Workshop Summary
WRI Carbon Dioxide Capture and Storage Workshop
28 February 2006

This full-day event served to launch a new project that the World Resources Institute is leading on carbon dioxide capture and storage. Discussions at the workshop were held under Chatham House rules (not for attribution), so no names are associated with conversations that followed formal presentations. The agenda for the workshop and color copies of all presentations can be found at http://carboncapture.wri.org.

Jonathan Lash, President of WRI, gave welcoming remarks and applauded participants for coming together to cooperate on a topic of critical importance.

Jonathan Pershing, Director of WRI's Climate and Energy Program, then described the objectives of the workshop and larger project. Despite all the work and interest in carbon dioxide capture and storage now, there is uncertainty in public acceptability of the technology. WRI believes much of this uncertainty can be addressed by ensuring safe and transparent practices in the field. Currently, there are regulatory and institutional voids that need to be addressed before CCS can be deployed on a large scale. Guidelines, regulations, best practices and other standards need to be agreed on through consensus building among industry, public interest, governmental, and research groups. WRI would like to use its unique experience in convening diverse stakeholders to build consensus on how to address key shortcomings in CCS governance and produce guidelines that a critical mass can endorse. Our goal today is to frame the set of CCS questions that need to be addressed, and begin thinking about a process that stakeholders can use to build consensus on how they are answered. Specifically, can we form several workgroups to begin exploring key issues that we define today as a group?

One comment after this overview noted that, although the workshop had good diversity from industry, governments, NGOs, and researchers, those with less favorable views on CCS should also be included in future discussions.

Session I – Overview

Jim Dooley, Senior Scientist at the Joint Global Change Research Institute, gave an overview presentation of the role that CCS technologies could play in stabilizing atmospheric concentrations of CO_2. Dooley outlined some of the opportunities and challenges that would need to be met if CCS technologies were to deploy on a large scale where annually gigatons of CO_2 were routinely being stored in deep geologic reservoirs around the world. Current research suggests that globally there are sufficient deep geologic reservoirs to accommodate foreseeable CO_2 storage needs over the coming century but that this CO_2 storage capacity is very unevenly distributed around the globe. Countries that have large CO_2 storage potential will likely have more options to power their economies in a greenhouse gas constrained world than countries which have relatively small CO_2 storage reservoirs. He argued that the range of heterogeneity within both the capture and storage subsectors will require a broader set of technological and policy options and greater planning and foresight than we are currently practicing. The market for CCS extends beyond new coal fired power plants (IGCC) power plants. CCS technologies are also key emissions mitigation options for the cement, chemical, refining, and steel industries. However, the largest potential market is new fossil-fired baseload electricity generation plants. These baseload units will need decades of proven CO_2 storage. That will become a key siting criterion for new plants. For all but a very small group of niche market opportunities, the deployment of CCS technologies will be a positive cost activity, i.e., CCS technologies will not deploy on a significant scale unless there is a policy in place that places a value on carbon emitted to the atmosphere.

Session II -Carbon Capture Issues

Ed Rubin, Carnegie Mellon University, started the sectorial focus of the workshop by framing issues related to carbon dioxide capture. He outlined types of capture systems and what new issues might result from their deployment. For example, greater use of amine scrubbing in post-combustion systems would result in at least marginally greater production of organics, ammonia, and solid hazardous wastes. Higher energy use per unit of electricity produced would also result in greater fuel and mineral resource consumption, solid waste production, and increases in some criteria air pollutant emissions per kilowatt-hour generated. Potential safety issues, such as those associated with the use of hydrogen and oxygen in capture systems based on IGCC or oxyfuel combustion, also may have to be addressed. But Rubin stressed that these are relatively minor challenges that can be dealt with by the existing regulatory system, and that in the larger framework there are no major regulatory gaps *per se* within the capture component of CCS.

