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Towards science in support of decision making: characterizing the supply of carbon cycle science

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ABSTRACT

As concern about climate change grows, so does interest in deliberately managing the carbon cycle to reduce atmospheric concentrations of carbon dioxide. Given the scientific and technical nature of knowledge of the carbon cycle, one would expect that carbon science would be directly of use to society in considering this objective. However, carbon science is not currently organized or conducted in such a way that it can be usable to the wide diversity of decision makers who might potentially be involved in managing the carbon cycle. This paper reviews the science policies and actors governing the production or ''supply'' of carbon cycle science, and suggests alternatives for enabling the supply to better meet demand.

1. Introduction

The publicly funded U.S. Climate Change Science Program (CCSP), of which carbon cycle science is a major component,[1] has a stated goal of providing ''usable information on which to base policy decisions relating to global change'' (U.S. Global Change Research Information Office, 2004).[2] Indeed, most carbon cycle scientists and climate change scientists would likely agree that they wish their research to be useful in addressing societal problems (see for example Sarmiento and Wofsy, 1998; Wofsy and Harriss, 2002).[3] What is considered ''usable'', of course, can vary from different perspectives, but it is clear that Congress intended this research program to provide information that would be useful for decision making outside of the scientific and academic community. Moreover, the current administration recently reaffirmed this goal even more strongly by the statement that high priority research areas such as carbon cycle science would ''best support improved public debate and decision making in the near term'' (U.S. Climate Change Science Program, 2003a). However, two outstanding, unanswered questions remain. How does carbon science ''best support'' debate and decision making, and how do we judge that such support is leading to ''improved'' debate and decision making? On the whole, carbon cycle science to date has not engaged in seeking the answer to these questions.

Many different sectors of society and levels of government are now interested in managing carbon, from the local to the national scale (Dilling et al., 2003). These decision makers

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[1] What is carbon cycle science? Carbon cycle science, broadly defined, is the study of how carbon, in its many forms, cycles through the earth system. It includes the study of carbon moving through the ocean, atmosphere, and terrestrial reservoirs. Carbon cycle science also includes the study of how carbon is added to the atmosphere by human activity (emissions) and how human activity alters exchange processes such as through land use. Because carbon is a part of all living (and many non-living) systems on Earth, many fields and disciplines contribute to understanding the carbon cycle.

[2] For early evaluation of USGCRP with respect to ''usable science'' see Pielke (1995) and Pielke and Glantz (1995).

[3] Nearly every report written by carbon cycle scientists states this; more formally, institutions such as the National Science Foundation embrace this now through their review criterion 2 of ''broader impacts'', and certainly anecdotally, most of my colleagues in research hope or assume that their work will be useful in some way.

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include non-profits trying to broker carbon trades or offsets, farmers and agricultural organizations, forestry managers, policy makers interested in incentivizing land use, city managers trying to reduce their carbon "footprint", policy makers at the state and Congressional level interested in reducing carbon emissions, and so forth. Carbon science may be of use to these groups, but we have little information on what they might need, at what scale, and in what context.

Information that is created and disseminated without awareness of and engagement with intended users generally fails to be usable (NRC, 1999; Pielke and Glantz, 1995; Pulwarty and Redmond, 1997). In the context of seasonal to interannual climate forecasting, for example, for science to be 'usable' meant that those affected by climate variability could take advantage of the advance warning about climate conditions in order to prepare or respond and improve their outcomes. The reasons that climate forecasts were not usable included the fact that the intended recipients did not receive or understand the information, the deliverers were not trusted, the information was not relevant to specific decisions, and so on. Lemos and Morehouse suggest that usable knowledge has several specific characteristics: it should "directly reflect expressed constituent needs, should be understandable to users, should be available at the times and places it is needed, and should be accessible through the media [meaning mechanisms of obtaining information] available to the user community" (Lemos and Morehouse, 2005). I would add that a corollary of this is that for science to be usable, it must have a target audience of decision makers who are making decisions in the reasonably near-term (whether the consequences of those decisions are near- or long-term).

These studies reflect a growing recognition within small pockets of the climate sciences community that creating science isolated from application in society and then expecting it to be useful to others is simply not usually effective. Although on parallel disciplinary tracks, calls to recognize the contextualization of science (or "mode-2" science) that aims to be relevant to society have been common from scholars in science and technology studies in the past decade (Jasanoff, 2003; Jasanoff et al., 1995; Nowotny et al., 2001; Sarewitz and Pielke, this issue). Nowotny et al. argue that modern science in industrialized societies has always been contextualized, i.e. that it reflects a "particular culture and set of social arrangements" (Nowotny et al., 2001, p. 121). Despite this observation, however, the practice of science has "developed an ethos of separation from its surrounding society" (Nowotny et al., 2001, p. 122; Cozzens and Woodhouse, 1995). As a result, they argue, much of the research funded by governmental programs has been only weakly contextualized, or only weakly able to apply to the specific problem contexts of current society. In proposing a framework to guide the production of contextually sensitive or "mode-2" science, Sarewitz and Pielke (this issue) suggest that new ways must be found to produce "science that is maximally responsive to the needs and values of those who may have a stake in the outcomes of the research" in other words, to better connect supply and demand and create "usable science".

