DECISION SUPPORT AND CARBON CYCLE SCIENCE: PRACTICAL STRATEGIES TO RECONCILING THE SUPPLY OF AND DEMAND FOR CARBON CYCLE SCIENCE

Workshop Report

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Executive Summary

A group of researchers and practitioners across disciplines and professions gathered to discuss the merits of various strategies to create usable carbon science. While the focus was on carbon specifically, the group included experts on usable climate science and public participation methods in an effort to share experience in this arena with the carbon community.

Participants discussed the following four topics:

- What are the effective criteria for successful "usable science"?
- What has worked in creating science policies that result in 'usable science'?
- How is carbon cycle science currently being used?
- Democracy, public participation and equity in setting science agendas

Certainly as society moves toward considering deliberate carbon management, there is a transition from only focusing on creating basic understanding of the carbon cycle (which of course will continue on its own merit), to a new phase of also producing decision- or policy-relevant information. Participants agreed that the topic of usable carbon science was ripe for focus, as the societal context for carbon management was still emerging and could potentially become an important consideration for resources managers, governments, corporations and individuals. Pockets of use of carbon information include: state governments such as California and Oregon, the Federal government for complying with the United Nations Framework Convention on Climate Change (UNFCCC) and developing national policies, agricultural interests, forestry interests, other natural resource managers, cities, energy-related corporations, and environmental non-governmental organizations.

These various communities will likely have different needs, but the process of producing information to be usable will likely require researchers and programs alike to wrestle with the following questions:

- There are a myriad of potential users, how do we determine, given limited resources and unequal access to information, which uses to focus on?
- The context for use of carbon information is highly uncertain and dynamic. There is a possibility both of working with the few existing users as well as creating new users (preparing the market). How do we strike a balance between these two types of activities?

The criteria for usable science will of course be unique to the situation, but general lessons suggest that the creation of usable science will require a mediated interface of some kind between researchers and potential stakeholders, that research is available to the potential users in a timely manner, and that its application or use leads to improved societal outcomes. Also, the science itself should be credible and transparent, with all assumptions and uncertainties clearly defined.

Participants agreed that there were existing models and experience in the use of scientific information that could be applied to the formation of an effort focusing on usable carbon science. Some of these examples and lessons learned include:

- Start with a "problem-centric" or stakeholder perspective to orient around as research is planned. Such a model is more likely to result in research that meets societal needs rather than beginning from basic science interests.
- Build in a dynamic, two-way relationship that is ongoing between knowledge producers and societal decision makers, or pursue fully-integrated co-production of knowledge. Experience has shown that a mediated

approach such as these is more likely to result in useful information that has a greater chance of being used.

- Allow for community creativity in seeking out projects that might provide good pilots for creating usable carbon science.
- Through appropriate metrics and evaluation procedures, ensure that accountability to the goals of usable science is met. Such governance and metrics may be different than the traditional ones usually relevant for basic research.
- Models exist that can be evaluated for their applicability for organizing a usable carbon science effort. Such models include dedicated institutions, regional integrated sciences and assessment projects, boundary organizations, and grant programs.
- Consider how successful usable carbon science efforts might transition to an ongoing, operational status. Do such organizations exist now for carbon? If not, can the function be incorporated into existing organizations?

There was much enthusiasm for carrying these messages to the broader community and moving forward with considering how to create a usable carbon science effort. Some of these ideas have permeated products such as chapter five of the SAP 2.2 (Synthesis and Assessment Product of the Climate Change Science Program, or State of the Carbon Cycle Report, North America--SOCCR), and have been presented at the Climate Change Science Program Decision Support workshop, the American Geophysical Union fall meeting, and the American Meteorological Society annual meeting.

BRIEF OVERVIEW

The goal of this workshop was to foster an interested community of researchers and develop a research agenda with the ultimate aim of improving the usefulness of carbon cycle science for the broader community of decision makers. Specific objectives included:

- To survey existing knowledge about successful decision support using carbon cycle science
- To enable cross-disciplinary transfer of knowledge about how to design and implement research agendas, projects and programs so that they can effectively serve users needs
- To develop a research and practice agenda for programs and scientists in carbon cycle science who are interested in serving the needs of users outside of the scientific community. Specifically, we will provide input to Section V of SOCCR on how we can improve the application of carbon cycle science in decision support, and create a broader research agenda on generating useful information in the North American Carbon Program (NACP) as NACP goes forward in its implementation.

