Petroleum Technology Transfer Council

Carbon Capture and Storage in the Permian Basin, a Regional Technology Transfer and Training Program

Final Report

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DISCLAIMER:

ABSTRACT

The Permian Basin Carbon Capture, Utilization and Storage (CCUS) Training Center was one of seven regional centers formed in 2009 under the American Recovery and Reinvestment Act of 2009 and managed by the Department of Energy. Based in the Permian Basin, it is focused on the utilization of CO_2 Enhanced Oil Recovery (EOR) projects for the long term storage of CO_2 while producing a domestic oil and revenue stream. It delivers training to students, oil and gas professionals, regulators, environmental and academia through a robust web site, newsletter, tech alerts, webinars, self-paced online courses, one day workshops, and two day high level forums. While course material prominently features all aspects of the capture, transportation and EOR utilization of CO_2, the audience focus is represented by its high level forums where selected graduate students with an interest in CCUS interact with Industry experts and in-house workshops for the regulatory community.

Table of Contents

List of Tables

Appendices

Executive Summary

Co-PIs: Lead Co-PI, Dr. William Lawson, Petroleum Technology Transfer Council (PTTC)
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The primary objective of the Permian Basin CCUS Center is for a Team having world class technology transfer, training and Carbon Capture, Utilization and Storage (CCUS) expertise to develop training materials appropriate for the current and prospective future work force in the Permian Basin, delivering them efficiently through established technology transfer networks, employing a variety of tools. The thrust of the program is outlining the CCS/CO_2 Enhanced Oil Recovery (EOR) opportunities, a thrust entirely consistent with the Permian Basin since it leads the world in CO_2 EOR projects and production. The ultimate goal is to create a CCUS training program that can continue without federal funding support beyond the end of this training contract.

Individuals from the Petroleum Technology Transfer Council (PTTC), the American Association of Petroleum Geologists (AAPG) and the Applied Petroleum Technology Academy (APTA) comprise the Team functioning as the Permian Basin CCUS Center. Initially envisioned products included:

- Five webinars/e-symposia (each offered twice during the life of the project)
- Five one-day workshops (each offered twice during the life of the project)
- Week-long short course (offered three times during the life of the project)
- CCS e-Certification (online after the first year)
- Research conference (once during the life of the project)

Disappointing industry response to initial webinars/workshops and the current realities of CCUS led the Center to adapt its offerings. Products now are a mix of (1) presentations, workshops, webinars, and an applications-oriented forum and (2) university outreach through on-campus seminars. The Team has requested, and DOE granted, a no-cost extension through September 30, 2013 to provide more time for university outreach and high level forums in March 2012 and June 2013 to yield results. Team members are leveraging their (1) prior experience in CO_2 flooding and CCS and (2) preexisting personal networks for the benefit of the Center. An Industry Advisory Board formed in spring 2010 exists, but their interest and contribution has waned since carbon capture legislation has not materialized.

The refocused effort, while not resulting in a full, self-funded organization was much better received by our expanded audience of graduate students, industry professionals, regulators, environmental scientists and other parties interested in CCUS. This technical success came through

- University Outreach Program. This effort has two facets: (1) visit schools with graduate Petroleum and/or Geology programs as a guest speaker at graduated seminars to give an overview of the CCUS industry. Fifteen presentations were made. (2) Organize several high-level, two-day forums on the business of CO_2 EOR featuring a number of industry experts and providing travel expenses to a similar number of graduate students, most of whom were engaged in CCUS research.
- Focused workshops conducted in conjunction regional professional meetings (SPE, APGA, Texas Alliance) Topics included CCUS Overview, Reservoir Characterization and CO_2 EOR Operations)
- In-house workshops on similar topics conducted for regulatory groups (Texas Railroad Commission, state air regulators)
- Continued web-based communication: e-alert, newsletter, website with general information, webinars

1.0 INITIAL STATEMENT OF WORK

The initial Statement of Work, which translated into Project Technical Milestones and DOE Project Management Milestones – Tables 1 and 2, included:

- Form Advisory Board and develop sponsorship program and marketing strategy
- Develop website, issue initial newsletter and email tech alert and plan technical content/location/scheduling of training
- Complete 1st session of extended-length short course
- Complete Certificate program and maintain availability online
- Conduct two webinars and topical workshops and issue two newsletters and tech alerts in the first year
- Conduct mini-Hedberg Research Conference
- Conduct four webinars and topical workshops, one extended-length short course and issue four newsletters and e-alerts in each of the following two years

2.0 MODIFIED STATEMENT OF WORK AND RATIONALE

Beginning in October, 2009, team members from the three collaborating organizations (PTTC, AAPG, and APTA) began planning the structure, calendar and organization for the Permian Basin CCUS Training Center. Initial progress was slower than planned as several key individuals needed to clear their calendar to accommodate the time required to develop the products planned.

Advisory Board, Sponsors, Marketing
In looking at each element of the original Statement of Work, the first, to form an Advisory Board, Sponsorship Program, and Marketing Strategy was completed on time, but with mixed success. The team was able to attract twelve experienced individuals from a diverse industry including several CO_2 EOR producing companies, service company, engineering, gas processing, power generation and academia. The initial meeting was held in Midland, Texas on March 15th where the team presented the outline of products and proposed schedule. Subsequent meetings were called as needed in the form of conference calls. Unfortunately, as the CCS Training effort in the U.S. began to lose momentum due to proliferation of products and organizations and lack of incentive due to failure to enact climate control legislation, interest and participation by individual board members waned.

Likewise, for the reasons cited above, a formal and robust sponsorship program never took hold. Without affiliation with a Regional Sequestration Partner with existing members and any real name or track record, getting money from industry was difficult. The team was successful in getting industry sponsors to subsidize the travel expenses for graduate students attending the very successful Annual Forums held in Golden, Colorado and Lubbock, Texas.

To market the program, several steps were taken: (1) a calendar of course offerings, including abstracts was developed, (2) information disseminated on the website and via electron tech alert and newsletter, and (3) as a specific time and place was announced the mailing lists of the three collaborating organizations were utilized.

2.1 Website, Newsletter, Tech Alert

Early on in the project, the website www.permianbasinccs.org was designed, constructed and populated. It has been repeatedly updated over the 4 year span to be current in the news, calendar, posted newsletters, tech alerts, webinars and other relevant information. While this has been a useful tool for anyone involved in CCUS, the number of hits on the site has been disappointing and an indicator of people trying to reduce, or at least control, the information hitting their computer screen. Newsletters and Tech Alerts were produced and distributed electronically. Individuals receiving it numbered in the low hundreds as the list was developed from people who signed up, not unsolicited.

2.2 Topical (one day) workshops, extended length workshop, webinars

The original plan was to have four one day topical workshops, with a webinar promoting each, and one extended length workshop, essentially comprised of the aggregate information from the four one day workshops. The course material was developed for the first three of the four planned one day workshops (Introduction to CCUS, Reservoir Characterization, CO_2 EOR Operations, and the Business of CO_2 EOR) and the first of four planned webinars was recorded. When it came to executing the planned workshops, the response to the extensive promotional efforts was nearly non-existent and the scheduled standalone one day workshops, as well as the extended workshop were cancelled.

2.3 E-certificate Program

This program involved the creation of a self-paced course on all aspects of CCUS with AAPG awarding a certificate for successful completion. A team member would function as an instructor, answering questions and reviewing answer to session question. It was developed in four segments intended in sum to be equivalent to a 3 hour graduate course and went online in May, 2011 six months behind schedule. The team considerably over-estimated the demand for this very time consuming product. In retrospect, without the climate control legislation there was little demand for the certificate and the program itself was quite daunting in terms of time required and pricey at $200 each for the 4 modules. A relatively small number of students started it, and none finished providing too little tuition revenue to maintain the links and information. The program was discontinued in early 2013.

On the other hand, several free course-war programs on AAPG's website, was not only free but fairly easy to cover the material and placed on a much higher volume website.