The history, process, institutions and practices involved in creating the supply of carbon cycle science have not questioned how best to produce usable knowledge. For much of recent history, the science policies and cultural paradigm governing research have implied that usable knowledge would emerge from basic research created unfettered by considerations of use (Stokes, 1997). The supply of carbon cycle science has therefore been prioritized primarily by scientific interest in fundamental aspects of the carbon system and by agency missions, with some indirect influence in recent years of international political negotiations on climate. Accordingly, the supply of carbon cycle information that has emerged has only been shaped in a very limited way by societal demand, and at the very least is missing opportunities to serve decision makers' needs. Given that carbon science programs have often stated that they will support decision making, an opportunity exists for carbon science to examine its practices for this purpose. In this paper I review the policies and practices that result in the supply of carbon science that we see today, and suggest that complementary, alternative policies for carbon science may be necessary to more effectively support decision making needs.

2. Post-world War II science policies in the U.S.

The science policies of the United States changed dramatically after World War II (Stokes, 1997). Prior to that time, public funding for science had been fairly small, with U.S. science generally being funded privately and at the state level. Toward the end of World War II and the apparent success of the high-energy physics community at rallying to produce a completely new weapon that was destined to fundamentally change geopolitical relationships, President Roosevelt asked for advice on how to ensure that such scientific talent was sustained and even augmented in the post-war years. Responding partly to fears of potential interference with or "fettering" of science, the final report led by Vannevar Bush both advocated for increased, stable public funding for science and advanced a clear paradigm about science's role in society. The report advocated that basic research should be performed and supported without thought of practical ends, while at the same time the results of basic research would be the pacemaker of technological improvement (Bush, 1945; Stokes, 1997). This paradigm has been accepted deep into the culture of the scientific enterprise and results in a "linear model" of thinking about how science translates into use by society—basic research is conducted without thought of practical ends, and then in a deliberately separate process, said research is picked up for application, use and societal benefit (Stokes, 1997). The deep-rooted assumption implicit within this paradigm, which again, emerged from the spectacular success of the application of physics to making the atom bomb, is that basic research is inherently useful and applicable to the myriad of problems that society may face.

The somewhat paradoxical paradigm that basic research conducted separately from consideration of societal need is the best way to advance societal improvement has dominated most scientific institutions, cultures and the scientific process itself for over a half a century in the United States (Stokes, 1997). Carbon cycle science is certainly no different. From the start, carbon cycle scientists, and indeed, climate scientists, took on the specific problem of the global impact of humans on the Earth by embracing the linear model and conducting basic research in the belief that it would aid in the solution of the problem.[4] For the most part, carbon cycle science has operated strictly according to the linear model—information is placed on the "loading dock", and it is someone else's responsibility to take the information away and use it. Implicit in this characterization is that (1) there is someone out there to "pick it up from the loading dock", and (2) that the "package" waiting at the loading dock for society is indeed what is needed or usable by the intended recipients.[5] This method of serving the needs of society relies heavily on serendipity—serendipity that the information provided is what is needed, and serendipity that someone will come along and use the science in the appropriate manner to improve the human condition. As a community interested in ameliorating the critical problem of climate change, carbon cycle scientists now have the opportunity of reflecting on more than 30 years of history to test the efficiency of this model, examine its merits, and evaluate alternatives.

3. Science, climate and the carbon cycle

Scientists have led the way in alerting the public to the threat of climate change from increasing carbon dioxide and in calling for research to address the issue. In the early 1950s, articles in the media began to report on the issue of climate change, but did not suggest it might be a problem (Weart, 2003). Roger Revelle, a leading oceanographer who later became a professor in public policy working on applying science and technology to solve world hunger, was one of the first scientists to warn that excess carbon dioxide in the atmosphere might create negative climate impacts. He testified to Congress in 1956 and 1957 while advocating for more funding for geophysical research and the International Geophysical Year, calling the Earth "a spaceship" and that we should 'keep an eye on the air control system'; i.e. conduct observations and research (Weart, 2003). In 1965, Revelle led the President's Science Advisory Committee Panel on Environmental Pollution that produced the "first authoritative U.S. government report in which carbon dioxide from fossil fuels was officially recognized as a potential global problem" (National Aeronautics and Space Administration Earth Observatory, 2006).

