California Carbon Capture and Storage Review Panel

TECHNICAL ADVISORY COMMITTEE REPORT

Beneficial Use of Carbon Dioxide

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CALIFORNIA CARBON CAPTURE AND STORAGE REVIEW PANEL

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Long-Term Stewardship and Long-Term Liability in the Sequestration of CO2

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Approaches to Pore Space Rights

Overview of the Risks of Geologic CO2 Storage

AB 32 Regulations and CCS

Public Outreach Considerations for CCS in California

Review of Saline Formation Storage Potential in California

1. Introduction

In addition to using CO_2 for enhanced oil recovery (EOR), there are many other possible beneficial and revenue-generating uses for captured CO_2 in various stages of development. Technologies for the beneficial use of CO_2 can advance greenhouse gas (GHG) reduction goals by either preventing the captured CO_2 from entering the atmosphere or by using the CO_2, or a chemical product produced from CO_2, in a way that displaces the emission of other GHGs.

2. Background

To date technologies making beneficial use of CO_2 such as EOR have had a negligible impact on overall anthropogenic CO_2 emissions. The volumes of the current merchant and captive CO_2 markets combined amount only to about 1% of global anthropogenic CO_2 emissions. Furthermore the current market demand for CO_2 is mostly addressed by geological sources of CO_2 (including essentially all of the CO_2 used in EOR); the use of which provides no reduction in GHG emissions to the atmosphere. The majority of CO_2 in the merchant market[1] is used for EOR (~70-80%),[2] along with a significant portion used in the food processing industry. CO_2 in captive chemical processes[3] is most commonly used in the production of urea ($(NH_2)_2CO$) for fertilizer. CO_2 currently being utilized that has been separated from flue gas or chemical process streams is generally either captured from relatively pure flue gas streams (e.g. ethanol distilleries) or from process streams where CO_2 capture and separation is necessitated by a need for product purity (e.g., natural gas pipelines or ammonia production). Only about 2% of the demand for CO_2 is currently met through capturing CO_2 from power plant or industrial flue gas streams, which have relatively dilute CO_2 content and no current requirement for CO_2 capture and separation.

New technologies that facilitate the beneficial use of CO_2 could increase the demand for CO_2 captured from power plant and industrial sources, improving the economic viability of CO_2 capture, and reduce GHG emissions, while providing useful products to the public. Technologies making use of CO_2 could possibly provide other positive environmental and economic benefits as well including reduced water consumption, replacement of toxic chemicals, and displacement of imported fuels, chemicals or minerals. Some of the technological possibilities for CO_2 use will be discussed in Section 3

The importance of finding value for CO_2 independent of any proposed regulation, carbon credit markets, or carbon taxes has been stressed in previous studies including the AB 1925 report to the California legislature "Geologic Carbon Sequestration Strategies For California: Report To The Legislature"[4] and the 2009 Integrated Energy Policy Report published by the California Energy Commission.[5] The example of Hydrogen Energy California (HECA) illustrates how a

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[1] Market in which CO_2 is bought and sold competitively by multiple market participants

[2] Tiina Koljonen, Hanne Siikavirta, Ron Zevenhoven, "*CO2 Capture, Storage and Utilization in Finland*", Project Report, VTT Processes, Systems and Models, Aug. 29, 2002, www.vtt.fi/inf/julkaisut/muut/2002/co2capt.pdf

[3] CO_2 produced onsite by the user of the CO_2 and not sold to outside customers.

[4] http://www.energy.ca.gov/2007publications/CEC-500-2007-100/CEC-500-2007-100-CMF.PDF

[5] http://www.energy.ca.gov/2009publications/CEC-100-2009-003/CEC-100-2009-003-CMF.PDF

commercial scale carbon capture project at a fossil-fired power plant can move forward in California under the current regulatory environment, without the existence of carbon credits or carbon taxes, if it is linked to a promising and potentially economical use for the captured CO_2; although it should be noted that HECA, like many new alternative energy projects, has received government support including $308 million from the Department of Energy (DOE) through the American Recovery and Reinvestment Act of 2009 (ARRA). In the case of HECA the captured CO_2 will be delivered by pipeline to Occidental Petroleum's Elk Hills oilfield for EOR, which is a relatively well established and understood use of CO_2. However there is a need for new, alternative uses of captured CO_2 since EOR will not be appropriate for all carbon capture operations and locations, nor will EOR be able to absorb all of the CO_2 that could potentially be captured from industrial point sources.