2.4 Conduct mini-Hedberg Research Conference

The series of Hedberg Research Conferences is an annual event offered by AAPG which is a high level group of research scientists and engineers discussing their work on varying leading edge topics. This was originally scheduled to be accomplished once over the life of the contract. It was initially deferred in the period of redefining tasks, then reborn as the very successful Forums (discussed below) held twice and made part of the University Outreach Program.

Recapping early project experience, the Team efforts to draw attendees to scheduled September 2010 workshops were unsuccessful. All were canceled due to "very low" preregistration. The Team, with input from the Advisory Board during a late September 2010 conference call, determined that:

- Industry-wide, there was a substantial reduction in CCS interest and sense of immediate need when no Climate Change bills were passed and the likelihood of any passing any time soon were remote.
- Attending a stand-alone course, priced to compete with SPE and industry offerings and requiring travel was too expensive and time consuming for many individuals/companies.
- Focusing on O&G industry personnel "only" and in a relatively small geographic area (i.e., the Permian Basin and just Texas) substantially limited the potential audience. Future Permian Basin CCUS workers could come from anywhere, making it reasonable for the project to look beyond regional boundaries.
- There was competition from a number of groups in and beyond the Permian Basin offering courses in EOR and CCS.

Since then, the Permian Basin CCUS Training Center has found (technical) success in other ways:

- Workshops put on in conjunction with regional and national technical societies. A number of workshops were well attended that were add-ons to SPE, AAPG and Texas Energy Alliance meetings.
- One day workshops developed and specifically tailored as in-house courses primarily for the regulatory community. Several have been held for the Texas Railroad Commission and the June, 2013 conference held for the North America 2050 association of state clean air regulators and recently for the Young Professional Group of the Permian Basin section of the SPE.

- The University Outreach Program, in which several team members travel to universities with Graduate Seminars in Petroleum Engineering and Geology to provide a broad overview on industry carbon capture, utilization and storage. Fifteen such presentations have been made over the last two years, and
- Organize high level forums such as been held in Golden, Colorado in April 2012 and Odessa, Texas in March, 2013 in which sponsors fund graduate students to participate at little or no cost in a forum in which they share their work with posters, hear prominent industry speakers on CCUS topics and interact with the industry attendees for the mutual benefit of all. Over 30 graduate students and a similar number of industry professionals attended each event. The feedback from all attendees at these events has been overwhelmingly positive.

Table 1 – Project Technical Milestones

MS #	Milestone Description	Latest Date
1	Form Advisory Board and develop sponsorship program and marketing strategy	3/15/10 **3/15/10**
2	Develop website, issue initial newsletter & email tech alert, and plan technical content/location/scheduling of training	5/15/10 **5/19/10**
3	Complete 1st session of extended-length short course	11/15/10 **On hold until demand solidifies**
4	Complete certificate program and maintain availability online	11/15/10 **Late (actual 5/17/11)**
5	Conduct two webinars & topical workshops and issue two newsletters & tech alerts in first year	11/15/10 **Workshops were delayed as program redefined**
6	Conduct mini-Hedberg Research Conference	5/31/11 **"Putting the Business Elements Together for CO_2 EOR Using Captured Carbon," forum held April 4-5, 2012 in Golden, CO** **Forum on CO_2 EOR Operations held 3/25 – 3/26/13 in Odessa, TX**
7	Conduct four webinars & topical workshops, one extended-length short course and issue four newsletters & e-alerts in second year	11/15/11 **<u>FY11 results</u>** **10 – Workshops/ presentations/poster sessions** **3 – Newsletters/e-alerts** **1 – Webinar** **1 – Exhibit** **2 – Open Courseware modules** **<u>FY12 Results</u>** **7 – Workshops/short courses/forum** **15 – Presentations** **4 – Exhibits** **5 – Webinars** **5 – Conference attendances** **4 – Newsletters/e-alerts** **<u>FY13 Results</u>** **4– Workshops/short courses/forum** **2 – Conferences held** **3 – Conference attendances** **3 – Newsletters/e-alerts** **3 – Animated Videos** **4 – Web interviews**

8	Conduct four webinars & topical workshops, one extended-length short course and issue four newsletters & e-alerts in third year	11/15/12 AND 11/15/13 **1st Qtr. FY12 Results** **1 – Conference attendance w poster session** **2 – Workshops/mini-sessions** **3 – Presentations** **1 – Webinar** **3 – Exhibits** **2nd Qtr. FY12 Results** **2 – Presentations** **1 – Conference attendance** **1 – Webinar (scheduled, cancelled)** **7 – University Outreach presentation** **3rd Qtr. FY12 Results** **1 – Forum** **1 – Exhibit** **1 – University outreach presentation** **1 – Workshop (Texas RRC)** **4th Qtr. FY12 Results** **1 – Conference attendance** **1 – Conference attendance/poster** **4 – Recorded webinars** **3 – Workshops/short courses (shared w PTTC's main DOE contract)** **1 – ROZ Core Workshop** **2 – Presentations** **1st Qtr. FY13 Results** **4 – Conference attendance/participate** **3 – Workshops/short courses (shared with PTTC's main contract)** **1 – Presentation** **2nd Qtr. FY13 Results** **1 – Forum** **3nd Qtr. FY13 Results** **1 – Conference and Field Trip** **4th Qtr. FY13 Results** **3 – Animated Videos** **4 – Recorded Interviews** **1 – Workshops/short courses**
9	Complete final Advisory Board Strategic Planning	**September 30, 2013**

Table 2 – DOE Project Management Milestones

MS #	Milestone Description	Latest Date
1	Participate in Project Kick-off Meeting	3/15/10 **Nov 2009**
2	Initial tech training plan completed and submitted	6/30/10 **MS #2 Report Submitted 5/19/10**
3	Conduct initial training event	9/30/10 **Web #1 – 8/18/10** **Web #2 – 9/1/10** **3 planned workshops postponed** **IOGCC L&L – 11/15/10**

		TX RRC workshop – 3/1/11 **AAPG Short course – 4/9/11** **SWPSC presentation – 4/20-21/11** **AAPG SW poster – 6/5-7/11** **Texas RRC workshop – 6/15/11** **Texas Alliance Corpus Christi – 7/14/11** **AAPG ES short course – 9/25/11** **Hill Subcommittee briefings – 9/26/11** **West TX Geological Society poster – 9/28-30/11** **South Dakota M&T Presentation – 10/7/11** **Permian Basin Petr. Assn. Presentation 10/13/11** **Webinar No. 4 10/20/11** **Texas Alliance Houston Presentation 11/8/11** **IPEC – Presentation 11/9/11** **Texas Railroad Commission Workshop 11/10/11** **University Outreach (Univ. of Kansas) 1/19/12** **University Outreach (CSM) 1/24/12** **University Outreach (SDSM&T) 1/31/12** **SPE Midcontinent Presentation 2/16/12** **University Outreach (LSU) 2/17/12** **University Outreach (OSU) 2/22/12** **AAPG GTW, New Directions Carbonate 2/29/12** **University Outreach (Univ. of Utah) 3/6/12** **University Outreach (MS&T) 3/12/12** **Forum in Golden, CO 4/5-6/12** **University Outreach (UT Austin) 4/30/12** **Texas Railroad Commission Workshop 5/9/12** **Webinar e-cert Module 1 7/10/12** **Webinar e-cert Module 2 7/25/12** **MORE 2012 Workshop 8/8/12** **Webinar e-cert Module 3 8/28/12** **EOR in the East Short Course 9/22/12** **Induced Seismicity Short Course 9/22/12** **Webinar e-cert Module 4 9/27/12** **ROZ Core Workshop 9/28/12** **Carbon Capture & EOR in the East Short course 10/3/12** **University Outreach (U of Tulsa) 10/11/12** **MORE 2012 Workshop 10/31/12** **MORE 2012 Workshop 11/14/12** **Forum in Odessa, Texas 3/25 – 26/13** **Conference and Field Trip, Houston 6/11 – 6/12** **Workshop, Midland 9/18/13**
4	Semi-annual progress report submitted	9/30/10 **(3rd Qtr. FY10 July 2010)** **(3rd Qtr. FY11 July 2011)** **(3rd Qtr. FY12 July 2012)** **(3rd Qtr. FY13 July 2013)**
5	Updated Tech Training Plan Completed & Submitted	12/31/10 **MS #5 Report submitted 12/31/10**
6	Trainers visit one field site	12/31/10 **MS #6 Report submitted 12/31/10**
7	Yearly review meeting	3/31/11