Geophysicists in particular played an active role both in identifying the potential problem, and in advocating for basic research in geophysics, and later biology, to tackle it. As is true today, the scientific community in the form of the National Academy of Sciences (NAS) and ad hoc workshops organized by agencies played an important role in advocating for research on climate change. In the 1970s, more than 20 different reports, conferences and even Congressional bills called attention to climate as a societal problem (National Climate Program Office, 1980). Importantly for research on human-induced changes in climate, including carbon cycle research, a National Research Council (NRC) Panel on Energy and Climate was convened in 1974 to study the issue. The study and panel were chaired by Revelle and organized under the auspices of the Geophysics Study Committee of the NRC, who provided guidance to the Geophysics Research Board on conducting studies related to geophysics. As stated in the preface to the report, one purpose of these studies was to "provide assessments from the scientific community to aid policymakers in decisions on societal problems that involve geophysics" (NRC, 1977). This report in particular was intended as a preliminary step in a process "aimed at placing in the hands of policymakers credible information on the most likely climatic consequences of major dependence on fossil fuels as a source of energy for an increasingly industrialized society" (NRC, 1977)

While the report did acknowledge that "the prospect of damaging climatic changes may thus be the stimulus for greater efforts at energy and conservation and a more rapid transition to alternate energy sources than is justified by economic considerations alone", its primary highlighted recommendations for the future centered on basic biogeophysical research (NRC, 1977). While topics such as food supply, energy and agriculture were mentioned, the primary recommendations centered four main topics: carbon cycle, climate, ocean–atmosphere interaction, radiation balance, and ocean–atmosphere monitoring. Carbon cycle science figured prominently, including research on rock weathering, calcium carbonate precipitation, ocean tracers, ocean circulation, biological and chemical processes in the ocean, and measurement of the terrestrial organic carbon pool. Because the research was defined as global in scale, the report recommended a worldwide comprehensive research program to be coordinated by international bodies such as the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) and the International Council of Scientific Unions (ICSU).

The linear model is implicitly invoked in the preamble to the recommendations themselves: "we can now summarize what will be needed to improve our understanding of the phenomena involved in the carbon dioxide problem ... to *close gaps in knowledge, so that future decisions regarding the*

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[4] The term "basic research" has many interpretations, including "research without thought of practical ends" (V. Bush's original definition), "curiosity-driven research", and "research in the quest for fundamental understanding". The term is generally used in opposition to "applied research", where there might be a direct application to an immediate or long-term need or technology. The concept of "basic research" has been adapted, however, over the past several decades and is often used to identify research done within mission agencies, e.g. "mission-oriented basic research" and even the agencies charged with "basic research" often include criteria to imply a more direct practical end, such as education and outreach. There can also be different perceptions and categorizations on the part of scientists and sponsors – and Kidd noted several decades ago that universities reported twice as much Federal support for basic research as the government thought it was providing – a difference in goals held by the two types of institutions (Stokes, 1997, p. 79). For the purposes of this paper, the term basic research is used to characterize carbon cycle science, because for the most part there is not an immediate application (so it is not appropriately called "applied") and the processes used to govern the research enterprise are consistent with the basic research end of the continuum. For more on these ideas see Stokes (1997).

[5] These notions have been discussed at length for the usability of climate forecasts (NRC, 1999).

exploitation of energy resources can be made on as sound a basis as possible (emphasis added)'' (NRC, 1977). The fact that basic research is called out specifically as an aid to decision making, but without recommendations as to how to make that connection to decision making, is a direct reflection of Vannevar Bush's paradigm at work. The corollary to this paradigm, also evident in the NRC statement, is that by closing gaps in knowledge in basic science, we will actually *improve* the decisions that are made (i.e. decisions will be made ''on as sound a basis as possible'').

Such statements are typical of program planning and advocacy for research programs in the carbon cycle science research area. Geophysicists and other atmospheric and oceanographic scientists had identified a potential problem, and in keeping with the operating paradigm, they made the case that further research in those topic areas would be necessary in order for society to solve the problem. But this paradigm was not only accepted by the scientific community, it was also accepted by governmental structures allocating public funds—clearly U.S. society had indeed agreed that basic research in carbon cycle science was necessary to inform decision making on climate. Scientists were therefore not alone in assuming that basic research was what was needed to address this emerging problem. Many Federal agencies also subscribe to the ''linear model'' paradigm that basic science is a direct solution to the problems society faces.[6]

4. The U.S. Department of Energy as an early sponsor of carbon cycle science

The Energy Research and Development Administration (ERDA) was an early leader in mounting a coordinated, focused carbon research program. A precursor to the U.S. Department of Energy (DOE), ERDA was formed in the wake of the 1973 oil embargo and associated concerns about energy supply.[7] ERDA was created from the Atomic Energy Commission (1947–1974), which was created after the war out of the Manhattan Engineer District (1942–1946), the unit in charge of organizing and sponsoring research to build the nation's first atomic weapon. One might speculate that the institutional history of this agency makes it more likely that the basic science conducted therein would be conducted separately from considerations of use—it was scientists after the Manhattan project was completed who were particularly vociferous in objecting to continuing the ''fettering'' of research that had begun during the atomic weapon effort (Stokes, 1997, p. 49; Fehner and Holl, 1994, p. 11).[8]