3. Technology Overview

3.1. <u>CO_2 Use With Geological Storage</u>

At the August 18th CCS Review Panel Meeting Dr. William Bourcier from Lawrence Livermore National Laboratory discussed coupling CO_2 sequestration to the production of brine under high pressure, which may allow relatively inexpensive production of fresh water from brine through reverse osmosis.[6] The recovery and desalination of subterranean brine to fresh water coupled with CCS represents one possible beneficial use of CO_2 (Figure 1). In addition to fresh water, it is possible that valuable minerals such as lithium, used in rechargeable batteries, can be economically recovered from some brines.

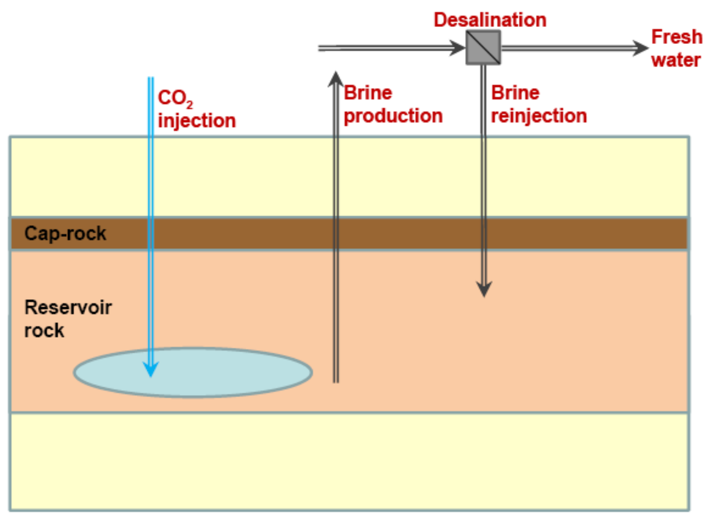

Figure 1 Desalination of aquifer brines displaced by CCS to create fresh water. Source William Bourcier, LLNL.

There are many other examples of beneficial CO_2 use technologies being actively researched including enhanced gas recovery (EGR) with CO_2 sequestration (Figure 2), and enhanced geothermal systems using CO_2 (EGS-CO2), instead of water, as a heat exchange fluid (Figure 3).[7] Both of these technologies resemble EOR in that they provide a dual benefit of additional energy generation combined with CO_2 sequestration. However instead of being joined to the recovery of oil, the sequestration of CO_2 is joined to the enhanced recovery of natural gas or geothermal heat for EGR and EGS-CO2 respectively. Research into EGR and EGS-CO2 is being carried out by a number of institutions including the Lawrence Berkeley and the Los Alamos

[6] http://www.climatechange.ca.gov/carbon_capture_review_panel/meetings/2010-08-18/presentations/01_Bourcier_Cal_CCS-Panel.pdf

[7] Donald Brown, "*A Hot Dry Rock Geothermal Energy Concept Utilizing Supercritical CO2 Instead Of Water*", Proceedings, Twenty-Fifth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA, Jan 24-26, 2000

National Laboratories. In addition the company GreenFire Energy is attempting to commercialize EGS-CO2 technology with a demonstration plant planned near St. Johns Dome in New Mexico and Arizona. Other companies involved in this EGS-CO2 project are Enhanced Oil Resources Inc. and Alta Rock Energy headquartered in Sausalito California.

3.2. CO_2 Use With Non-Geological Storage

As mentioned in the AB 32 Scoping Plan published by the California Air Resources Board there are other strategies for preventing the release of CO_2 into the atmosphere in addition to geological sequestration, such as the industrial fixation of CO_2 into inorganic carbonates.[8] Technologies are being developed today that synthesize solid materials such as plastics, or carbonates that can be used in cement or glass, from a CO_2 feedstock. Los Gatos-based Calera Corporation is one of the companies trying to commercialize a technology for the production of carbonate building materials (e.g. $CaCO_3$ and $MgCO_3$) using CO_2 captured from flue gas. They are recent winners of a DOE ARRA award for "Innovative Concepts for Beneficial CO_2 Use", and report CO_2 capture rates of above 85% at their Moss Landing Pilot Facility. Calera has also developed an electrochemical process for producing carbonates from CO_2 and salt, which they claim requires substantially less energy than other competing technologies. Another example of a business making carbonates from CO_2 is in Trona California where a Soda Ash plant owned by Searles Valley Minerals Inc. has captured CO_2 from an onsite coal-fired plant for over 20 years to produce sodium carbonate (Na_2CO_3) that is used in making glass and as a water softener.