		• **Lance Cole attended/presented at DOE review in Pittsburgh (October 2010)** • **Bill Lawson & Dwight Rychel attended/presented in 2011** • **Dwight Rychel attended August 2012 project review meeting and staffed poster session**

3.0 PROJECT ACCOMPLISHMENTS

For the reasons cited above, the program conducted over its four year life is quite a bit different than what was originally approved. The nature of the offerings, audience and the many competing CCUS training programs caused a change in direction which proved to be technically successful, but not at a financial level to sustain the contract level of activity. For example, our most successful programs, the University outreach, including the forums for graduate students and five in-house workshops for regulators, had virtually no revenue potential, but garnered high praise from those groups. Likewise, the well-attended short courses that were given in conjunction with Technical Society meetings, at best generated revenues that only covered the speaker travel expenses. All of the activities and accomplishments over the contract period are listed in Tables 1 and 2 above. To summarize:

- The project website www.permianbasinccs.org is content rich, with news, calendars, references, historical newsletters and tech alerts and more, including access to the free course-ware, 8 recorded topical webinars by the team and other industry experts.
- The tech alerts and Newsletter "Catch and Store" were all delivered according to schedule, and were well received whether delivered on-line or in print form at the many exhibits the team participated in.
- By far, the biggest accomplishment was the University Outreach Program. In over a dozen presentations at graduate seminars and student chapters of SPE and AAPG, hundreds of promising graduate students were introduced to Carbon Capture, Utilization (with EOR) and Storage. Then, many of these same students attended, learned and presented posters at the very successful Forums held in 2012 and 2013 in Golden, Colorado and Lubbock, Texas. The goal was to subsidize the travel expenses of 25 – 30 graduate students with an interest in CCUS and bring in a similar number of high level industry experts to present various aspects of the CCUS industry. The interaction was rewarding for both groups, providing mentors to students and potential employees to industry.
- Another significant accomplishment was the series of in-house workshops on CCUS overview and Reservoir Characterization given to the regulatory community – four to the Texas Railroad Commission in Midland and Austin, and one to a group of state clean air regulators in Houston with a field trip to Air Products Port Arthur facility producing Hydrogen for the refinery and CO_2 for EOR. This series averaged 50 attendees.
- The numerous presentations to Technical Societies and workshops conducted in conjunction with a regional or annual meeting were certainly was consistent with the overall goal to provide CCUS training for the future workforce; they did not contribute to the other overall goal to achieve self-sufficiency.

4.0 CONCLUSIONS AND RECOMMENDATIONS

A number of conclusions can be drawn about the project and the circumstances in which it operated:

1. The world view of Climate Change, Greenhouse Gas and how to reduce it in general and with CCS in particular have changed substantially today versus 2009. In 2009 there was the promise of adhering to the principles of the Kyota Accord and expanding it to the undeveloped countries, billions of research dollars pledged to CCS technology, the promise of the monetization of carbon, similar to that of sulfur and oxides and plans to march toward a world with hundreds of capture projects in the U.S. and worldwide. Enter the recession, abandonment of climate control legislation, and the reality of the huge costs associated with full

scale capture projects, particularly with coal powered generation, resulting in a much reduced vision of the need for a workforce skilled in the many aspects of CCS.

2. While some aspects of CCS are unique to a region (e.g. CO_2 EOR in the Permian Basin), most are not. Furthermore, the primary delivery medium for CCS training materials is over the internet. Given those facts, it is no surprise that there was a large overlap in the product offerings between and among the seven CCS training centers. It would be just as easy to send a newsletter to the lists maintained by all seven centers as just one. The same applied to online courses, webinars, general news, calendars and most other plan elements produced by the seven centers. Consequently, the same training materials were created seven times and the training centers ended up competing for the same shrinking potential audience, leaving each insufficient student to be economically viable.

3. The ideal student for the specialized training for the CCS industry is a graduate student or one just out of school are the least able to afford to pay for such training. The same can generally be said for state regulators and environmental oriented NGOs. So the individuals with the greatest interest and those most likely to benefit are the least able to pay for it, leaving the training center needing another entity to fund it. The surviving CCS training centers would appear to be those that are a part of a much larger entity such as one of the Regional Sequestration Partnerships or university.

Several recommendations become evident from the above conclusions:

1. Longer term funding (such as that for PTTC and Stripper Well Consortium) for substantially fewer than seven, probably just one, training centers would be more effective.

2. The training focus should be on distance learning (internet based). Face to face training should be limited to in-house workshops, tailored to the hosting entity and workshops in association with the larger technical meetings. No standalone course offerings.

While the Permian Basin CCUS training center did not find a mix of products that made it financially viable at the level of activity demonstrated in the 4 year contract, it is not going to cease to exist. The web site has been recently expanded and upgraded and will be maintained for at least another two years. All the intellectual property intact and it is expected that there will be opportunities to continue training that will pay for itself in the form of workshops, both associated with technical societies and in-house industry and non-profit organizations as well as opportunities to collaborate with other organizations for special studies and advanced research.

5.0 COST STATUS

(ATTACHED TO FINAL REPORT SUBMITTED TO DOE-NETL)

(Cost plan & status is accessible upon request to PTTC)

APPENDIX A TOPICAL REPORT "INTERNATIONAL CCUS DEVELOPMENTS"

Petroleum Technology Transfer Council

DOE Award No.: DE-FE0002060

Topical Report
September 30, 2013

International CCUS Developments

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ABSTRACT

It is well documented that the global temperature of the earth, including the oceans has been rising for several decades beyond its normal cycles. Since 1978, the University of Houston has documented increased temperatures in the lower troposphere increasing by 0.14 ° C/decade. It is also well documented that the amount of Greenhouse Gases (GHG), in particular Carbon Dioxide, in the air has risen from 250 in 1900 to over 380 ppm recently. Increasingly, scientists have linked these two phenomena. A number of international agencies and research facilities have forecast the progression of both, lacking action and began working on strategies to slow and even reverse the level of GHG entering the atmosphere. The plans include replacing carbon fueled electric capacity with renewables and nuclear, switching to lower carbon fuels, greater efficiencies of cars and stationary sources and the capture and long term storage of CO_2 (Sequestration). These plans were quantified through the Kyota Protocol and a number of subsequent meetings. In the last decade much research and demonstration projects have been conducted world-wide to prove capture technologies and drive the cost of those down. Different countries have different emission targets and varying levels of efforts to meet those targets. However in recent years, plans have been scaled back due to a variety of factors, but not the least the persistent high cost of capture and worldwide recession. The question is what is needed to get back on track?

Table of Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

Global temperatures have been measured very accurately since thermometers were invented in 1850 and less accurately with sediment cores as far back as 5 million years. Changes in global temperatures can have a profound change to the climate. A one to two degree (Celsius) drop brought about the most recent small ice age from 1350 to 1850. Since 1850, the earth's temperature has risen 0.8 ° C, 0.54 ° C since 1978. Virtually all of the scientific community point to the increase in atmospheric Greenhouse Gases (GHG), primarily carbon dioxide, as the principal cause of the rise in temperatures. Since 1900 the concentration of CO_2 has risen from 250 ppm to 400 ppm, and is driving the increase in ocean temperature and melting of ice caps. Various scientific groups have forecast future effects and mitigating strategies to slow down the increase and level out before it exceeds 2 degrees. One of the mitigating strategies is the capture and permanent storage of the CO_2, coming primarily from coal fired electrical generations.