Rubin also noted that policy drivers would be required to enable future CO_2 capture. How might different policy measures at the federal or state level (cap and trade system, performance and portfolio standards, etc.) influence development of the CCS framework? A combination of carrots and sticks would be most effective in guiding formation of a well-run system.

Respondents, Discussion, and Questions:
Most of the discussion focused on the need for greater incentives to deploy IGCC and other technologies to capture carbon dioxide While CO_2-enhanced oil recovery (EOR) might serve as a "lubricant" for capture in the power sector, and may help to finance needed pipeline transport infrastructure, it is insufficient to drive large-scale capture in the power sector. The current ambiguity over future carbon regulation is perhaps the biggest barrier to more IGCC projects. One respondent discussed how a portfolio standard requiring a portion of total electricity sales from low-carbon sources spreads risk and minimizes overall costs. Others noted the role of state utility regulators in providing rate recovery for project-based carbon capturers. Another noted that the EPA was not providing any clarity to the states, who deferred to it with questions about regulating

CCS. Finally, the lack of performance guarantees for IGCC systems also slowed development of projects.

Another topic dealt with how pure captured and injected CO_2 needed to be. Small amounts of hydrogen sulfide (H_2S) in the CO_2 stream, for example, could change the regulatory requirements immensely. But small amounts of sulfur species might allow capture costs to come down while having little additional risk during the post-injection phase. One participant noted that studies analyzing co-sequestering CO_2 and H_2S show only a modest cost reduction (3%) but carry a large increase in perceived public risk. Additional studies on that topic might be useful.

Participants had a lively discussion over the legal definition of CO_2: is it a commodity, a pollutant, or a toxic waste? How we eventually classify it will dramatically impact the regulatory regime and liability under which it falls. One participant used the example that oil is defined as a commodity when held in a tank and a pollutant when released into the ocean. In the same way, carbon dioxide might be a commodity to enhanced oil recovery practitioners and a toxic waste if it leaked into the basement in a home adjacent to an injection site.

Several participants noted that two constituencies were not represented at the workshop: the financial community and the (re)insurance industry.

Session III – CO_2 Transport Issues

Russell Martin, Vice President for Business Development at Kinder Morgan CO2, outlined the issues related to transporting CO_2 from sources to injection sites. He noted that there are currently 76 active CO_2 enhanced oil recovery (EOR) projects operating in five countries, with the majority in the Permian Basin of Texas. This year, the one-billionth barrel of oil using CO_2-EOR is expected to be produced. To get one wedge from CCS, we would need to ship supercritical CO_2 equivalent to the current volume of oil that is distributed by pipeline in the U.S.[1]

Carbon dioxide pipelines are regulated under Department of Transportation's compliance law 195. Rights of way for CO_2 pipelines are the same as for oil, gas, and liquids pipelines.

As long as CO_2 is kept dry, pipelines are very safe and stable. In transport, this is relatively easy to ensure. In field production, however, pipelines and related infrastructure are exposed to wet CO_2, so inhibitors are needed to prevent corrosion. Martin provided U.S. quality specs for pipeline gases used in CO_2-EOR (see presentation). Generally, CO_2 is compressed to 1100 psi for transport, but this can be increased to 2000 psi or higher in many situations. Pipeline inspections are required with "smart pigs" and by other forms of direct assessment every 5 years.

[1] See S. Pacala and R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science*, August 2004.

Environment, health and safety issues include: asphyxiation, noise, frostbite, and high pressure. Careful monitoring is required, especially in high consequence areas (areas that are populated, sensitive to environmental damage or near commercially navigable waterways). Generally, however, any significant pipeline CO_2 leak will be evident from loud noise, pressure drop, or visual signs (white plumes).

To co-dispose of SO_2 and CO_2, a new specification would probably be required. Co-disposing of H_2S would have a positive impact on CO_2-EOR operations because it helps lower the minimum miscibility of the flood. Whether this would outweigh its drawbacks as a highly toxic gas was not discussed.