Carbon cycle science in DOE was originally housed within the Office of Basic Energy Sciences, which administered ''basic, mission-oriented research programs'', and then later DOE's Division of Biomedical and Environmental Research, which ''conducts studies to determine the health and environmental effects associated with high-priority energy technology developments and conservations options'' (US DOE, 1979b; US DOE, 1988). In 1977, this Division convened a workshop to examine the carbon dioxide problem as a result of ''the growing concern about the long-range consequences of carbon dioxide emissions resulting from ever increasing fossil fuel consumption'' (US DOE, 1979a). The workshop brought together leading carbon cycle scientists (or those who would become known as such in their later careers) and asked them to assess current knowledge of the CO_2 cycle and the consequences of increases in CO_2 content. They were also asked to identify significant gaps in understanding and for recommendations on action to fill those gaps (US DOE, 1979a). The implication of this charge to the workshop reflects the assumption that additional carbon cycle research would help to address the potentially negative consequences of rising CO_2. While the introduction to the report stated that there was not ''yet enough understanding ... to state with confidence that increased fossil fuel consumption will bring on catastrophic climate changes'', the best current estimates do indicate potential problems; it ''behooves all to heed the warnings inherent in these calculations and support efforts to reduce the uncertainties of the predictions''. Like the 1977 National Academy report, this report recommended basic research in a number of areas of uncertainty in carbon cycle science, including new techniques for measuring atmospheric concentrations and isotopic composition, instrumentation to measure fluxes and biological effects, ocean geochemistry measurements, and understanding climatic effects on the carbon cycle (US DOE, 1979a, pp. 1–6).

By 1979, the 1-year old U.S. Department of Energy (DOE) had incorporated carbon dioxide and climate research into its

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[6] In the decades to come, as Shackley and Wynne (1995) demonstrate, investment in General Circulation Models (GCMs) came to dominate global climate change science, not only because of the desire of the scientists involved to pursue that specific research methodology, but also because of the perceived policy need for more certain trajectories of future climate change. Both science and policy makers had an interest in this particular direction for research, even though the scientific knowledge at that time was not yet being used directly in decision making and indeed was not yet useful for decision making. The emphasis on future predictions effectively results in delaying consideration of currently available actions or excluding alternatives for consideration in policy (Sarewitz et al., 2000; Shackley and Wynne, 1996). Shackley and Wynne argue that such research is ''mutually constructed'' rather than being strictly separated, although application of such research to near-term decision making remained elusive and therefore would not be considered ''usable'' for the purposes of this discussion.

[7] For an early articulation of research priorities, see USERDA (1975, p. VIII-11).

[8] Incidentally, even as early as 1978, the Office of Technology Assessment (OTA) of the U.S. Congress questioned whether this research strategy was effective. They suggested that the research management policy outlined in the ERDA plan carried over from the Atomic Energy Commission and was in fact ''polarized'', meaning that basic and applied research were separated. OTA went further to suggest that this ''approach can tend to isolate scientific and engineering research and, therefore, has not produced innovative advances in technology'' comparable to institutions where applied and fundamental research is carried out under the ''cooperative leadership of scientists and engineers'' (OTA, 1978, p. 34). They suggested that both engineers and scientists had strengths and weaknesses to bring to the table, and that scientists in particular ''do not generally apply their insights to the solution of practical problems when they are isolated from engineers and participating in mission-oriented problems''.

activities and its annual report to Congress. The report stated that the DOE was developing a program in this area with the goal to ''predict the environmental, social and economic costs of increasing atmospheric concentrations with sufficient confidence to permit policy decisions to be made on the future use of fossil fuels'' (US DOE, 1979b, p. 112). It was not stated what ''sufficient'' confidence would be, but the carbon cycle portion of the program involved studying the fluxes of carbon dioxide between Earth system reservoirs, monitoring atmospheric concentrations, obtaining past records of carbon dioxide and modeling the carbon cycle (US DOE, 1981, p. xi). As a program manager familiar with the effort states, the goal of the DOE carbon cycle science program in those days was to ''quantify source and atmospheric response relationships so we could put confidence into measurements of the secular trend''.