In recognition of the need for dramatic global action on a number of fronts to diminish and even reverse the growth of carbon emissions; in 1994 the UN convened the UN Framework Convention on Climate change in Kyota, Japan with 192 participating countries. The goal was a plan to hold the increase at no more than 1 ½ ° C by 2050. By 1997 the Protocol was approved to put mandatory caps in place (different for each country) for the initial period 2008 – 2012. For the first round, developing countries such as China and India had no limits. The U.S. never signed it and Canada withdrew, so the limits were only in place for Europe and Australia. Subsequent conventions were convened to expand the Protocol with great fanfare and little progress. The second period, with expanded coverage was to have begun in 2013, but to date only three countries have approved it.

An integral part of carbon control is the concept of registries and exchanges. These entities would document the quantities emitted (or not emitted), and create a marketplace where emissions could be traded (e.g. shut down a plant in one place and use the credits to build a new one elsewhere), bought, or sold. If the issuing agency then reduces the number of credits issued over time, it is the traditional cap and trade concept. Two versions of cap and trade were introduced in the U.S. House and Senate in 2010, however neither made it to the floor and there is no likelihood they will be reintroduced in the foreseeable future. There are a couple of voluntary registries in North America, but they do not monetize the carbon savings. The European Union was initially successful, but with over supply and reduced interest, prices have declined from 25 to 5 Euros/tonne from 2008 to 2013. California instituted their own system this year, but it is too early to tell how effective it will be.

One of the biggest impediments to the development and widespread application of CCS is the cost of the capture, both the capital and the operating expenses. Over 100 different capture technologies are in various stages of test and demonstration, none of them have yet overcome the issues of cost, parasitic load, and scale-up issues. Some industrial plants, such as ethanol, ethylene, hydrogen and fertilizer have byproduct CO_2 streams that require little more than cleanup and compression and are economic sources of CO_2 for EOR. Unfortunately, the volumes are relatively small and they are scattered geographically. The largest sources are coal fired power plants and to a lesser degree, natural gas fired power plants, cement plants and steel mills. Most of the capture technologies fall in a few categories: Pre and Post-combustion sorbents where a solvent is used to separate the CO_2 from the syngas produced from a gasifier for pre-combustion or from the post combustion stream for post combustion. It can be utilized on new plants (pre-combustion) or retrofit on existing plants; Pre and Post-combustion sorbents, where the CO_2 is separated with a solid substance that absorbs the gas or liquid on its surface or pores; Oxy-combustion, where the solid carbon fuel is combusted in oxygen instead of air, so there is no nitrogen to separate and Chemical Looping, similar to Oxy-Combustion but utilizing a metal oxide as the oxidizer; and membranes. All have advantages and disadvantages, but none achieve the goal of producing power at no more than a 30% increase in the cost of power.

Under the IEA GHG plan for holding the temperature increase to the 1 ½ - 2 degree level, CCS is forecast to accomplish 14% of the reduction (others include renewable, efficient cars, efficient industry, conservation). But that will take over 100 full scale multi-billion dollar plants. With the signing of the Kyota Protocol there was a flurry of CCS activity in the U.S., Canada and Europe. Recently that has diminished. The recent Global CCS Institute 2013 report shows 3 new announced projects (in China, Brazil and Saudi Arabia) and 10 cancellations (U.S. and Europe). Virtually all 29 projects cancelled in the last 5 years had plans to inject in saline aquifers. Those targeting EOR as a storage reservoir are still viable. Reasons for the diminished interest include rising costs, already unacceptably high in the face of a global recession, and no replacement for the first Annex of the Kyota Protocol that would require some action by all countries.

1.0 THE PROBLEM

Global Temperatures

The detailed temperature of the lower troposphere has been accurately measured since 1850 with the availability of accurate thermometer instruments, and since 1978 with satellites (see Figure 1 Below). For the 2,000 years prior to 1850, tree rings and ice cores have been used as proxies. For older periods – up to 10,000 years and beyond at some sites, paleoclimatology techniques are used. Sediment cores have been used to estimate temperatures back as much as 5 million years.

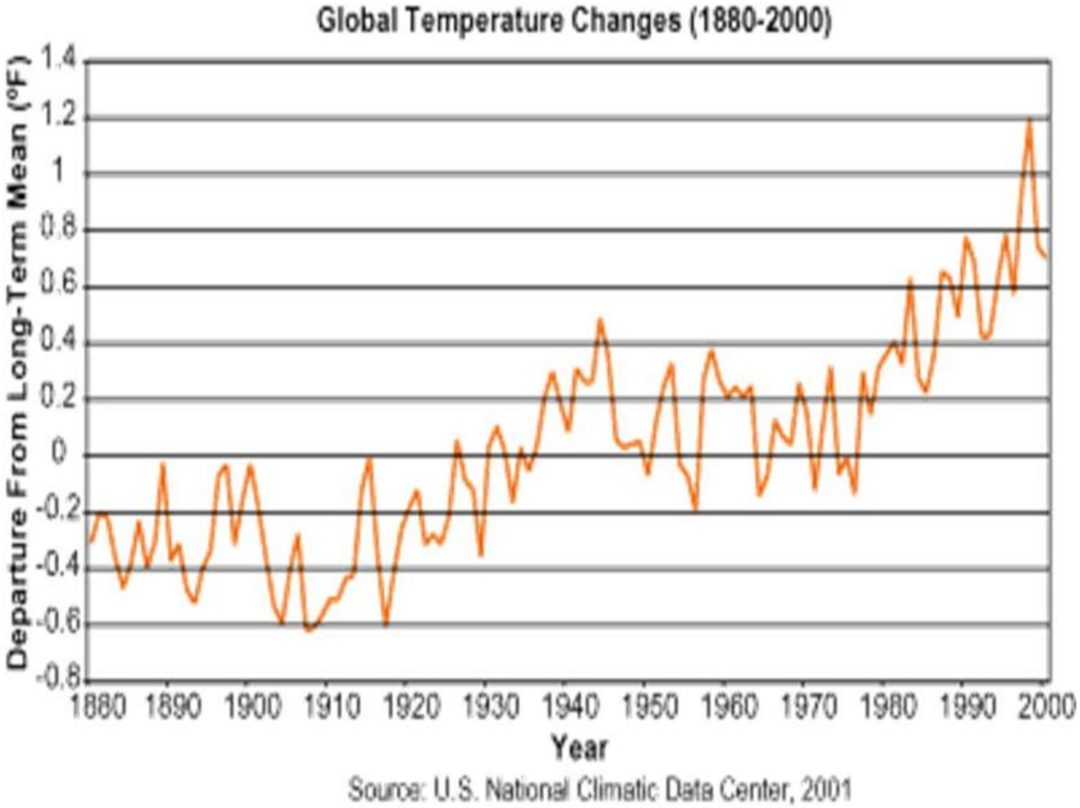


Figure 1 – Global Temperature 1880 to 2010

With these tools, much is known about the temperature of earth over time. The more recent measurements are known with a high degree of certainty. The scientists at the EPA's Goddard Institute for Space Studies have shown the global temperature has increased 0.8 ° C (1.4 ° F) since 1850 and 0.54 ° C since 1978, or about 0.14 ° C per decade. While this may seem like a subtle change relative to those seen in geologic time or even day to day, the effects can be significant. According to the NASA Earth Observatory, a one to two degree drop was enough to bring about the Little Ice Age (from around 1350 to 1850) and a 5 degree drop resulted in most of North America being covered by a massive ice thickness (2 to 3 million years ago).

On the other hand, the recent rise has had noticeable effect on the ocean temperature, ice caps and weather. The U.S. Environmental Protection Agency (EPA), working with a number of other agencies, has identified and quantified 26 Climate Change Indicators (see www.epa.gov/climatechange/science/indicators/#learn more) grouped in the categories of Greenhouse Gases, Weather and Climate, Oceans, Snow and Ice, and Society and Ecosystems. While controversial two decades ago, there is now total agreement among qualified scientists and environmental agencies that the recent increase in global temperatures is the result of increasing levels of Greenhouse gases in the atmosphere and to a lesser extent variation in the sun's energy reaching earth. The effects of the increased levels of GHG include increasing global temperatures, changes in precipitation patters, increasing sea levels, increased storm events and increasing ocean acidification. Based on atmospheric models and forecasts by the International Energy Agency (IEA GHG), that if unabated, rising levels of GHG could raise the global temperature as much as 4 ° C with disastrous results.