In measuring CO_2 for sales, custody transfer currently relies on orifice meters, which are generally accurate to 1 percent. This is considered sufficiently sensitive. Other measurement methods provide less accuracy.

Respondents, Discussion and Questions:
Regulations and industrial best-practices that govern existing CO_2 transport work well. Siting of pipelines in high consequence areas require the most care. Current regulations give much authority to states. If state PUC's are the enforcer of DOT Office of Pipeline Safety requirements, the system general works well. But many states are currently not thinking about CO_2, only other liquids and gases.

Carbon dioxide is not currently listed as a hazardous liquid under the Safe Drinking Water Act regulations, so it is always referred to separately as "CO_2 and hazardous liquids". It is also not considered explicitly in the Underground Injection Control classification. The Resource Conservation Recovery Act covers all non- CO_2 hazardous waste transport.

Siting of new pipelines may require use of a state's power of eminent domain. The issue of interstate vs. intrastate eminent domain depends on whether a company is considered a public utility or not. The National Regulatory Research Institute (NRRI) has completed a comprehensive study on CCS transport issues that is currently under review by DOE and will be released soon (probably in April 2006). We will help to distribute this work once it clears the review process, as well as other relevant NRRI research on CCS.

One option could require future pipelines to be "supersized" so that they can grow in capacity as more capture is undertaken. We also need to consider issues related to making CO_2 pipelines "common carriers" (open access to all users under equal requirements).

Is there a need for additional regulation at valves and compressors if we go to massive deployment?

While CO_2-EOR has relatively small potential for CO_2 storage compared to saline aquifers, it could help to anchor necessary investments in the CCS infrastructure because it will be the first mover.

Session IV - Siting and MMV

Sally Benson, Senior Scientist at Lawrence Berkeley National Laboratory, discussed issues related to siting and monitoring of CCS projects. According to the IPCC Special Report on Carbon Dioxide Capture and Storage, if MMV and siting are done right, then geological sequestration risk is comparable to that in natural gas storage or enhanced oil recovery.

Benson delivered the following key messages.

The regulatory frameworks to govern geological carbon sequestration are largely in place due to our existing work with natural gas storage, oil-field brine disposal, and liquid and hazardous waste injection. Modifications can address the outstanding issues. There are definitely new issues introduced with carbon storage due to the large underground plume size (100km^2), reactivity of CO_2 with well materials, and specific geographical locations.

Performance specifications regarding CO_2 mitigation need to be developed. How good is good enough? We need to develop criteria for siting acceptability that ensures local environmental safety and CO_2 mitigation effectiveness. Should we measure the latter in terms of retention rates (> x%/1000 years) or leakage rates (<y%/year)?

There are a variety of monitoring methods available. We need to adapt the existing methods to field specifics and develop protocols for storage projects. Technology will continue to improve, giving better resolution.

We need approaches to facilitate early site selections to gain more experience with geological sequestration. We have the tools to start and should focus on “learning by doing”.

More specific issues related to her talk included:

Is it possible to decouple local and global MMV goals? Not completely, as a leaky well can cause global climate problems without any local environmental problems.

Efforts needed to assess a storage site depend on formation type: oil, gas, and saline. For example, for CO_2-EOR we need to devote the greatest effort to understanding the condition of active and abandoned wells in the overburden. For saline formations, we need to devote the greatest effort into understanding and ensuring proper seal formation.

Monitoring methods can be broken down into three groupings:

- Well maintenance and operations: cement degradation and overpressuring
- Plume tracking and leakage monitoring: seismic, gravity, pressure, land surface deformation, electromagnetic
- Surface seepage: eddy covariance, flux, laser, soil gas

Each method has limits of detection that need to be considered when designing a comprehensive system.

Questions we need to ask ourselves when designing monitoring protocols?

- What is the purpose?
- What detection levels are we limited to?
- Which methods are available?
- At what frequency will we monitor?
- How long will we monitor?

Finally, we need 4-6 industrial scale projects to facilitate "learning by doing". Facilitate early site selection, streamline permitting process, employ robust monitoring programs, and gain confidence.