To this end, 22 participants from the carbon cycle science community, the community of researchers studying science-user interactions in the seasonal to interannual forecast arena, and the science policy research and practitioner communities gathered on June 13-14, 2005 at the University of Colorado, Boulder (see appendix III, participant list).

Substantial progress was made on outlining the options available for carbon cycle science to pursue. Participants at the workshop were quite positive about the workshop itself, the need for a network to continue the dialogue, and the importance of raising awareness about these issues in many different venues, those both scientifically- and community-based. Individuals also carried away from the workshop new information that some directly incorporated into their research endeavors.

BACKGROUND

The Carbon Cycle Science element of the Climate Change Science Program (CCSP), especially the North American Carbon Program (NACP) has as a primary goal providing near-term information of use to decision makers.[1] However, as demonstrated by several other areas of emphasis in Earth science, generating information that is useful to anyone outside of the scientific community does not automatically result from conducting scientific research. Specific findings include: information provided is not needed; information is needed but not provided; information lacks regional specificity; inaccessible presentation; poor communication; lack of trust in information or deliverers; institutional constraints prevent use of new information; and so on.[2] The concept of managing carbon is a relatively new concept in the spectrum of managing natural resources or environmental issues—while carbon management has been discussed for merely a few decades, water, land and marine resources have been managed by society for centuries. The carbon cycle science community therefore does not have wealth of experience internally from which to draw upon in trying to develop a scientific agenda that will successfully meet the needs of decision makers. Preliminary evidence suggests that carbon cycle science is not currently meeting some important needs ("missed opportunities").[3] The goal of this workshop was therefore to examine options for research agendas to fill this gap.

WORKSHOP APPROACH

As a first step we established a workshop executive committee made up of individuals from the various communities that we wanted to connect up to examine this question (see appendix I). The executive committee consisted of: Lisa Dilling (University of Colorado, workshop organizer), Maria Carmen Lemos (University of Michigan), Dennis Ojima (Colorado State University), Steve Pacala (Princeton University), Chris Potter (NASA/Ames), and Steve Rayner (James Martin Institute, University of Oxford). Together we developed a participant list representing the various fields and potential users of the information (see appendix III). In our case, the users we were targeting were primarily decision makers for science policy, in other words, program managers at the Federal level.

Our goal in developing the workshop agenda and approach was to create a dynamic exchange with a minimum of time spent passively listening to presentations. As a result, we did not have formal presentations, but rather discussion organized around the following four topics:

- What are the effective criteria for successful "usable science"?
- What has worked in creating science policies that result in 'usable science'?
- How is carbon cycle science currently being used?
- Democracy, public participation and equity in setting science agendas

Each participant was assigned a role to play in the agenda either as discussion "provocateur", "rapporteur" or respondent in a particular topic. Participants gamely accepted this structure, and as a result we were able to focus discussion on the heart of the issues.

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1. Climate Change Science Program Website: http://www.climatescience.gov/Library/stratplan2003/vision/overview.htm
Climate Change Research Initiative (CCRI) website explicitly focused on near-term support, of which NACP was a key component: http://www.climatescience.gov/about/ccri.htm

2. Many references available, some from the seasonal to interannual climate forecasting experience include: Pagano et al. 2002, Eakin and Conley 2002, Pulwarty and Redmond 1997, Letson et al. 2001, Pielke Jr. and Conant 2003, Lemos et al. 2002\

3. Reconciling Supply and Demand – Carbon Cycle Workshop Report: http://sciencepolicy.colorado.edu/carboncycle/workshop/

The latter half of the workshop was spent addressing nuts and bolts to form the heart of the findings and recommendations for this workshop. This discussion focused on the question: ***What are the essential elements of a "usable" carbon cycle science research agenda?*** The details were fleshed out in two sessions of discussion and drafting, the first focused on the elements of creating a research agenda for "usable" carbon cycle science and the second on implementation, gaps and needs, first steps, organizational needs and implications.

Because this structure did not allow for overview talks on aspects that were unfamiliar to some participants because of the very nature of the cross-disciplinary meeting, Lisa Dilling prepared a white paper to familiarize all participants with some of the background literature and foundational arguments that framed the workshop questions and approach (appendix IV). In addition, to help participants more quickly get to know each other, Ami Nacu-Schmidt compiled brief biographies for all participants that was shared in advance of the meeting (appendix V). Many participants remarked that they appreciated these biographies in advance.