GHG Emissions and Levels in the Atmosphere

There are several types of GHG with different reflective properties and different concentrations in the atmosphere (See Figure 2 below). Carbon Dioxide (CO_2) is present in much greater concentrations than the others.

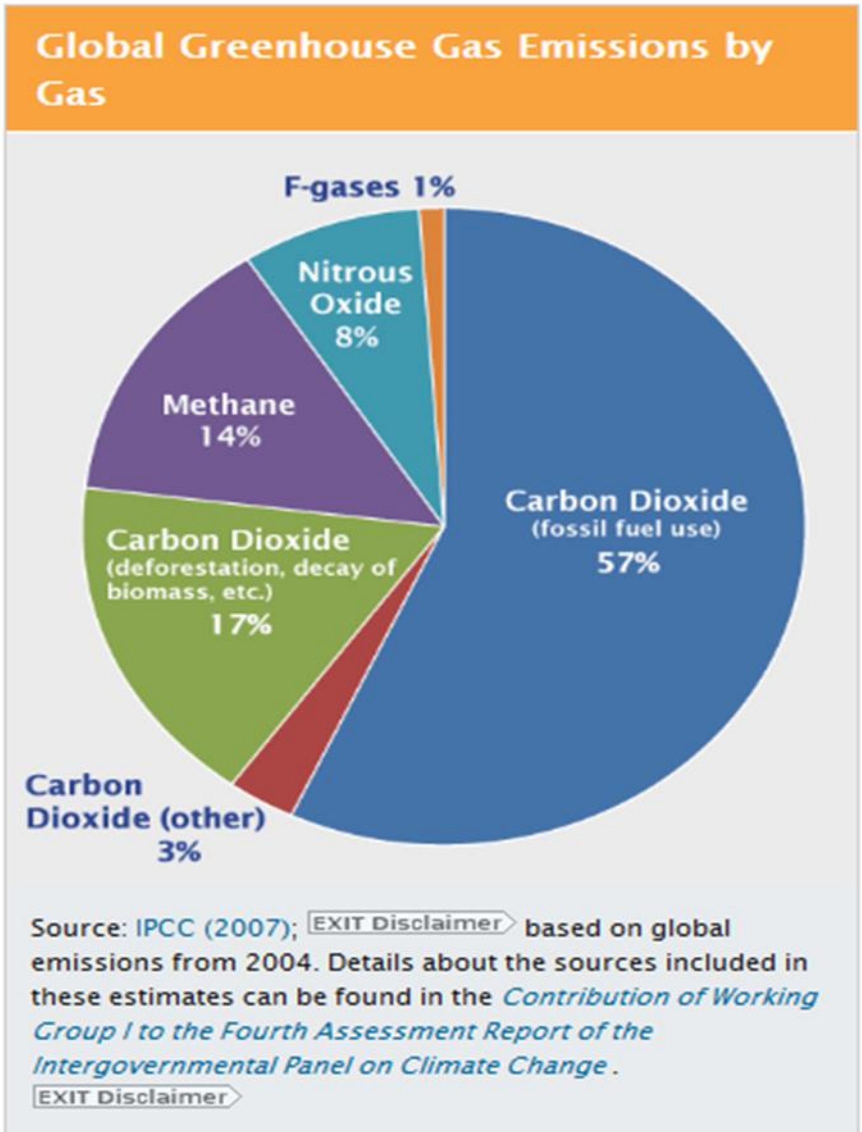


Figure 2 – Greenhouse Gas by Gas

CO_2 emissions caused by man are mostly from combustion of carbon based fuel, both stationary and mobile. Other manmade CO_2 emissions include deforestation and other land changes. Methane, while not as concentrated, has a greater effect on reflectivity. It enters the atmosphere through animals, coal and oil well emissions and waste management. Nitrous Oxide enters the atmosphere primarily from the use of fertilizer. Fluorinated gases come from refrigeration and industrial processes. CO_2 in the atmosphere is measured in parts per million versus parts per billion for the others so receives the most attention.

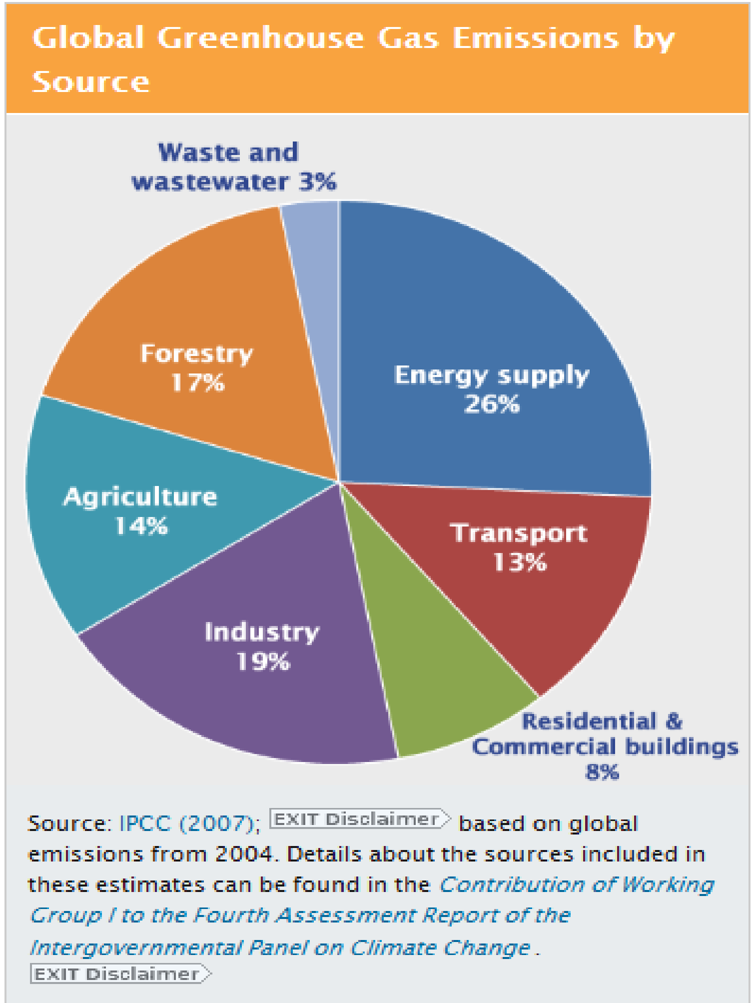


Figure 3 – Greenhouse Gas Emissions by Source

As shown in Figure 4 below, beginning around the turn of the century, or soon after the beginning of the industrial age, anthropogenic (manmade) worldwide CO_2 emissions grow from essentially zero to over 7,000 million metric tonnes in 2000 (and measures over 9,000 million today). Over the same period, the atmospheric concentration rises from a fairly constant 280 thousand ppm to nearly 400 thousand today. Just as interesting is where the emissions are coming from. Figure 5 shows 2008 global CO_2 emissions, by country.

China is, not surprisingly, the largest. They are also the fastest growing, along with India. The U.S. is the second largest, but is actually decreasing in recent years. None of these three, along with a sizeable piece of "Other" signed the Kyota Accords, which will be covered later, but designed to compel nations to cut CO_2 emissions.