Respondents, Discussion and Questions:
EPA's efforts are focused on applicability of the Safe Drinking Water Act and inventory issues right now. The SDWA focuses on protecting underground sources of Drinking Water and regulates injection of all fluids – liquid, gas, or slurry. SDWA also states that underground injection should be done in a way that avoids adverse impacts to human health and the environment. EPA is responsible for permitting injection wells in some States and some States have primacy for their Underground Injection Control programs and are responsible for permitting wells directly. EPA is evaluating approaches that allow flexibility for early demo projects.

Do we need a new UIC well class ("Class VI")? EPA technical discussions on how to permit CO2 injection and what "best management practices" are appropriate will start in March 2006.

There will be a site characterization conference at LBNL from 20-22 March 2006. See http://esd.lbl.gov/CO2SC/

Do we have the institutional capacity to meet the challenges related to the scale of implementation (100km^2 plumes), ground water concerns, and integration of water and carbon segments? Is the current research portfolio addressing these important environmental issues?

Safe Drinking Water Act – If CO_2 is classified as a criteria pollutant, it will not impact the well type. (Well types are not based on or determined by CAA determinations.

The re-insurance industry's voice is needed at this discussion. So far, a 50-year insurance policy is the longest ever issued and carbon storage may be much longer than this.

The Texas legislature gave regulatory control of post- CO_2 EOR fields from the Railroad Commission to the Department of Environmental Quality.

How much do we need to do to characterize a field? One answer: Big difference depending on if it is a greenfield or existing one. What scale is meaningful? One answer: 500,000 to 1 million tons per year.

Monitoring costs are small compared to total CCS costs (1-2% of total). Our focus shouldn't be on developing a monitoring template *per se*, but on knowing where CO_2 might migrate through intelligent analysis and developing a site-specific MMV strategy. We need to invest in good predictive models and ask intelligent questions about where leaks could happen. Simulation capability w/ monitoring is the key. But who will do the MMV and how much should be required?

Another observer echoed the comment above by saying that monitoring and verification should be risk based. We shouldn't require soil testing, for example, in Texas where shale seals are very common (you'll never find it!). Use intelligent MMV.

Several participants reiterated that large-scale project demos are the most important way to gather knowledge on what works best. Get out and do it on large scale and create regulations based on what we learned.

We don't have the luxury of sequencing the steps needed to deploy CCS in the most logical manner (R&D, field tests, regulations, more field tests, etc.) We need to integrate R&D with the regulatory process. Design standards may not be met in the real world, but we can adapt them with experience and "learning by doing". This will be analogous to the Intel chip deployment (286, 386, Pentium I, II, III, etc.). The design criteria must evolve.

One participant argued that the UIC Class 1 injection well should be the design standard for saline aquifers: it is strict, but it provides all the needed tools and people can depend on it. A question remains about its appropriateness for large volumes of CO_2.

There is a need to focus most of our experiments on saline aquifers because it's what we know least. We already have 30 years of experience with CO_2-EOR in depleted oil fields.

To ensure public acceptability, how will we deal with remediation and well abandonment? How long is long enough? This issue cross-cuts with the final session on liability.

Another participant noted the need for uniform global standards and compatibility so that trading markets would work smoothly and mitigation would be accounted for accurately.

Finally, a participant noted that we might be placing too much emphasis on the need for regulation and not enough focus on the need to conduct public outreach.

Session V - Accounting and Liability Issues

Elizabeth Wilson, Assistant Professor at the University of Minnesota, discussed accounting and liability in her presentation, and posed a number of outstanding questions that needed to be addressed. As time was short, many questions were posed in this session that did not receive extensive discussion.

Injected CO_2 must count for something within a larger national and international framework. For international firms, in particular, compatibility with international accounting standards is critical. Wilson outlined some of the FCCC and US DOE 1605b pronouncements on accounting, noting that operationally, accounting is fairly straight forward. Greater difficulties arise in developing baselines and determining additionality. The Marrakech Accords deal with some of this, but many open questions remain.