Workshop Discussion Summary

1. Criteria for successful "usable science"

There was much discussion among participants as to what "usable science" means. In some sense, all science has the potential to be used—whether or not in the manner intended by the creators of the knowledge itself. Decision makers often use science to justify positions on issues already decided for other reasons, or to lend support and sharpen the debate. Indeed, even blatant "misuse" of science, for example, someone deliberately misrepresenting what a scientific piece of data actually means (for example, stating that the color red in satellite false color images means that the ground in on fire), is in some sense "use" of science. So, we must more clearly qualify what we mean here by "usable science" in a normative sense. By whose opinion or standards are we considering that science is usable? Are we, as scientists, open to changing the supply and how we create it, or are we strictly focused on increasing demand for what already exists?

If we had to characterize the normative stance of the workshop participants, it would be that usable science means that it is produced by some sort of mediated interface, is available to the potential users in a timely manner, and that its application or use leads to improved societal outcomes . Even this short statement contains within it a myriad of assumptions when one attempts to apply it in practice. Which users are to be targeted, given limited resources? Who gets to select the priorities for research? What do we mean by improved societal outcomes? We will return to these questions throughout this report. Timeliness is an important issue. Interestingly, information may not need to be perfectly accurate—sometimes relative information is useful as well. There are likely also many points along a decision process where information could be useful.

There are many specific examples that demonstrate how specific processes and new ways of operating may be necessary in order for research to be useful in different circumstances. The old concept of "throwing research results over the transom" to have them be picked up by society and used seems to no longer be valid in many cases. Creating usable science is a dynamic process that involves both researchers and stakeholders in the information—the research itself evolves and is changed by the interaction. Over the course of a project, directions and priorities may shift and new expertise may be needed as participants zero in on what is achievable and desirable from a decision making perspective.

Research that examines the use of information focuses on three general categories under which critiques fall: 1) data are not good enough, or relevant to the problem, or not being communicated well; 2) understanding the different categories of people who may be using information or not, and why; and 3) institutional barriers and constraints may be limiting uptake or implementation of new information. As scientists experiment with deliberately creating usable science, they have pursued different strategies to address these issues, whether explicitly or implicitly, and move forward. Even as it is difficult to define usable science, participants noted that it is still possible to develop processes that improve the chances that such research will indeed be useful. Characteristics of such processes include a functional interaction between researchers and potential users, a large investment of time to build trust, understanding and knowledge and a true commitment to potentially changing research direction based on that interaction.

Interactions for usable science may be envisioned at least two ways—what we might categorize as the "promotion of knowledge" approach and the "two-way assessment and interaction." In the former, researchers or scientists with information that they feel should be "usable" interact with potential users to persuade them to adopt the new information, perhaps tweaking or changing the knowledge as they interact. In the second mode, the line between providers of knowledge and potential users of knowledge might be more blurred, researchers are more open to creating knowledge of a different type or with different content than they might have envisioned going into the process. Such a process has been called "co-production of knowledge" for the sense that both researchers and practitioners contribute to the creation of new knowledge for use. It is clear that creating usable knowledge can be thought of as a dynamic process—a single "build it and they will come" model is widely seen as ineffective.

Do these processes of interactive knowledge generation result in more usable knowledge and "better" societal outcomes? The jury is still out on this question. The participants agreed that while the experience thus far seems to be promising, it was still unknown in an empirical sense whether or not these new ways of interacting between researchers and practitioners resulted in information being used more often or resulted in better societal outcomes. It turns out to be extremely difficult to measure or discern whether science was better used in one particular process compared to another.

So where do we stand in terms of creating usable carbon cycle science knowledge? Clearly there are pockets of use of carbon information—at the state level in California, Oregon and elsewhere, at the national level for UNFCCC negotiation, in some energy and utility corporations, in agricultural and forestry interest groups, and among non-governmental organizations involved in climate change issues and also those working toward biodiversity goals. Some participants suggested that the condition of the market and policy environment for carbon management with respect to climate mitigation will play a large role in determining the future demand for usable carbon knowledge. On the other hand, participants discussed at length the concept of "preparing the market" for carbon management—while federal policies may not be in place at the moment, there is interest at least in the private sector and among those who might be directly affected to lay the groundwork for later policies and markets by providing information now. Some of this groundwork may be in the form of promoting the use of existing information, whether for policy and incentive development, credit for voluntary action or competitive business strategizing. So carbon information is and may be used in this environment in anticipation of a future carbon market or policy.