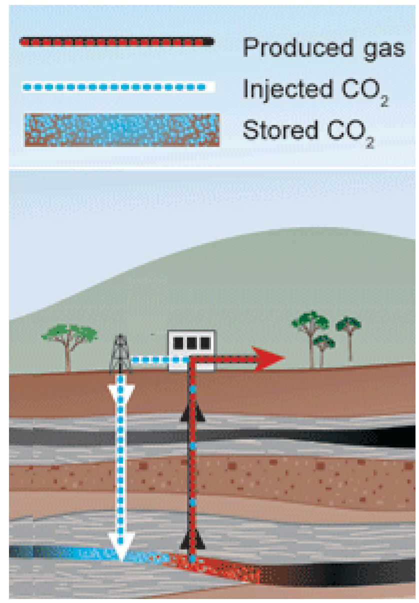

Figure 3 Enhanced coal bed methane recovery. Source LBNL

All of the examples given in Section 3.1 and 3.2 represent technologies that could help advance GHG reduction goals by storing CO_2 long-term, while providing additional benefits and useful products to the public.

3.3. CO_2 Use Without Long-Term Storage

There are other technologies under development that do not provide long-term storage of CO_2, but which still could reduce overall GHG emissions by either 1) using CO_2 in a way that displaces the emission of other GHGs, or 2) converting CO_2 into a chemical that can in turn displace the emission of other GHGs.   An example of the former is using CO_2 as a refrigerant that substitutes for chemicals currently used in refrigeration that are far more potent greenhouse gases than CO_2, such as hydrofluorocarbons (over 1000X stronger

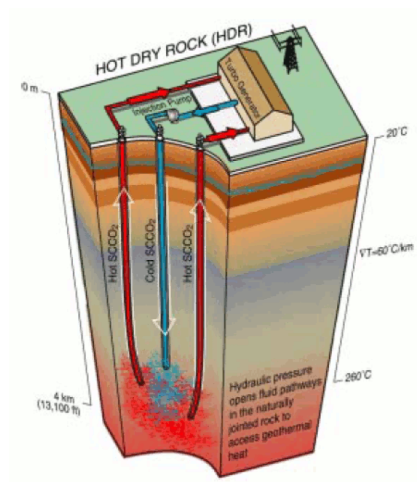

Figure 2 Enhanced geothermal system using supercritical CO_2. Source Donald Brown, LANL.

[8] http://www.arb.ca.gov/cc/scopingplan/document/adopted_scoping_plan.pdf

greenhouse effect per unit volume than CO_2). An example of the latter is the wide array of "CO2-to-fuel" technologies being researched with the goal of producing liquid fuels ranging from methanol or ethanol to gasoline or diesel out of CO_2 and water, along with an energy input (preferably from a CO_2-free source such as solar or wind). Fuels produced from waste CO_2 could displace the use of petroleum-derived fuels, which would result in reduced net GHG emissions, as well as address security issues related to importing oil.

Some of the better-known types of CO2-to-fuel technologies are biologically based and use algae and other photosynthetic microorganisms in the conversion of CO_2, water, and sunlight into liquid fuel. A number of different companies are trying to commercialize technologies that use photosynthetic microbes to convert CO_2 to fuel such as San Diego based Sapphire Energy and Synthetic Genomics, Joule Unlimited, Inc., and Algenol to name just a few. The California Energy Commission through the Public Interest Energy Research (PIER) Program is funding R&D in this area such as the Algae OMEGA project at NASA Ames.[9] The federal government is also investing a substantial amount in this area including recent funding for the Consortium for Algal Biofuels Commercialization based in San Diego. Perhaps less well known are the efforts to chemically convert CO_2 into liquid fuels, but research is also being conducting in this area at a number of places including the newly founded DOE Joint Center for Artificial Photosynthesis headed by the California Institute of Technology.