The existing international accounting framework does not deal with long-term physical leakage. How should it deal with the potential for leakage? Is it best to use a system that assumes impermanent storage, similar to terrestrial sequestration, where short-term credits are issued and verified at the end of each accounting period (ton-year accounting vs. reserve credit or insurance)?

How is escaped CO_2 reported in national inventories? As fugitive emissions, or under a new category? What about CO_2 that has already been injected for EOR? How much should we assume has stayed down?

How will the monitoring and crediting of cross-border CCS projects take place?

In the second half of the presentation, Wilson noted that liability is more than just leakage to the surface. Subsurface liability includes potential damage to hydrocarbon resources, potable water supplies, and induced seismicity, while surface liability includes leakage causing harm to people, agriculture/forestry, natural ecosystems, and climate. She outlined the contractual and tort mechanisms to manage long-term liability. Operational liability is assumed by the injecting party now, but no solutions are in place for long-term liability. Special funds and insurance have been proposed but it is uncertain how these would be paid for. It is also unclear how long private entities would be held liable and when or if the liability would be transferred to the state. Project participants are liable for all the CO_2 that is captured in a project, but credited for only the CO_2 avoided.

Respondents, Discussion and Questions
Inventory and accounting methodologies are under development by the IPCC and DOE (1605B) and are likely to be finalized this year. Some of the questions raised will be addressed under those efforts.

How does the nature of insurance/liability change over time?

What are the implications of using different accounting methodologies?

Texas reports to be the only state that accepts the CO_2 liability in the FutureGen project.

Public acceptability: How should we describe liability strategies to the public?

There are other ways to do EOR so additionality questions may arise.

We need to establish a fund for ongoing monitoring and remediation in post-injection period.

Can we draw a distinction between local liability and climate liability?

Comparative liability and risk assessment. Should we have a preference for the relatively known liability of injection versus the unknown liability for emissions to atmosphere?

Are there ways to establish liability reduction incentives?

Insurability is the flip side of liability. We need a rating system for sites that would address risk issues. This addresses due diligence and good faith.

BLM land and CO_2-EOR. What liability do they perceive?

What history of damage has occurred in the past 30 years in the EOR industry?

Session VI – WRI's Experience with the Stakeholder Convening Process

Jennifer Layke, Deputy Director of WRI's Climate and Energy Program, outlined some of the stakeholder consensus-building projects that WRI has used. She described two corporate partnership programs (the Green Power Market Development Group, and the Climate Northeast Collaborative) and two multi-stakeholder processes (Global Forest Watch, and the Greenhouse Gas Protocol Initiative).

In the multi-stakeholder process, participants collaborate to work towards a jointly defined goal. Typically, the larger body meets quarterly or semi-annually to share information that the smaller working groups develop. A diversity of opinions is purposefully sought so that true consensus-building can occur. She noted that the process requires a significant investment from participants and often covers several years (the GHG Protocol process is in its 6^{th} year of operation, for example).

Session VII – Integration and Workplan

Jeffrey Logan, Senior Associate at WRI, summarized presentations and discussions from the first 5 sessions. The capture and transport sessions have some outstanding questions, but the existing body of regulations largely work at present. Most of the interesting questions were raised relating to siting and MMV, and liability and accounting. There appeared to be unanimous agreement that we should continue as a group to explore issues in these two large topics. Time ran out before we could agree on how to form workgroups to continue but almost all participants expressed enthusiasm to contribute to the process. A question of travel funding for future work was raised and WRI noted the possibility of raising support from foundations to help cover travel costs of some participants. WRI will be back in touch with participants very soon to propose workgroup activities. Interested parties who did not participate in this workshop should contact Jeff Logan at jlogan@wri.org.

Finally, although there were 33 stakeholders represented in this workshop, there are others that would like to join the process and participate in future workgroup activity.