What he meant in a nutshell was, because only about half of the CO_2 released by human activity stays in the atmosphere, that the program should focus on where the rest was going, and to directly quantify those reservoirs—in other words measure or model the ''carbon budget''. A great deal of effort has been spent on understanding both carbon sources, meaning the activities or mechanisms that release CO_2 to the atmosphere, and carbon sinks, meaning mechanisms that absorb CO_2 out of the atmosphere into the land surface or ocean. Until the past decade, most of this work centered on the global scale, with work in the 1970s, and 1980s focusing on global carbon ''budgets'', or accounting for where all of the human-released CO_2 was going. An important debate centered on the role of terrestrial ecosystems in the carbon budget—whether they were a net source or sink (Bolin, 1977; Broecker et al., 1979; Detwiler and Hall, 1988; Woodwell and Houghton, 1977; Woodwell et al., 1978). Questions about even the sign (net sink or source) of the terrestrial component of the carbon cycle persisted even into the 1990s (Wisniewski and Sampson, 1993). Research programs since the 1970s have therefore been implemented to investigate key uncertainties in resolving the global carbon budget, such as global surveys of ocean carbon concentrations and circulation patterns,[9] as well as numerous modeling, atmospheric and terrestrial studies organized at various scales.

While these studies definitely would be considered clearly in the domain of basic research, agencies continued to view them as instrumental in solving the problem of climate change. In 1983, DOE stated that the goal of the program was ''the identification of possible policy options for governmental action in response to these changes (meaning the effects of increasing atmospheric CO_2 on climate)'', and that ''the achievement of this goal requires a significant increase in our scientific knowledge of the atmosphere, the biosphere, the oceans and the cryosphere...'' (US DOE, 1983, p. v). This again represents the institutionalization of the linear model advanced by Vannevar Bush. Indeed, an early schematic representation of the full DOE Carbon Dioxide and Climate Program laid this principle out graphically—interconnecting basic research foci in carbon cycle, climate, vegetation, and so on, flowing through a one-way arrow to evaluation of possible controls (which had a feedback to the research), then a one-way arrow to assessment, options, and finally, decisions as an end point. So, fundamental research in carbon cycle science was seen as the foundation for ultimately supporting decision making. Notably, however, the research agenda did not include ''identification of policy options''—this appears to be an area outside the domain of the program as graphically represented.

The DOE Carbon Dioxide and Climate Program grew in budget and conducted significant basic research into the carbon cycle throughout the decade. In the early 1980s, DOE spent a peak of approximately $11 M a year (adjusted 2004 dollars) on carbon cycle science research (Fig. 1). Other Federal agencies such as the National Science Foundation also conducted significant amounts of carbon cycle science, but the DOE program in carbon dioxide and climate research represented as much as 45% of the national effort at that time (Fehner and Holl, 1994, p. 50). But this was pocket change in comparison with the amount of funding spent on carbon cycle science research across the government once a new nationally organized program came on the scene—the U.S. Global Change Research Program.

5. The era of the U.S. Global Change Research Program

As is typical with efforts to launch large scientific programs, part of the backing for the formation of the USGCRP came from an organized scientific community. In 1988, an NRC committee, the Committee on Global Change, issued a report detailing recommendations for U.S. research contributions to the then fledgling International Geosphere-Biosphere Program (IGBP) which was to focus scientific effort in an interdisciplinary, large-scale coordinated effort on the problem of global change. While still concerned with carbon dioxide, greenhouse gases and climate change, the focus of this committee also included the broader impacts of a ''host of other changes in our environment'' and emphasized that the ''problem of global environmental change is crucial and urgent'' (NRC, 1988). Nonetheless, many of the recommendations of the report are startling familiar to the Energy and Climate report of 1977.

In keeping again with the dominant paradigm, the committee stated that ''the prediction and ultimate management of environmental problems inescapably require development of a new earth *system* science aimed to improve understanding of the earth as an integrated whole (emphasis in original)'' (NRC, 1988, p. 2). Here, the assumption again is that additional information will help society to better manage environmental problems. The new twist is that these disciplines and research streams must be integrated, reflecting the reality of the system itself. While the phrasing and some of the emphases had evolved since 1977, the dominant recommendations focused on familiar categories of basic science—developing models (this time of ecosystems, not just

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[9] For example GEOSECS (Geochemical Ocean Sections) expeditions in the 1970s, the TTO (Transient Tracers in the Ocean), SAVE (South Atlantic Ventilation Experiment) of the 1980s and the 1990s CO_2 Survey (Feely et al., 2001). The Global CO_2 Survey was implemented cooperatively under the auspices of two international scientific programs, the Joint Global Ocean Flux Study (JGOFS) and the World Ocean Circulation Experiment (WOCE).