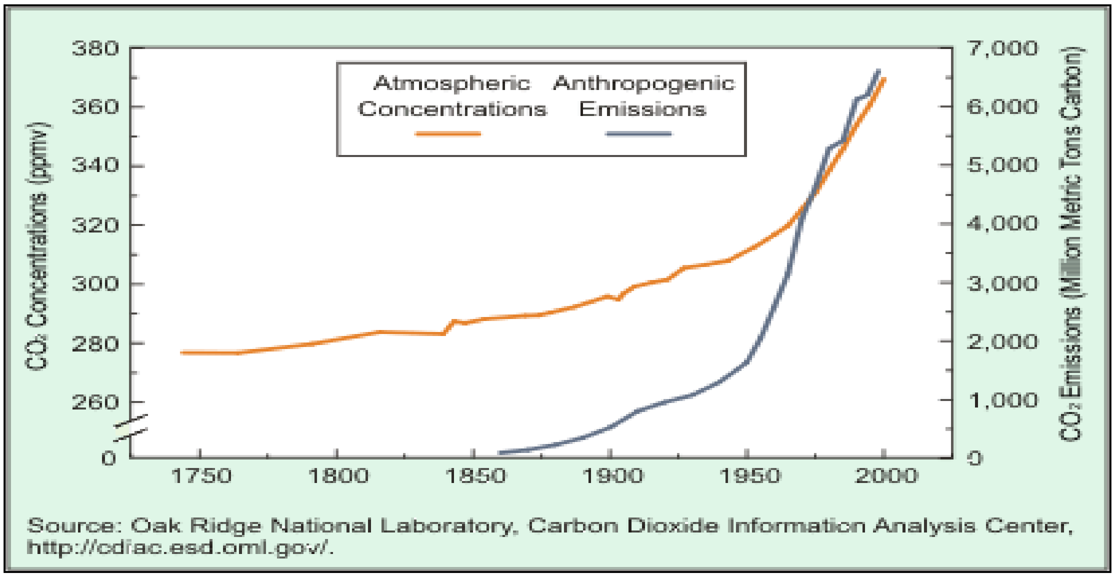


Figure 4 – World-wide Emissions and Atmospheric concentrations

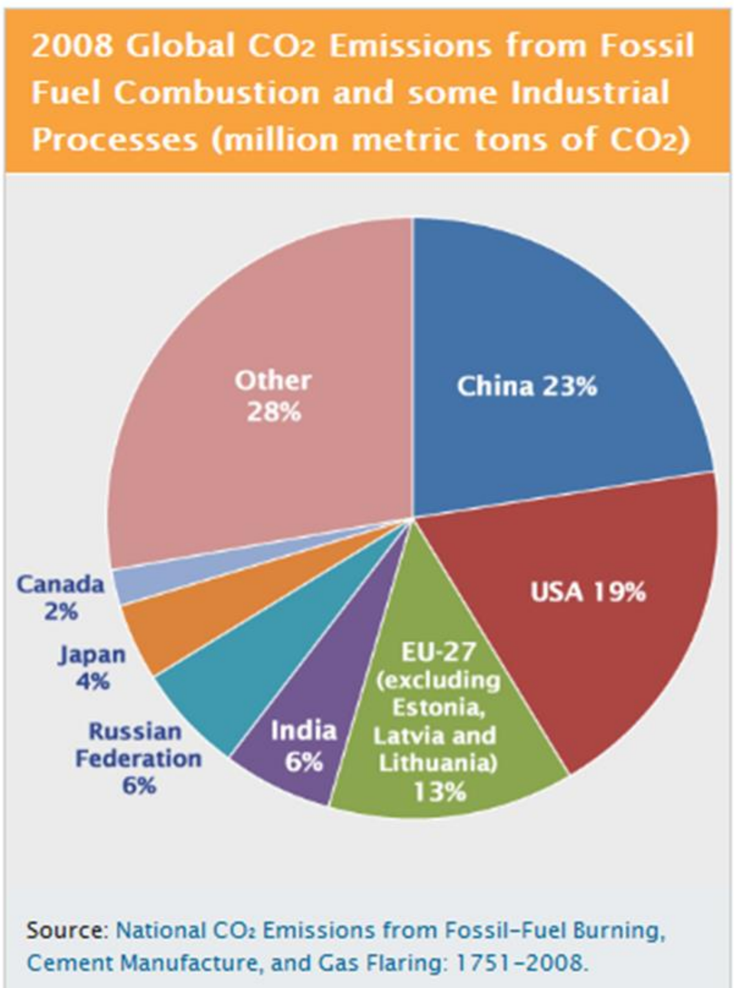


Figure 5 – Global CO_2 Emissions by Country

2.0 THE PROMISE OF KYOTO

In response to the growing recognition of global warming caused by GHG emissions, the United Nations convened the UN Framework Convention on Climate Change in Kyoto, Japan in 1994. It was comprised of 192 countries, including all but a handful of the UN members. Its goal was to come up with a global plan to reduce GHG emissions so that the global temperature was held at 1 ½ ° C over what it was at the beginning of the industrial period. It was tasked with balancing the diverse views of the members and balancing the need to reduce GHG while recognizing economic realities. By 1995, the convention recognized the need for assigning enforceable targets for each country with flexibility on how those targets could be met. In February, 1997 the text of the Kyoto Protocol was unanimously approved.

A key principle of the Protocol was the recognition that the developed nations (e.g. Europe and the U.S) were responsible for most of the GHG presently in the air and was responsible for steps to reduce that level. On the other hand, developing countries would be allowed to increase their emissions in recognition of their future economic growth. Every country had a different target ranging on reductions ranging from -8% in Europe and -7% in the U.S. to increases as high as 25 - 27% in Greece and Portugal. Another feature of the Protocol was flexibility on how to meet the binding targets that included trading carbon credits among countries, reforestation, and credit for capture projects in other countries. The Annex 1 period entered into for February, 2005 for the period 2008 - 2012. While the U.S. signed the original agreement, it was never ratified. Canada renounced their participation in 2011. Ultimately, it only became binding on the European countries (including Russia) and Australia.

The Convention has a supreme decision-making group, the Conference of Parties (COP) that has met nearly every year since 1995 to review and modify goals set in the Protocol. Recent meetings (COP18 in Copenhagen, Denmark in 2009, Cancun in 2010, and Durban, South Africa in 2011) all began with the promise to extend and expand the Protocol but did not lead up to the promise.

At the Durban meeting the 194 parties to the UN Framework Convention on Climate Control agreed to the “Durban Platform.” It brings all countries – developed, developing and under developed – to be covered under the same legal regime by 2020. The new legal agreement is to be negotiated by the end of 2015 and will start to be implemented from 2020 after it has been approved by an adequate number of countries. It also calls for implementing the Cancun (non-binding) agreement under which the major countries pledge to take actions to reduce their emissions, set up a Green Climate Fund which has a goal to raise $100 billion from private and public entities and work to disseminate green technologies to the under developed countries. It also calls for implementing the second period of the Kyota accord.

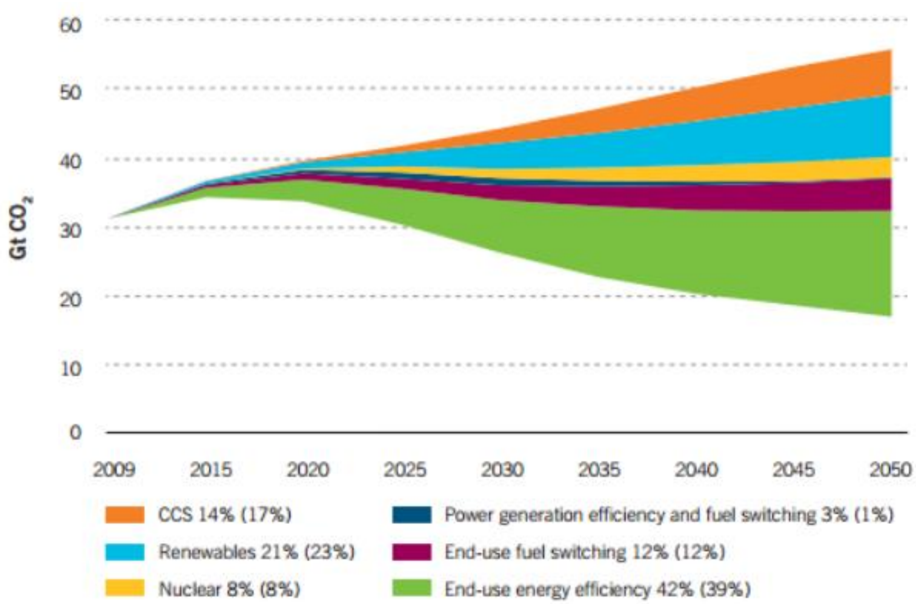
However, after Kyota, Copenhagen, and Cancun the world’s carbon emissions continued to increase. More commercial scale capture and store projects are being cancelled than built because of the increasing costs and global recession. With the withdrawal of Canada and the fact that it would only cover 15% of the world’s emissions, the second Kyota period is not likely to happen. The Cancun agreement was non-binding. The Durban platform calling for a legally binding document by 2015 is simply an agreement to negotiate and the $100 billion is a goal, not an obligation. Finally, the trillions of dollars per year potentially spent to meet the stated goals only addresses a part of the 3 ½ percent of the total carbon emission due to human activity.