There was also significant discussion of what usable carbon science might look like in the future. Until now, it is fair to say that the vast majority of carbon science has been focused on studying uncertainties in the global carbon budget, understanding processes related for sinks of carbon, and, more recently, apportioning sinks and sources of carbon to finer scale geographic regions. If we think of knowledge as somewhere along a continuum of scientific problem identification to social problem definition to developing solutions and acting on them, carbon science appears to be largely still within the area of scientific problem identification and elucidation. In order to move forward and create knowledge that might be of more direct short-term use to society, participants discussed the need to consider moving toward solution or option-based knowledge, which might inform societal alternatives for action. How might we provide information on consequences and impacts? On alternatives and adaptation? What is economically and socially feasible? Focusing on alternative generation helps to give direction to what types of science to involve in usable carbon science. A suggestion was made also that perhaps the carbon community could begin to interact more with the engineering and technological communities to move more toward this end of the spectrum. Are there lessons from how health research is organized that might inform how carbon science can add an applied component? Of course there are some areas of carbon research already that are quite applied, but there are missed opportunities and no organized strategy for how carbon science might become more usable. One option is to focus on and learn from groups already experimenting with usable climate science in other areas, such as the Regional Integrated Sciences and Assessments projects (RISAs), in order to build off their knowledge and expertise, while expanding their portfolio to include carbon. It is also clear that there is a delay effect when considering the creation and use of knowledge—what's in use now, for example, is what's already available. We can produce small tweaks in the next 4-5 years, but how do we plan now for generating knowledge that might be useful in the next few decades?

Finally, from a "philosophy of science" perspective, what is the scientist's goal in this, does she have a different notion of usable than the general public? Is it considered usable if someone takes the information provided and makes the decision the scientist would have made? Are we as scientists subconsciously hoping for certain of decision outcomes? Being self-reflexive as a community will allow much more transparent decisions as to what course of research to pursue and why.

2. What has worked in creating science policies that result in "usable science"

One participant laid out a helpful framework of three aspects of policies that are needed to encourage the production of usable science. First, successful policies must create a "mediated interface" between scientists and potential users of science. Both the mediated and interface aspects are important. These mediated interfaces might include an institution, a program, or a specific office. The National Institutes of Health, Offices of technology transfer at universities, and the Defense Advanced Research Projects Agency (DARPA) research programs of the Department of Defense are all examples of effective mediated interfaces. It is important not to bring users to the table naively, that is, without thinking through which users and for which problems, and in full knowledge of the need for the interaction to be mutually influential. Focusing on problems (such as cancer or detecting submarines) makes it more likely that research will be useful. Another suggestion, mentioned above, is to focus on providing options, not just information. Offering options and tradeoffs provides users with more usable knowledge rather than simply an overload of information.

The second aspect of policy frameworks for usable science is to focus on accountability for results. Becoming clearer on what is promised from science and who is served is necessary to increase accountability. The time frame upon which results will be judged is also important. For accountability to be practical, one must have reasonable expectations of success or at least check points for decision to continue or terminate should the pathway not seem to be particularly panning out. Simply saying that research is a long-term investment is not sufficient, as other policy choices could make similar arguments (e.g. long term investments in education, roads, and so on). Remember that here we are talking about research specifically aimed and justified for its ability to be useful to a specific problem—we're not trying to apply these metrics to "blue sky" or "basic" research that is just aiming to provide general knowledge for the future. Usable science is a companion to basic science, not a replacement or a substitute.

The third component of creating successful usable science policies is scientific leadership. This seems obvious, but without sincere leadership that attempts to "do the right thing" in creating the possibility for usable science to occur, it will not likely spontaneously occur, given the current status quo and inertia in the system. Being willing to consider genuine alternative institutional arrangements is a good start, as long as those arrangements are not merely token or purely for show.

Another participant emphasized the need to provide funding for usable science—the above issues are moot if there is no support or funding for it. One example of a newly formed program emphasizing creating usable science out of the National Aeronautics and Space Administration (NASA) data streams is the NASA Applied Sciences program. The NASA Applied Sciences program seeks to use NASA Earth Science to enhance the decision support tools of agencies and organizations that seek to partner with NASA for that purpose, including in the area of carbon management. Key elements in the approach NASA uses in Applied Sciences are to identify a decision support tool in use by the partner agency before beginning a project and benchmark the results of the enhancement decision support tool from the NASA input. Benchmarking describes and quantifies the performance of the tool with the enhancement in place and, in essence, demonstrates the reduction in uncertainty resulting from the enhancement. The NASA approach follows the first mode of science-user interaction discussed above (promotion of existing knowledge). The science is created following traditional scientific priorities, but then scientists work in partnership with potential users to look for opportunities to apply NASA data to specific problems. The users must have an existing decision support system to accommodate the information in question, and must show interest in the project from the get-go. So these projects do not create decision support systems, but rather look for opportunities to input or promote the use of science into existing decision support systems. While NASA has expressed interest in user input into prioritizing and selecting science missions to eventually serve societal goals and does work to assess user needs in mission design through interaction with the scientific community, this type of "end-to-end" approach with non-scientific end users has not yet been put into practice.