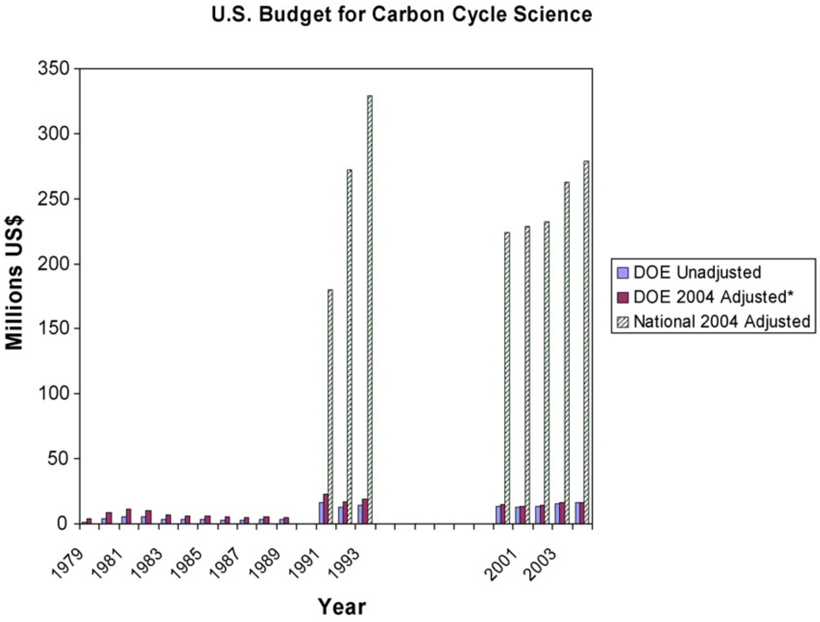

Fig. 1 – Federal funding for carbon cycle science research in the United States from 1979 to 2004. Figures are reported from the following sources: 1978–1984, Carbon cycle research plan 1984 page 36 (red book); 1985–1989, Carbon Dioxide and Climate: summaries of research in FY1989 (red book)—numbers are ballpark from graph page xii; and Our Changing Planet 1990–1993, and 2000–2004. Dollars were adjusted to 2004 dollars using the consumer price index calculator at http://woodrow.mpls.frb.fed.us/research/data/us/calc/.

the physical climate system), measurements and monitoring the earth, both from space and in situ, biogeochemistry of ocean systems, fluxes of materials through the earth system, earth system history, and human interactions with global change (NRC, 1988, p. 2–3).

The U.S. Global Change Research Program (USGCRP) thus emerged through alignment of a political window of opportunity and rare cross-agency cooperation (Pielke, 2000a,b). For the scientific community and scientific agencies, it was a chance to advance research agendas in preparation for over two decades. An internationally linked research program put forward by an organized scientific community combined with entrepreneurial executive branch program managers who were cooperating across agencies at the time, offered a solution for an Administration who was pressured to respond to a public increasingly concerned with potential climate change. As a result, the U.S. Global Change Research Program (USGCRP) was formed by an act of Congress in 1990 (Pielke, 2000a,b).

The conditions that allowed this to happen were indeed unprecedented. Establishment of a large, coordination program of climate-related research had been advocated for throughout the 1970s, including in the previously discussed NRC ‘‘Energy and Climate report’’ of 1977. While the National Climate Program Act (PL 95-367) of 1978 did establish by law a National Climate Program Office in 1980, this office failed to achieve its purpose and the large program of research did not materialize at that time (Weart, 2003). By contrast, the USGRCP quickly grew in size within a few years to over $1.7 billion a year and continues to this day, 15 years later, under the name U.S. Climate Change Science Program.

The law that enacted the USGCRP’s mission states that it should provide ‘‘usable information on which to base policy decisions related to global change’’ (U.S. Global Change Research Information Office, 2004). However, from the execution of the program it is clear that the agencies consider their mandate to be primarily the support of basic research according to the specifics of each agency mission.

Briefly, the primary agencies that fund carbon cycle science under the USGCRP (now the Climate Change Science Program) are: the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), the Department of Energy (DOE), the Department of Agriculture (USDA), the National Oceanic and Atmospheric Administration (NOAA, in the Department of Commerce, DOC), and the Department of Interior (DOI; the U.S. Geological Survey (USGS). In the decade of the 1990s and into the 2000s, this has represented a national investment of over $200 M per year (Fig. 1).

The National Aeronautics and Space Administration (NASA) is by far the largest budget element in USGCRP regardless of topic. For example, in FY2002 NASA managed over 70% of the $221 M total dollars allocated to carbon cycle science (not adjusted) (USGCRP, 2002). The growth of USGCRP over the decade of the 1990s was mainly in NASA’s budget with the development and launch of the satellite-dominated EOS (Earth Observing System) and EOSDIS (EOS Data and Information System). NASA’s mission as far as Earth system science is to ‘‘develop a scientific understanding of the Earth system and its response to natural or human-induced changes to enable improved prediction capability for climate, weather and natural hazards’’ (NASA, 2000), ‘‘as only NASA can’’, meaning from space, either through spacecraft, satellites, or high-altitude aircraft. NASA also states that it follows an "end-to-end" strategy in which its work will achieve "maximum usefulness to the scientific and decision making communities" (NASA, 2000). NASA has supported work on biogeochemical cycles and ecological systems and dynamics, through its programs in terrestrial ecology, ocean color (primary productivity measurements), and land use/land cover.

