EOR and Sequestration project will generally use the equipment described in Appendix F.

8.7 MONITORING, MEASUREMENT, AND VERIFICATION APPROACH FOR THE ELK HILLS FIELD

Monitoring, measurement, and verification (MMV) is an integral part of the UIC permitting process pursuant to fluid injection and gas storage regulations required by DOGGR. The MMV requirements will achieve the key sequestration objectives: (1) ultimate containment of the stored CO_2; (2) protection of human health and the environment; (3) confirmation that the EOR project is behaving as planned; and (4) fulfillment of all applicable regulatory requirements.

The site specific MMV Plan for the Elk Hills Field will include consideration of the existing detailed subsurface, seismic, geochemical and wellbore characterization that has been generated from the extensive data covering the field area. Also, selection of the appropriate suite of tools to fulfill the MMV goals (including the demonstration of CO_2 sequestration) will be based on an assessment of the potential risks taking into account the unique characteristics of the field and the performance expectations at the site, as agreed to by DOGGR.

There are several components that will be incorporated into the MMV Plan, including OEHI's development plan for the Elk Hills Field, reservoir characterization, and simulations that will be used to develop reliable forecasts, which will be confirmed by applying the following:

- Monitoring of wellhead and annular pressures of all wells completed in EOR reservoirs, supplemented by downhole pressure and temperature where available.
- Monitoring of wellhead and annular pressures of wells completed in vertically adjacent reservoirs, supplemented by downhole pressure and temperature measurements in the offset reservoirs where available.
- Well integrity monitoring and cement evaluation.
- Material balance.
- Produced fluid geochemical sampling.

In connection with the site specific MMV at Elk Hills, OEHI will supply any information requested by DOGGR to ensure the Elk Hills MMV Plan will demonstrate sequestration of the injected CO_2.

8.8 CLOSURE

The Closure phase of a CO_2 EOR and Sequestration project consists of site decommissioning, well plugging and abandonment, and appropriate post-injection site care and monitoring to demonstrate that the injected CO_2 is properly contained within the confinement zone and is not endangering human health or the environment. Site closure at the Elk Hills Field will be conducted pursuant to a post-injection site care and site closure plans that will be performance-based and specifically tailored for this field. The site will be closed upon demonstration of the following:

- Either (a) no evidence of significant leakage of injected or displaced fluids into formations outside the confining zone, or (b) the integrity of the confining zone.
- That based on the most recent geologic understanding of the site, including monitoring data and modeling, the injected or displaced fluids are not expected to migrate in the future in a manner that encounters a potential leakage pathway.
- That wells at the site are not leaking and have maintained integrity.

8.9 CONCLUSION AND SUMMARY

The Project has completed an evaluation to prioritize and select appropriate CO_2 sequestration sites. The evaluations included a preliminary evaluation of North American basins, basin screening studies and detailed geotechnical (depth, seismicity, porosity, permeability, geochemistry, fault analysis, seal capacity) and engineering (pressure, miscibility, EOR potential, injectivity, mechanical integrity, infrastructure and operational requirements) analyses of high potential individual fields within select basins. This study was to assess their CO_2 storage capacity, containment and the viability for enhanced oil recovery projects. Based on these assessments, the Project identified the Elk Hills Field as one of the premier CO_2 EOR and Sequestration sites in the United States. As described in this section and Appendix F, analysis and study of the Elk Hills Field has confirmed that it is an optimal site for the safe and secure sequestration of CO_2.