As far as carbon specific trends in the area of science policies that create usable science, it was felt that the current context for carbon management policies, i.e. that there was not great activity yet, very much affected the existing policies, institutions and strategies that might be followed. Because of the lack of clear policy signals, the full potential of carbon management is not likely yet realized. There are as yet very few mediated interfaces between potential users and carbon scientists—often individual scientists serve that role in an ad hoc basis. Some felt we were still therefore in a stage of "market preparation," where there was perhaps more effort in the way of promoting carbon information in various sectors. Participants felt that we as yet don't fully know what the decision tools might be, or what might be needed. Certainly there is also some use, for example, in California partnering with Department of Energy. However, as yet, without a strong demand sector, science policies specifically aimed at creating usable carbon science are not the dominant mode.

3. How is carbon cycle science currently being used?

Participants brought up examples of the current use of carbon cycle science in several instances. Use of carbon information is embedded in climate decision processes, as well as land use decisions, for example. These examples included international and national processes, local implementation of voluntary federal policy, private sector firms, and states such as California and Oregon. Certainly there has been use of carbon cycle science by nations and by the United Nations Framework Convention on Climate Change in order to comply with or set up rules for the Convention. Carbon science is used to help nations develop quality inventories, quantify uncertainties, and obtain a better understanding of carbon budgets for negotiating positions and compliance. At the national level, in the U.S., there is use of carbon information for crafting agricultural and farmland conservation policy, and at the local level information is used by those entities who are voluntarily reporting their emissions under Section 1605b of the Energy Policy act. This includes collaborative development, between university scientists and Federal agencies involved in land management (e.g. USDA's Natural Resource Conservation Service and the Forest Service), of on-line decision support tools for carbon management (COMET-VR, http://www.cometvr.colostate.edu; COLE, http://www.fs.fed.us/ne/durham/4104/1605b.shtml). Projects supported by NASA Applied Sciences in the carbon area include CQUEST (a model that can estimate the amount of carbon sequestered given a certain vegetation type and land use history), and other work to inform the 1605b voluntary emissions registry. In the private sector, participants discussed the example of BP/Amoco, a global fuel extraction and distribution company, which has acted internally upon carbon information generated by the Carbon Mitigation Initiative (of which they are a major funder) at Princeton University. At the state level, the examples of Oregon and California were discussed—they have used carbon science in their policy formulation such as in developing offset programs and crafting climate policy responses.

Participants also discussed a broad category of options that could be described as "potential future use" or trends in use. In this discussion, there was a fairly healthy tension between the use of carbon information as persuading, or convincing others that something should be done in general about climate change, and the need for a new focus on creating options and solutions for society to use in its response to the issue of rising carbon in the atmosphere. As one participant discussed this distinction-- "right now there is too much scolding, and not enough problem solving." Some time was spent to discuss the notion of "market preparation." Market preparation within the business sector involves working with decision makers such as executives, building capacity, understanding the potential reasons for engagement with the issue, such as protecting assets, identifying liabilities, seeking lucrative investments, gaining competitive advantage, and so on. The phase of market preparation is necessarily a two-way interaction, as scientists learn what decision makers are concerned with, and decision makers learn what science can provide. And of course many other sectors are similarly involved in "preparing the market" for responding to climate change, such as the religious community, states, non-governmental organizations, from whatever perspective they may come from. The notion of workable solutions is different than simply focusing on convincing a user that there is a problem to respond to in the first place. Providing options and alternatives enables a user more information and flexibility in deciding what might be possible to do in a given situation. Examples of such solution-oriented information include the intersection of energy and carbon issues, sequestration options, and other options that specifically address reduction in emissions.

A number of "conditioning factors" that affect the development of the use of carbon science in the future in the United States were discussed. What the rules and policy environment might be for garnering credit or receiving penalty for actions related to carbon is still not established. The call for usable science in the future is therefore highly dependent on the outcome of how such rules operate, if they are established. Of course there is much use of information to promote various actions or options, often in conflicting situations and using conflicting science—this is not the sense in which we are using the term "usable science".