The National Science Foundation contributes the next largest amount of funding to carbon cycle-related research under USGCRP (about 10% of the $221 M in FY2002; NASA, 2000). The NSF funds broadly categorized research and education in science and engineering. Like NASA, or any other Federal agency for that matter, NSF views itself as having a fairly "unique place" in the landscape of funding for scientific research in the United States. Specifically, NSF focuses on funding "basic" research, and is responsible for the "overall health of science and engineering across all disciplines" (NSF, 2004). NSF has historically funded a broad range of carbon cycle-related science, including research in atmospheric sciences, terrestrial ecology and biology, oceanographic research, and earth sciences such as geology.

As discussed above, the Department of Energy (DOE) is a long-time supporter of carbon cycle research, through its Office of Science. The mission of the Department of Energy includes to "advance the national, economic and energy security of the United States" and "to promote scientific and technological innovation in support of the mission" (US DOE, 2006). The Biological and Environmental program, as it is now known, of the Office of Science, conducts research in modeling of the carbon cycle, and quantifying sources and sinks of carbon in the ocean and on land.

The research that the USDA supports, through its many laboratories and field offices or through its competitive grants program, must "benefit consumers and promote agricultural prosperity and sustainable agricultural practices" (U.S. Department of Agriculture, 2005). Until recently, this research was not focused on carbon cycle science, per se, but as interest has grown in the value of agricultural soils and timber reserves as "carbon sinks", the USDA has developed a larger research portfolio in this area. While much of the data that the USDA collects on agriculture and timber is related to carbon cycle studies (such as inventories of forest biomass), it generally must be converted or otherwise translated in order to make the data useful for carbon cycle science. Forest inventories are not collected for carbon science purposes, for example, and measure timber volume and forest health, rather than carbon directly. The USDA, however, has the most applied program in carbon cycle science, because this research emerged directly from programs that were closely linked to the fundamental mission of the agency, to promote agricultural prosperity.

The other two agencies that support carbon cycle science funded less than $10 M combined in carbon cycle science research in 2002. The National Oceanic and Atmospheric Administration (NOAA) resides within the Department of Commerce, and has as its mission: "To understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social, and environmental needs" (NOAA, 2004a,b). NOAA maintains the operational global atmospheric greenhouse gas monitoring network, which continues the pioneering effort begun by Keeling in the International Geophysical Year in 1957 (Keeling, 1998). NOAA conducts research on ocean chemistry, air-sea CO_2 exchange, new technologies and experiments in CO_2 monitoring over land, and integrated carbon cycle modeling. The U.S. Geological Survey (USGS) of the Department of Interior, views itself as a science agency with a mission—to provide "reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life" (U.S. Geological Survey, 2006). The USGS portfolio focuses on biogeochemical cycling in lakes, streams and wetlands, carbon cycling and sequestration in soils and sediments, land cover trends, and climate–vegetation change history and modeling. Research has recently targeted Alaska and the Mississippi River Basin.

6. Decision making to create the supply of carbon cycle science

Currently, as we have seen, the prioritization of funding, and therefore supply of carbon cycle science is controlled by a combination of scientists and agency program managers. Both the peer review process and the membership of committees reflect the deliberate separation of governance of the scientific process from "societal influence" (as described in Bimber and Guston, 1995; Jasanoff, 2003). Scientists have influence through peer review, as well as through committees such as those organized through the National Research Council of the National Academy of Sciences. The (generally) anonymous peer review process is a long-standing tradition in academia, and is used to select proposals for funding, papers for publication, and scientists for promotion. Almost all oversight or advisory committees providing input on priorities for carbon cycle science, whether at the agency or national level, consist exclusively of practicing scientists.

Program managers at Federal agencies have always been involved as proximate decision makers as they are responsible ultimately for writing the announcements of opportunity, selecting reviewers for proposals, and ultimately recommending proposals for funding. They receive formal and information input from their major stakeholders, the scientific community, in setting priorities. The program manager is responsive to the overall mission of the agency, and trying to make sure that the research funded falls within that mandate. Projects that are funded generally must meet a standard for scientific merit as judged by peer review, but, equally important, must meet the mission goals of the agency. In this case, fulfilling mission goals for scientific decision makers generally means filling their particular niche, whether it be remote sensing related science, research that advances fundamental understanding, research that focuses on the chemistry of the atmosphere, and so on. The broader question of whether such research actually advances the larger mission of the agency, e.g. protecting life and property, meeting economic, social and environmental needs, or advancing energy security, is rarely ever asked. Accountability rests with committees made up of scientists who periodically review agency programs for their scientific merit (quality of basic research), and appropriateness of research to their particular niche.

