**CO2 Enhanced Oil Recovery: A Key Bridge to Large Scale CO2 Sequestration**

My name is Ian Duncan. I have a PhD in Geological Sciences and I am an Associate Director of the Bureau of Economic Geology (BEG) at the University of Texas at Austin. The BEG is engaged in a wide range of applied research in a broad range of energy related and environmental issues including CO2 sequestration. The BEG's Gulf Coast Science Center (GCCC) part of my group is an industry-academic collaboration that has been working on geologic CO2 storage including CO2 EOR since 1988. The GCCC currently has significant field tests underway, one Scurry County Texas (Kinder Morgan's SACROC CO2-EOR field) and two in Mississippi (Denbury resources Cranfield CO2-EOR sit). These field tests seek to how effectively CO2 injected for EOR is retained in the subsurface, and how we can best predict and document this retention through modeling and monitoring. These studies are funded by about $50 million in Department of Energy funds (over 10 years). For the past nearly four years I have been doing research on the role that CO2 Enhanced Oil Recovery (CO2-EOR) can play in mitigating greenhouse gases in the atmosphere and in increasing domestic oil production in the US.

The key points that I would like to make are:

(1) In the near term CO2-EOR can make a significant contribution to mitigating increases in CO2 emissions into the atmosphere by putting significant quantities of anthropogenic or man-made CO2 (CO2-A) into permanent storage in depleted oil reservoirs

(2) Government should encourage "early-entry" capture at power plants and other industrial sources of CO2 emissions to supply CO2-A for CO2-EOR projects in conjunction with sequestration. It is critical that these projects be allowed qualify for whatever carbon credits or offsets arise out of federal legislation.

(3) Government should provide a policy/regulatory environment that encourages CO2 EOR operators to change business as usual by: a) utilizing CO2-A when made available at a reasonable cost from capture at power plants and other industrial sources; b) creating and implementing monitoring, verification and mitigation (MMV) plans to provide assurance of permanent sequestration; and c) conduct life cycle analyses of their projects to measure CO2 avoided.

(4) CO2-EOR can provide the financial capacity and rationale for developing a CO2 capture, compression and transportation infrastructure across a significant portion of the US that can later be used for large scale CO2 sequestration in deep brine reservoirs.

(5) In the Texas Gulf Coast alone, BEG staff have estimated that an additional 3.8 billion barrels of oil recovery could be achieved through CO2-EOR. This is almost twice the entire annual domestic oil production of the US at this time.

(6) Industry and University experience related to CO2-EOR in the US has provided most of the knowledge, expertise and human capacity that will enable CO2 sequestration to be

implemented. Creating funding for CO2-EOR related research in the Department of Energy's budget could have a significant positive effect on knowledge creation, technological innovation and technology transfer related to CO2 sequestration. Such funding would also help produce young engineers and geologists trained in CO2 injection related technologies and help alleviate a shortage that is critical now and will grow more so in the near future.

(7) An aggressive research program including pilot projects would help improve the performance of current EOR activity and enable the development of new more effective approaches that could increase oil recovery, reduce the geological and technical risks, and enhance sequestration rates incidental to CO2-EOR.

CO2 sequestration will involve the capture anthropogenic CO2 (typically from electric power plants) followed by deep subsurface injection into oil and gas reservoirs, deep unmineable coal beds or deep brine reservoirs. Approximately 80% of the CO2 injection in the world takes place in the Permian Basin of Texas and New Mexico, making the region the largest commercial market for $CO_2$. Texas corporations and technical workers have a unique experience base and outstanding safety record, in pipeline transport and subsurface injection of $CO_2$. Since the early 1970s, $CO_2$ has been injected into many Permian Basin oil reservoirs to enhance production. Injected $CO_2$ is dominantly produced from natural accumulations and pipelined to the Permian Basin. In addition, on the order of ~10% is now derived from other sources such as gas processing plants where the $CO_2$ would otherwise have been released to the atmosphere. Currently roughly 30 million metric tons (MMt) of $CO_2$ are injected annually in the Permian Basin in operations that are closed-cycle. In other words, $CO_2$ that is produced from the oil reservoirs in association with the recovered oil is recycled (re-injected into the reservoir for additional recovery).