Related to the lack of certainty on the policy environment of the future, at the local level, financial incentives are generally not yet strong enough to compel actions with carbon management as a primary goal. As economics are the first consideration for local users, this is likely to constrain the demand for carbon information at the local level until such time as these incentives might change. On the other hand, should markets or policies shift to more highly value active carbon management, actors may see a financial opportunity and may then preferentially seek out carbon information useful to them. Maintaining credibility with or garnering trust of persons is also a major factor in whether or not information is useful. If participants in the conversation do not trust that the person with information has their best interest in mind, it is unlikely that they will be open to considering, much less using the information. To return to the example above, if the conversation is about "scolding" with few if any options for the participants to consider, it is likely to be a relatively short one. Carbon information is, of course, only one of many considerations of actors who influence carbon management currently. As such, future use of carbon information will need to consider this multiple-constraint context. Finally, creating usable carbon information may require shifts and integration in the community that is knowledgeable about carbon management options, to involve not only atmospheric, oceanic, terrestrial scientists, but also economists, policy scientists and engineers.

One participant suggested exploring the potential user combinations possible by envisioning a three-dimensional diagram with 64 cells. One axis is type of organization, one axis is type of decision maker, and one is problem orientation, such as water management or agriculture. Such a diagram might be useful to identify the various cells, map them out, and discover what might be usable information for any one particular cell. Of course this would only be a suggestion to guide research, these cells would not be archetypes or specific. And of course, some cells might be more important for the issue than others.

4. Democracy, public participation and equity in setting science agendas

For natural scientists not accustomed to working with these issues, it might seem unusual to include the issue of democracy and public participation in dealing with the issue of the use of science. But, in a democracy where public funds are used to support science, where the implications of scientific results are often highly contested, and where the ramifications of science and technology are often not evident immediately, experience shows that democracy and public participation are essential to consider. An additional concern at play is the typical unequal access to information, particularly technical information. In many societies, technical knowledge often translates into power, if the society is a highly technocratic one. In selecting potential users of information, one might be tempted to pursue the "efficient" approach, that is, the approach that quickly connects up your information with people who can already use the information. Such an approach might exacerbate problems of inequity in society. Alternatively, one might be concerned about the equity of resources, and therefore focus on a more "distributional" approach, that takes into account whether information is uniformly available for use. Transparency and public participation are at least a start toward finding out how accessible science is and how it is being used to make decision making. Finally, for the topic of our conference, thinking about reconciling supply and demand for carbon information, the issues of democracy and equity appear almost immediately if one begins to discuss questions of potential users, and whom is to be served given limited resources.

There has been much research on the issue of public participation, although more experience in scoping and reviewing decisions, not necessarily participation throughout a research analysis. Models for participation include (in order of less time and cost to more time and cost): a) standard advisory committees (least involved, least transformative, e.g. EPA), b) committees with stakeholders (NIH with AIDS advocates, sense of transformation), c) negotiated rulemaking, d) deliberative polling (engage with scientific community, there is a change in values), e) multi-stakeholder advisory groups.

Some of the lessons learned from this research include: one size does not fit all; participation may vary depending on the stage of the process; participation in assessments is different than participation in decisions; demand and supply for participation involves incentives and concerns more than agencies would like, less than advocates would like; it is an evolutionary two-way process; public participants are experts in their own rights; leadership has a powerful influence; process does not bring consensus, merely clarifies points of view; and consider what participants get in return, sometimes they want to be part of an ongoing process.

Because carbon management in the U.S. has not yet really emerged into the public radar screen (a large majority of Americans do not know the term carbon sequestration or carbon capture and storage, for example), how to apply these lessons to carbon science and public use has not yet been explored. Perhaps the top-most question was "what is the problem"? Why might we want even want to consider public participation? What are the measures of success- do we know what a good process and a good outcome consist of? Who is included in the process? Is the problem intractable, or is it likely that, with time and effort, some resolution can be reached? More specifically, what is the role of public participation in science policies? In most contexts, science is largely internally self-governed by practicing or trained scientists. For example, the National Science Foundation is both an open institution, in that anyone can submit a proposal, as well as an extremely elite organization, in that only those proposals succeed that meet are judged meritorious by scientific peers, a highly selective process. If one is interested in producing outcomes with scientific knowledge that are of more use to society, is it therefore important to represent "society" somehow in the review, selection and prioritization process? How could this need to have public participation in science policies be accommodated practically, and what are the positives and negatives? Finally, what is the role of scientist in society? Scientists have sometimes emerged beyond their strictly academic or scientific role to raise an issue in the broader media, sometimes to no response, other times with great impact. Our discussion did not resolve these issues, but raising them early in the process of creating usable carbon science was thought to be important.