Some uses of CO_2 that are being researched do not clearly reduce GHG emissions directly or indirectly, but still provide some other public benefit such as displacing the use of the toxic chemicals or saving water. Examples include using CO_2 as a solvent in place of perchlorethylene for dry cleaning, or using CO_2 as a non-toxic grain silo fumigant. CO2Nexus out of Hermosa Beach California is receiving PIER funding to demonstrate a Supercritical Carbon Dioxide-based Laundry System that avoids the use of toxic chemicals and saves water.

3.4. Summary Of Technologies

These examples give just a few of the possible beneficial uses for CO_2. It is evident that the possible uses of CO_2 vary greatly, and cover a wide range of fields and applications. However, they can generally be placed in the following categories:

- Carbon capture and geological sequestration joined to the enhanced recovery of any geological resource, including oil, natural gas, geothermal heat, minerals, or water
- Biological conversions of CO_2 to fuel or other useful chemicals
- Chemical conversions of CO_2 to fuel or other useful chemicals
- Use of CO_2 as a heat exchange fluid or working fluid
- Use of CO_2 as a cushion (or base) gas (e.g. for natural gas storage or Compressed Air Energy Storage (CAES))
- Use of CO_2 as a solvent
- Use of CO_2 as a fumigant, propellant, or inert gas

[9] http://www.energy.ca.gov/2010publications/CEC-500-2010-FS/CEC-500-2010-FS-001.PDF

- Use of CO_2 in the dry ice state

The many different technologies being investigated for the beneficial use of CO_2 vary widely in their stages of development, from those being tested at the bench-scale, to technologies that are close to commercialization. They also vary widely in their potential to impact overall GHG emissions. There is a need to better understand the viability of the various technological options for CO_2 use and their potential to incentivize industrial carbon capture and provide substantive GHG emissions reductions. Where research funding can be most effectively invested in this area to advance GHG reduction goals, given the many diverse types and stages of beneficial CO_2 use technologies, is an important question. The California Energy Commission is preparing a research roadmap to address this question.

4. Policy Options On Beneficial CO2 Use

Given the many possible beneficial uses of CO_2, one option for consideration would be for California to declare that CO_2 is a commodity, as other states have done including Louisiana (HB 661 2009).[10] This would follow the recommendation of the "Storage of Carbon Dioxide in Geologic Structures - Legal and Regulatory Guide for States and Provinces"[11] published by the Interstate Oil and Gas Compact Commission (IOGCC) of which California is a member. Declaring CO_2 to be a commodity could have implications on how, and by which agencies CO_2 capture and use is regulated.

In public comments received by the California CCS Review Panel there has been an expressed desire that non-geological sequestration strategies, such as the carbon conversion process utilized by Calera and other companies, be formally recognized as a viable sequestration option, and that there be a more explicit recognition that CCS is broader than simply gas separation and geologic storage. [12] These comments also highlight how concerns involved with non-geological types of sequestration and CO_2 use will likely have different policy interests and priorities than ones involved with geological sequestration.

For beneficial uses of CO_2 that involve geological sequestration such as the enhanced recovery of natural gas, geothermal heat, minerals, or water, it would seem possible that such technologies could be treated under a similar policy framework as EOR joined to CCS (CCS/EOR). However, we have seen that there may be significant differences between CCS/EOR and CCS in saline formations e.g. differences in monitoring, measurement, and verification (MMV), possible differences in UIC well classification, as well as possible differences in state permitting agencies. One can reasonably foresee that each type of enhanced recovery of a geological resource joined to CCS would likely have its own set of unique requirements as well.

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[10] http://www.legis.state.la.us/billdata/streamdocument.asp?did=668800

[11] http://groundwork.iogcc.org/sites/default/files/2008-CO2-Storage-Legal-and-Regulatory-Guide-for-States-Full-Report.pdf

[12] http://www.climatechange.ca.gov/carbon_capture_review_panel/meetings/2010-06-02/comments/Calera_Comments.pdf

The differences between CO_2 use technologies that generally involve geological sequestration of CO_2 (e.g. Section 3.1), and those that do not (e.g. Sections 3.2 and3.3), are even more significant, and one would expect that to be reflected in the policy priorities associated with each respective technology type. For example in the case of carbonate materials made using CO_2, many of the significant issues that confront geological sequestration such as long-term stewardship, liability, and risks associated with storage are far less of a worry. This is due to carbonates generally being solid, highly thermodynamically stable compounds. However, carbonates could still have their own unique accounting issues since carbonates can react over time releasing CO_2 under certain conditions (e.g. acidic environments), so sequestration over the long term could be less than the CO_2 initially captured.