Many individual operations in the Permian Basin are at the scale of $CO_2$ production associated with coal burning power plants. $CO_2$-flooding for enhanced oil recovery (EOR) has been active at SACROC in Scurry County since 1972. Kinder Morgan the current operators at SACROC currently inject ~13.5 MMt $CO_2$/yr and withdraw/recycle ~7 MMt $CO_2$/yr, for a net storage of ~6.5 MMt $CO_2$/yr. For comparison, a 500 MW pulverized coal power plant produces roughly 3–4 MMt $CO_2$/yr. This magnitude of annual CO2 storage at SACROC is over six times the rate of Statoil's Sleipner project offshore Norway.

The Gulf Coast has a large potential for $CO_2$ enhanced oil recovery (EOR) outside of the traditional area of $CO_2$ EOR in the Permian Basin. Using the miscibility screening criteria BEG staff have inventoried 767 oil reservoirs where miscible $CO_2$ EOR could be applied for an additional 3.8 billion barrels of oil recovery. By way of comparison, annual oil production in USA is about 1.86 billion barrels. This incremental production target is attractive because of value in terms of wellhead value, tax revenue, and economic activity. This EOR activity would lead to the use of large amounts of $CO_2$, however, it is small in the context of the projected 55 to 70 billion tons of $CO_2$ emissions for the Gulf Coast over the next 50 years. Deep brine reservoirs in the Gulf Coast have been estimated by BEG staff to have a sequestration capacity about 4 times this value (that is over 200 billion tons of CO2).

EOR results in storage of $CO_2$ dissolved in residual oil, dissolved in brine, and trapped as an immobile supercritical phase. Experience in Permian basin EOR projects is that 30 to over 60% of the injected $CO_2$ is retained in the reservoir during the first pass through the reservoir. Ultimately through recycling 99.. However, the volume retained as a by-product of EOR is small relative to total point source emissions. The large synergy between EOR and reducing carbon emissions is that EOR would enable the construction of an infrastructure linking sources to reservoirs. Very large volumes of brine reservoirs can then be accessed beneath oil production, a concept that we describe as stacked storage. Existence of an infrastructure would reduce the cost of storage of Gulf Coast power plant, refinery, and chemical plant emissions for the next 50 years or more.

The Gulf Coast of the USA is a region of high $CO_2$ emissions that overlie thick, extensive, and well known subsurface geologic formations. Path forward toward developing an economically viable system for capture and storage include: (1) development of a climate favoring construction of gasifiers using coal, lignite, petcoke and/or biomass as sources (IGCC electric power plants for example), (2) construction of a pipeline backbone to transport $CO_2$ regionally, (3) a market for $CO_2$ for EOR in areas beyond the traditional area of use in the Permian Basin, and (4) development of stacked storage, using deeper brine-bearing formations beneath hydrocarbon reservoirs.

Sequestration credits may play a significant role in future CO2 EOR based on anthropogenic CO2. The criteria to qualify projects for CO2 credits are likely to evolve as the industry matures. A recent Texas law creating a tax credit for CO2 EOR using anthropogenic CO2 requires projects to establish a reasonable expectation that they can meet a performance standard of 99% retention for 1,000 years. To meet this standard, operators will likely have to: characterize the seal for their reservoir and demonstrate that it is compatible with this standard; design and implement an appropriate monitoring program and complete a CO2 life cycle analysis to verify the amount of CO2 avoided.

Up until now, CO2 purchase has been the largest cost component of a CO2-EOR flood. As a result engineers and geologists in companies and the Universities have developed and refined technologies and approaches to minimize CO2 usage in CO2-EOR projects. We may be entering a new regime in which CO2 injection gains credits that changes the fundamental economics. Under these circumstances new or previously little used approaches to CO2 EOR projects such as vertical floods and CO2 alternating with CO2 foam may become viable. Such approaches offer great opportunities for increasing the total oil recovery and maximizing CO2 storage. However research in combination with full scale field test are almost certainly necessary to convince companies of the viability of these and other “game changing” technologies.

Although this testimony has focused on the Gulf Coast and Permian basin of Texas, significant CO2-EOR potential also exists in a number of other states including

Louisiana, New Mexico, Oklahoma, Wyoming, Illinois, Michigan, California, Kansas, Mississippi, North Dakota and others. In the context of economic growth, global oil demand and atmospheric mitigation of $CO_2$, a 'first step' mechanism is required to sequester large volumes of $CO_2$ in a manner that later allows pure $CO_2$ storage to initially 'piggyback' via the commercial leverage of the oil recovered.

In summary I would leave you with the following points:

- $CO_2$-EOR can play a key role in developing the infrastructure and the technical understanding to enable large scale $CO_2$ sequestration in brine reservoirs.
- $CO_2$-EOR combined with carbon capture from power plants and other stationary sources can have a significant positive impact on domestic oil production.