TOWARD A RESEARCH AGENDA FOR "USABLE" CARBON CYCLE SCIENCE

As many participants remarked, carbon cycle science is not starting from scratch in its endeavor to create "usable" knowledge. We can learn from other earth science examples, such as seasonal to interannual climate forecasting, and those examples farther afield, such as health, food safety, and so on. There are also fledgling efforts at creating usable carbon cycle science underway, at the state level, in agriculture, in forestry, and in carbon and climate modeling. But it is clear that there is potentially a large gap between our current scientific programs and the needs of society—a gap that could be filled by a dedicated program that deliberately supports the creation of usable carbon science. What would such a program look like? There are many options. Here we summarize some of the overarching elements that should be considered when creating such a program, followed by our assessment of the available models for such programs and their components. We conclude with a short section on "next steps."

Elements:

1. *Clarify the goal*

Before embarking on a program for usable carbon cycle science, it is important to clarify what the community and societal sponsors of research (e.g. governments) want to achieve. It is important not to skip this step and go directly to formulating a program. Clarifying goals allows one to identify the various values operating and in the end, design a much more effective program. For example, is the goal simply making better use of existing information, or does the goal extend to creating new information where needed? The answer will determine how much flexibility to build into the research agenda, who the players should be, and by what criteria progress will be evaluated. We suggest, as a starting point that the goal of a usable carbon science program could be "to produce knowledge in a mediated manner that is useful in a timely way to specific decision makers in specific contexts and enhances the ability of society overall to make good decisions with respect to carbon management." Obviously this goal would need to be further refined should such a program be considered for implementation in consultation with the various participants involved.

2. Keep societal stakeholders at the center

Because a usable science program, unlike basic science, focuses on application of knowledge in society in a relatively short period of time, keeping societal needs front and center in the program is paramount. There is a wide spectrum of potential users of information, and given that resources are limited, only certain stakeholders will be involved. The process of selecting stakeholders or justifying focus on any particular problems will need to be transparent and clearly justified. The involvement of non-researchers in the research process will require a mediated interface of some kind, whether a project contact, an existing boundary organization, or an office. Such an interface allows a more "iterative" process between researchers and stakeholders, which is often necessary for effective co-production of knowledge.

3. Allow dedicated "program" space and funding

Participants agreed that creating a usable carbon science program would build on existing programs, adding and extending them while maintaining feedbacks that informed the established basic science programs. Funding would be necessary to entrain researchers into this area, and projects could be selected through an "RFP" (request for proposal) process, although perhaps one with more flexibility for interdisciplinary, interprofessional research (e.g. scientists, engineers, and non-technical decision makers) than currently exists in the carbon landscape. The encouragement of linkages between science and technology programs was seen to be helpful.

4. Develop appropriate criteria to approach research

Discussion centered on allowing community flexibility in responding to the call for usable carbon science, while acknowledging that the evaluation process for proposed projects would need to build in perhaps different metrics in addition to traditional scientific ones, if indeed the outcome is to effectively meet the desired goal. If the criteria are specific to the ways, methods and outcomes of producing usable science, rather than being prescriptive of the users, tools and disciplines, then projects are able to be proposed in a creative manner that still meets the objectives of the overall program. Such criteria might include, does the project have an effective mediated interface between knowledge producers and potential stakeholders, or even does the project build in co-production of knowledge? What are the proposed deliverables of the project, do they attend to the desired goals of usable science? Participants noted that allowing maximum creativity in choice of problem and user would likely yield the earliest success in soliciting quality projects.

5. Foster novel mechanisms to evaluate success

One of the features of a successful science policy to create usable science is accountability, in other words, there are means to measure or document that the results of a project meet the goals of the overall program. All projects are in some sense accountable to their sponsors, but those that aim to be usable science may need to explore alternative mechanisms beyond simply counting peer-reviewed papers, conference talks, graduate students trained and the like. If the desired outcome is to produce usable science, then new ways of judging success toward this end will need to be described and implemented. This workshop did not specifically name these mechanisms, but several models exist for evaluating this type of work that could be looked to for a starting point for carbon cycle science.

Sample Models and Components:

Carbon cycle science likely has unique characteristics that may make it more amenable for one type of programmatic structure than another to create usable science. It was not clear to participants which models would be best, although clearly some are more likely to produce usable science than others.