Harvard scholar Daniel Bodansky concluded in 2011 “The problem is that relatively few states, representing only about a quarter of the world’s emissions, have been willing to assume emission targets under Kyoto. And even some of these seem unwilling to continue down the same path, certainly not if others do not join the effort as well. The future of the Protocol seems doubtful at best.” In 2012, the Protocol was amended in Doha for the period 2012 – 2020. To date only three countries have approved it.

3.0 CARBON EXCHANGES, MARKETS AND CREDITS

In order to meet the carbon reduction goals set in the Kyota Protocol and other agreements, it was contemplated that a number of technologies and actions would be employed. The U.S. EPA, IEAGHG and other international agencies have periodically published "wedges" as depicted in Figure 6 below to illustrate the planned reductions under different scenarios. In this scenario, CCS is to be 14% of the carbon reductions. It was further assumed that there would be some monetary incentive to encourage the capture and long term storage of carbon. While the Protocol does allow for trading credits among countries to meet their target, it did not set up a global marketplace, so each country (or state considering California) was left to devise their own incentives.

Incentives can be structured in a number of ways, some as carrots to the entity capturing the carbon, some as a stick. In any case, the public ultimately pays. The most common carrot is Cap and Trade. Emissions trading has been successfully used in the U.S. to reduce the NOx and SOx produced by stationary sources (mostly power plants). In a nutshell, credits were issued to current emitters generally by the government (volume constitutes the "cap"), vintage by years, fewer each year. A new plant would require the builder to buy credits to emit from existing credit holders willing to shut down or use technology to reduce emissions. The following reference provides an overview of concept, how the Kyota Protocol has driven global carbon markets, a discussion of active markets outside of the U.S., and overall trends in the carbon market. Outside of the U.S., this is a large and growing market http://en.wikipedia.org/wiki/Emissions_trading. However, it is not in the U.S.as they are not a signatory to the Kyota Protocol and further, failed to pass climate change legislation that would drive reduced emissions with some form of cap and trade. Related to the trading of emission credits is the carbon offset market. Several registries are available to provide standards for verification and certify emission reductions or offsets. They also buy and sell Emission Reduction Tons (ERTs). Two such organizations are the American carbon registry http://www.americancarbonregistry.org/ and the Climate Registry http://www.theclimateregistry.org. This concept may be mandatory in other countries, but is small and voluntary in the U.S., more symbolic than useful. The exception to the lack of trading in the U.S. is the cap and trade program recently begun in California. Under the plan each quarter, the emitter can purchase the right to emit one metric ton of Carbon in a designated year, now through 2016. 2016 contracts sold out at $11.10/tonne (around $0.60mcf).



Source: IEA 2012a. Note: Percentages represent the share of cumulative emissions reductions to 2050. Percentages in brackets represent the share of emissions reductions in the year 2050.

Figure 6 – Planned Emissions Reduction by Technology

The 15 members of the European Union participate in a robust carbon trading system, covering over 40% of the carbon emissions in Europe. It provides a diminishing cap and buying and selling of credits. Early trading in 2008 was robust at 25 Euros/tonne, but it has been in gradual decline since and now sells at below 5 Euros/tonne. Over-supply and diminished interest by the member countries are blamed

As mentioned, the U.S. did not sign the Kyota Protocol and is not bound by it. Efforts to date in the U.S (other than California) have been voluntary and only marginally effective. The 2010 U.S. legislature failed to muster the votes for either climate control bill approved in committee www.grist.org/article/2009-06-03-waxman-markey-bill-breakdown/ and http://daily.sightline.org/daily_score/archive/2010/05/12/kerry-lieberman-climate-bill-the-details. While The two failed climate control bills attempted to accomplish the same goal, there was (and is) disagreement on who would get the initial credits, who would pay, and whether it would be a cap and trade system or cap and tax.

The EPA recently announced proposed rules regulating carbon emissions from power plants and refineries. (This is "the stick"). The proposed rule would require capture and storage on new and upgraded coal fired plants, effectively doubling the cost of power from that plant compared to a natural gas fired plant. The other stick would be to impose a flat tax on carbon emissions.

4.0 CAPTURE TECHNOLOGY OPTIONS – COSTS, PLUSES AND MINUSES

As described in the previous section, the goals for sufficient carbon reduction to stop or even slow down the rise in global temperatures are daunting. And to make it even more difficult, the cost to capture that carbon, compress and transport it, then inject it into a brine, oil or gas saturated geological formation, essentially forever is very expensive, as shown table 1 below.

Table 1 – Cost of Capture and Compression for Industrial Processes (Courtesy Praxair)

Source	Flue Gas % CO2	CO2 MMSCF/D	Capture Cost $/ton
• Ammonia Plant	98+	0-37	~ $19*
• Hydrogen Plant	95+	24	~ $19*
• Ethylene Oxide	98+	9	~ $19*
• Ethanol Plant	98+	5-8	$28–$38
• Coal Power Plant	12-13	222	$68
• Natural Gas Turbine	4-5	72	$83
• Cement Plant	14-33	56	$45-$48
• Steel Mill	15-20	184	$53-$65

* Cost of dehydration and compression

While the first four industrial processes appear to be significant emitters and less expensive to capture; they account for a relatively small percent of the total. As shown in Figure 7 below, two thirds of total stationary carbon emissions comes from electricity generation and three quarters of that is from coal. So, to even begin to meet the capture goals, most of the money and effort is focused on new and existing coal powered generating facilities.

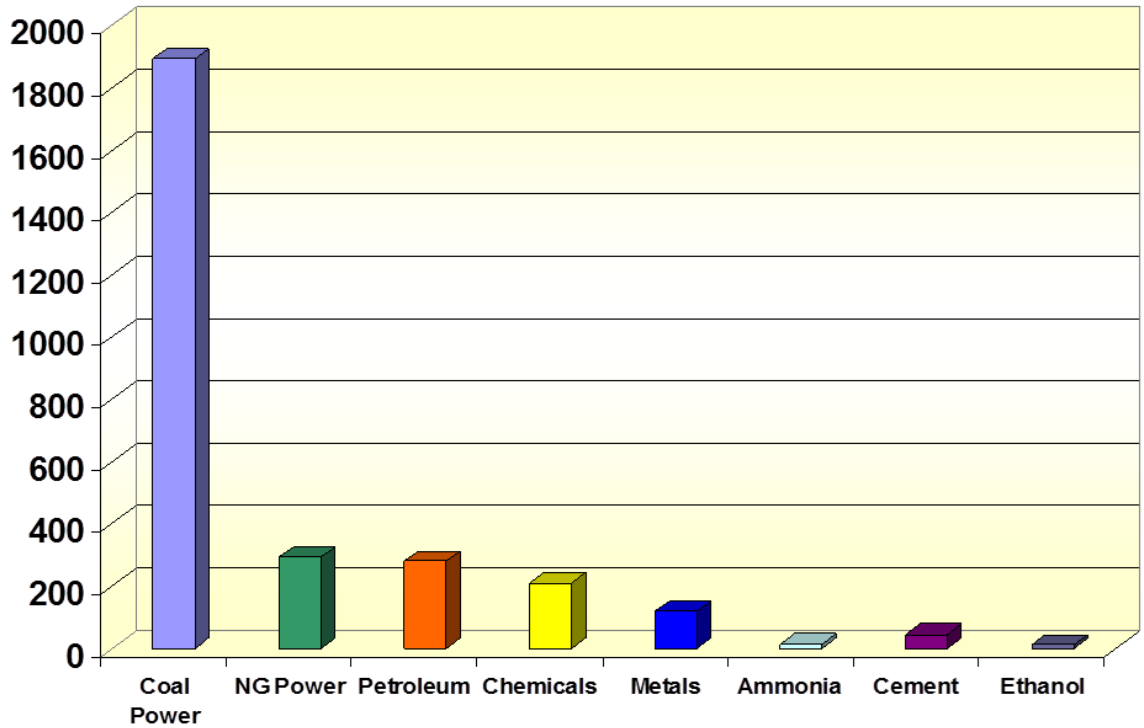


Figure 7 – Emissions of Greenhouse Gases in the U.S. in Million Metric Tonnes/year, Source: EIA