There are policy issues confronting the non-geological CO_2 sequestration strategies that could be addressed to help them advance. For example, it has been proposed that the state could help create a market that establishes value for CO_2 mitigation through a policy framework that resembles what has been implemented for renewable power with the Renewable Portfolio Standard (RPS).[13] It has also been suggested that sources creating CO_2 neutral or negative products should get reduction or offset credits not only for the emissions prevented at their facilities, but also for those that would have resulted in the use of carbon intensive conventional materials.[14] For example, if a power plant captures a ton of CO_2 and converts it to two tons of a cement product, the source could get credit for both the initial emissions captured, and for the emissions that would have resulted from the production of conventional cement. Since Portland (i.e. conventional) cement manufacturing emits roughly one ton of CO_2 for each ton of cement,[15] under such a system credit would be given for three tons of CO_2 emissions avoided per ton of CO_2 captured and converted to cement product.[16]

The idea of getting credit for emissions avoided that would have resulted from the production of conventional products is very relevant to all of the beneficial CO_2 use technologies that do not sequester the CO_2, such as CO2-to-fuel technologies. The claimed GHG reduction for these technologies generally rests on a comparison to a “business as usual case” e.g. a car burning diesel made from CO_2 captured from flue gas versus one burning diesel made from petroleum. In both cases CO_2 is emitted from the tail pipe but the former case could result in less net CO_2 emissions than the latter business-as-usual case when accounting for both flue gas and tailpipe emissions combined. Further complicating matters is the importance of the source of the CO_2 in

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[13] Ibid.

[14] Ibid.

[15] CO_2 emissions in conventional cement manufacturing result from heating limestone ($CaCO_3$) in a process known as calcination, which releases CO_2 to give quicklime (CaO), as well as from the fossil fuel consumed in generating the heat needed for calcination, along with energy needed for the rest of the manufacturing process.

[16] A number of complicating factors can be envisioned under such a system including the possible application of CCS at conventional cement factories to capture CO_2 emitted from calcination and/or fossil fuel combustion, as well as the energy source used in a process like Calera’s – whether it’s fossil-fuel or renewable. Since both the company manufacturing CO_2 negative cement, and the source of CO_2 used in the cement e.g. a power plant, should not both receive credit for carbon captured, the regulatory regime would need to be structured so that double counting of CO_2 reductions does not occur.

this accounting. For example CO_2 captured from a fermentation process at an ethanol refinery is made from carbon absorbed from the air through photosynthesis, while the carbon from CO_2 captured at a coal plant is from underground.   The California Low Carbon Fuel Standard provides a model for addressing these kinds of life-cycle carbon intensity questions in a way that could be applied to emerging CO2-to-fuel technologies,[17] [18] as well as in a more general sense to other CO_2 use technologies that displace the emissions of other GHG rather than sequester CO_2.

5. Summary

There are many different opportunities for beneficial CO_2 use that could serve the dual purpose of reducing GHG emissions and providing some additional public benefit including, but not limited to, useful new or improved products, new jobs and industries, increased energy independence and security, reduced water consumption, replacement of toxic chemicals, or displacement of imported fuels, chemicals or minerals by locally abundant CO_2 feedstock or chemical products or fuels derived from CO_2.

Some types of beneficial CO_2 use such as the enhanced recovery of natural gas, geothermal heat, minerals, or underground water involve the geological sequestration of CO_2, and hence might be able to be treated with similar policies as CCS/EOR, although each type of technology would likely have its own unique set of requirements.

Other uses of CO_2 do not involve geological sequestration, and the policy priorities connected to these technologies will likely differ significantly from those associated geological sequestration. Addressing their unique policy priorities could help some of these other promising technologies advance towards commercialization, and help California meet its greenhouse gas reduction goals.

[17] http://www.arb.ca.gov/fuels/lcfs/lcfs.htm

[18] http://www.energy.ca.gov/low_carbon_fuel_standard/