Models:

- "Basic Science" or "Linear" Model: This model posits that science is produced by scientists in disciplines, largely separate from societal considerations. The results of science are then taken into societal decision making by other entities. This model has been extensively critiqued for its inefficiency and often inability to meet the current needs of society for information. Nonetheless it is a powerful model that permeates much of our science policy today.
- "Meditated" Model: This model suggests that the creating of usable science is "mediated" by a process, institution, or individual that deliberately connects and integrates the production of knowledge with the needs of society. These models can exist as boundary organizations (e.g. the Agricultural Extension Service) that do not do much research themselves but serve as two-way translators between entities, as research projects that have deliberately structured themselves to involve individuals from other institutions who might utilize information as part of the research process (e.g. several of the Regional Integrated Sciences and Assessment projects), or as whole programs that mediate the interface between society and researchers through deployment of resources and establishing criteria for success that include use of information in society (Climate and Societal Interaction program of NOAA, NASA Applications program). Such models may focus on a sector, a specific problem, on a level in society (e.g. state), or on a geographical region (e.g. the Southwest).
- "Stovepipe" Model: This model is not generally one that institutions seek to create, but is often the result of trying to categorize science into logical categories. In order to seek organizational practicality, projects may be divided into grouping based on discipline, sector, or region. This model is described here not as one to emulate, but simply to point out that mechanisms are needed to avoid the stovepipe model, especially in the area of usable science, as societal needs are often multifactor and decision makers must be able to make use of knowledge from a broad range of categories.

Participants also discussed some of the characteristics that should be considered if one desires to create a usable carbon cycle science program or entity. These include creating flexible mechanisms, at least a two-way flow of information between knowledge producers and users, if not fully integrated co-production of knowledge, and developing mechanisms to involve users in science policy execution, whether through aspects of setting the agenda for usable science, the process by which it is implemented, the prioritization and selection of activities, and the evaluation process. If possible, participants felt that continuous involvement or at least frequent opportunities for interaction was a key component. Interdisciplinarity was also deemed to be quite important for successful usable science activities. Processes should reflect an awareness of decision making in the "real world," bringing stakeholders or participants into the process of creating usable science early, and look forward to how information might continue to get out on a long term basis--in other words, how do projects transition to operations? In terms of who might be interested in this process it is important to consider multiple agencies as potential customers for information, as well as the community beyond the federal government. For practical implementation terms, options for usable carbon cycle science program might be structured so as to be implementable at different levels, depending on the level of resources and interest among potential sponsors. Partnerships of course were also quite important in order to be able to leverage resources, including in kind contributions.

NEXT STEPS

Participants were enthusiastic about the many potential next steps that could be taken. These steps included inserting language into documents and processes that would ensure consideration of usable science activities. Processes at the international level in particular are looking for ways to improve the science-society dialogue (see for example InterAmerican Institute-IAI, Asia Pacific Network-APN, and the recent ICSU-International Council of Scientific Unions- Strategic Plan). It was suggested that perhaps the NRC could conduct a study of this issue modeled after the 1999 study led by Bill Easterling entitled "Making Climate Forecasts Matter."

In terms of written documents, it was variously suggested that a "one-pager," a synthesis paper and a white paper would be useful in different venues. Various science policy leaders within and without the agencies could be informed on the results of this workshop, with a short 1-2 page document and accompanying visits. Summaries to society journals, newsletters, bulletins, international program newsletters, etc., would help to build interest among the scientific community at large. Outreach beyond the scientific community of course is very important in diagnosing or establishing what society might need from carbon science efforts- this might include going to trade organization meetings, government association meetings, and writing articles of interest for those organizations.

Participants suggested a myriad of venues for discussing carbon information and entraining participants from different sectors who might be interested in usable carbon cycle science. These suggestions included the Western Governor's Association, various user groups, fire safety councils, local government, decision makers from regional databases, program managers, the Carbon Cycle Interagency Working Group, and so forth. There is a need to build interest and focus on concrete examples as this networking is accomplished.

Participants suggested that a two-week summer institute or perhaps a shorter one might be of interest to being to build a community interested in usable carbon science. Such an institute might include tutorial material, hands-on experience, and involve direct experiences with intermediaries. Visitors and speakers could be brought in for a few days if they couldn't make the whole time. Such an activity would need an aspect of continuity as well—one shot activities don't generally work as well. Follow-through could include creating a network of individuals that could be a source of interaction for the future. Participants were quite enthusiastic to continue dialogue and effort for this topic in the future.