There are at least 100 research projects worldwide focused on reducing the cost of separation. Many of those are currently supported by the U.S DOE. The DOE has published and maintains a handbook describing all www.netl.doe.gov/technologies/coalpower/ewr/pubs/CO2Handbook/ ongoing capture technology research activity and categorizes and assesses types of technology. It clearly lists the challenge of moving these technologies out of the lab through demonstration and commercialization. The state of development and challenges are:

- All are in the early stage of investigation – there are a few demonstration projects capturing a portion of a power plant output, but no operating, full scale capture projects in coal power generation
- Scaling – for most of the technologies, the footprint would be considerably greater than the power plant itself
- Cost – even the most promising capture plants planning to use state of the art technology costs billions more than conventionally fueled (coal or natural gas) plants and must be subsidized by the government, electricity customers or the developer
- Parasitic Load – most of the technologies being investigated require substantial energy, up to 35% of the plant output, effectively derating the facility by that amount.

The general classes of capture technologies and some of their plusses and minuses are:

- Pre-combustion solvents – after processing the coal in a gasifier to create syngas fuel, the byproduct adsorption of the CO_2 is performed with a chemical (such as amine) or physical substance (choice depends on process pressure); it is a well-established technology long used in the gas processing industry that does not require heat to reverse a chemical process, but requires substantial energy, low solubility CO_2 will require large pump loads and CO_2 pressure is lost during flash recovery
- Post-combustion solvents – decades old technology in which chemical solvents provide fast kinetics to allow capture from streams with low CO_2 partial pressure, but requires significant amount of energy to reverse the chemical reaction

- Pre-combustion sorbent technology – (or “dry scrubbing”) in which the fluid (gas or liquid) is adsorbed on the surface or in the pores of a solid; primarily a pressure swing, versus heat energy process that can simultaneously remove both CO_2 and H_2S, but CO_2 pressure is lost during the flash recovery and some H_2 may be lost with the CO_2
- Post-combustion sorbent technology – same advantages as used for pre-combustion, but the pressure drop in flue gas applications is greater and more of the sorbent is lost in the process
- Pre-combustion membrane technologies – has no steam load or chemical attrition and can be used in hybrid applications with liquid solvents, but separation of H_2S and CO_2 is more challenging due to much different molecular weights, has high capital costs and requires the CO_2 be compressed
- Post-combustion membrane technologies – like the pre-combustion application, there is no steam load or chemicals, but has bad economy of scale, may require multiple stages and recycle streams, with a trade-off between recovery rate and purity
- Oxy-combustion technology – can be used with pre- or post-combustion projects; uses pure oxygen to combust the coal, negating the need to separate the N_2, leaving CO_2 and water; the O_2, however can be very expensive to buy or separate from the air and requires high temperature metallurgy
- Chemical Looping technology – is much the same as the Oxy-Combustion except it utilizes a metal oxide such as CaO_2 in place of the oxygen, and shares the same advantages and disadvantages

5.0 CAPTURE PROJECTS – THEN AND NOW

In the late 1990s, as the limits of the Kyota Protocol were being set, governments, NGO’s, universities and others came to an agreement that to have a chance to meet the goals of reduced carbon emissions, whether mandatory or not, that Carbon Capture and Storage technology needed to be aggressively developed and built. Over 100 full sized plants would be needed to help meet the 2050 IEA goal of removing 7 GigaTonnes of CO_2. The U.S. committed billions of dollars to subsidize a dozen power plants and three industrial CCS plants under the Clean Coal Initiative (5 are still being developed) and the Industrial program. Canada and the European Union (including Great Britain) also kicked off aggressive programs.

Table 2 – Hydrocarbon Conversion Facilities with CO_2 Capture (Phil DiPietro, NETL April 2012)

Primary Product	Owner	Capture Location	Status (online year)	CO2 Capture Rates MMmtCO2/yr
				2015
Ammonia	Agrium, Inc.	Borger, Texas	Operation	0.50
Ammonia/Urea	Koch	Eind, Oklahoma	Operation	0.68
Ethanol	Conestoga	Liberal, KS	Operation	0.29
Ethanol	Bonanza	Garden City, Kansas	Operation	0.15
Fertilzer	CVR Energy	Coffeeville, KS	Construction (2013)	0.8
Hydrogen	Air Products	Port Arthur, TX	Construction (2013)	1.0
Power	Mississippi Power	Kemper County, MS	Construction (2014)	2.7
Power/Urea	Summit	Ector County, TX	Planning (2014)	2.3
Methanol	Leucadia	Lake Charles, LA	Planning (2015)	4.0
Power	NRG	Thompson, TX	Planning (2015)	1.4
			Total	**13.8**

However, for reasons discussed above relating to increasing costs coupled with a 3 – 4 year global recession, there have been many more cancellations announced than new projects. In their latest report "The Global Status of CCS: 2013" recently published, the Global CCS Institute states "there are currently 65 large-scale projects (power generation and industrial) projects under various stages of development worldwide, 10 projects fewer than this time last year. Five projects have been cancelled, seven put on hold and one downscaled. In that time, it has also identified three large-scale CCS projects – all of which pair natural gas processing or chemical production with enhanced oil recovery in Brazil, Saudi Arabia and China."

There are at least 3 organizations that maintain interactive global databases on capture projects – active, announced and cancelled with up to 10 characteristics of each. All are available in tabular and graphical modes. The first is maintained by MIT http://sequestration.mit.edu/tools/projects. The second is maintained by the Global CCS Institute www.globalccsinstitute.com/data/status-ccs-project-database. The third is maintained by DOE NETL, Atlas III – National Energy Technology Laboratory (must have Google Earth loaded). In viewing the MIT database, several trends are evident:

- There are 29 projects listed in the "Cancelled and Inactive" list. Virtually all of them had targeted saline aquifers as a storage formation
- All of the DOE projects listed in Table 2 target EOR production as the storage formation
- The North American model is to connect the captured CO_2 to existing EOR infrastructure or lay a dedicated pipeline to nearby production to initiate EOR
- The European model, absent any existing EOR infrastructure, is to connect large emitters to an onshore pipeline network which feeds into a much larger pipeline and exported to a North Sea Platform for injection either into a saline or depleted oil reservoir
- As the typical industrial process is a less expensive overall and has better overall economics, they are much more likely to go through to completion

The 2013 Global CCS Institute report acknowledges, as do most experts that the rate at which CCS is being deployed is insufficient to meet the 2 ° C temperature rise goal. Clearly, the two largest impediments are (1) no successor to the Kyota Protocol that would encourage or compel all emitting countries to make a meaningful contribution, and (2) the lack of a breakthrough on reducing overall capture costs to a level acceptable to the public, who ultimately must pay for it. Brad Page, CEO of the Institute, was quoted to say that "Seventy percent of CCS proponents agree that policy uncertainty is a major risk to their project. Indeed ongoing uncertainty about the timing, nature, extent and durability of emission reduction policies is limiting investment in CCS and stalling its development and deployment. This must be addressed."

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