Because funding for research is largely through Federal funds, members of Congress, their staffs, the Office of Management and Budget, Agency Administrators, and University/Research Institution lobbyists also play some role in decision making on the priorities and budgets allocated for scientific research. Science agencies propose their budgets to the Office of Management and Budget (OMB), usually after receiving guidance, and when approved by OMB the budgets become part of the President's Budget. The President's budget is then taken to the House and Senate, who will usually develop their own versions based on the President's budget. The greatest calls for "usable science" and science that serves decision making have emanated from decision makers in Congress, who must make their case for research funds against the many other competing priorities of the Federal discretionary budget (e.g. House Committee on Science, 2002). However, even Congress members charged with reviewing budgets for science have been reluctant to challenge the paradigm that "unfettered" basic research will eventually result in societal benefit, with some notable exceptions.[10]

Without a change in fundamental attitude towards empowering the use of information as a central goal for research programs aimed at serving societal needs, the supply of information is not likely to become significantly more usable. The processes that govern the prioritization, selection, advocacy and accountability for research stem from the internal operating norms of the scientific community and are extremely appropriate for basic, curiosity-driven research. Should the community wish to shift their research agenda to one more focused on the needs of society, however, changes in these operating norms would be appropriate.

7. The current supply of carbon cycle science

Clearly, the agencies have each absorbed and follow the post-WWII science policy paradigm and adapted it to their specific niche area such as remote sensing, atmospheric monitoring, and so on. The supply of carbon cycle science has reflected this prioritization, focusing on critical controversies or uncertainties within carbon science, assuming that this information might at some point be useful for societal decision making, but without making the connection directly.

After 30 years or so of established programs in carbon cycle science, later organized under global change, the supply of carbon cycle science overwhelmingly consists of advances in the basic understanding of global budgets of carbon fluxes, process understanding of exchanges of carbon between various reservoirs, measurements of concentrations and fluxes, terrestrial vegetation and ocean chemistry at both a global scale and a very local scale, and models that now couple biogeochemical dynamics to physical elements of the Earth system at a global scale (Houghton et al., 2001, chapter 3). This has been tremendous for advancing basic understanding of the carbon system on Earth. Whether "closing these gaps in knowledge" has allowed for improved decision making, however, is an open question, and the evidence suggests that carbon cycle science is not organized to produce usable information to those outside of the scientific community, especially at more regional and local scales.

Of course research knowledge is sometimes used regardless of whether the knowledge was intentionally created to be usable. Certainly basic research can be and is used in decision processes to support positions, inform decision pathways, and alert the public to potential problems. The iconic curve of rising CO_2 in the atmosphere initiated by Keeling has certainly been used many times both as an alert and to demonstrate to the public the importance of action on climate change. The notion that some excess anthropogenically released atmospheric carbon was currently stored in forests and agricultural soils (sinks) – in other words on land where it could potentially be managed – was of great interest to negotiators in the Framework Convention on Climate Change process. The concept of carbon sinks has become intensely politicized and nationalized throughout the climate negotiations, and information on carbon budgets, whether national or global have certainly been used in positioning and negotiation (Lövbrand and Stripple, 2006). Knowledge can be, and often is, selectively used to support claims or lines of argument on different sides of any issue, often as a substitute for debates over competing values (Sarewitz, 2000).

Highly technical and uncertain scientific knowledge is increasingly being required to implement provisions for carbon sinks based on the Kyoto protocol (e.g. Apps et al., 2003). As a result, especially in nations who have ratified the Protocol, carbon science is becoming more closely linked to particular national policy questions, although simultaneously the importance of the separation of the science from policy is still definitively invoked by actors on both sides of the science–policy interface (Lövbrand, this issue). As Lövbrand discusses, this may result in less transparency in how knowledge is supporting decision making, because although fundamentally connected to policy through largely unseen "knowledge brokers", the actors on both sides are not openly engaged in the discussion of usable knowledge. In the U.S., which has not ratified the Protocol, carbon sequestration is nonetheless of great interest and thus agencies such as the USDA have begun to sponsor research into examining the potential for carbon storage in various land use types and through different management practices (Logar and Conant, this issue). Most of this research is aimed at national level policy making, but some is intended for individual carbon decision makers and the like. This research in the U.S. is however, a very small percent of the carbon cycle science activity, as mentioned above.

8. The context of demand

It is beyond the scope of this paper to do a full analysis of the potential demand side for carbon cycle science; such a study would provide a necessary complement to this analysis of the supply and provide a more complete picture. It is instructive,

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[10] For example Representative George Brown, Senator Wirth, Senator Murkowski, Representative Walker.

however, to note the context under which carbon cycle science has evolved over the years. Demand for carbon cycle science emerged as a response to perceived policy problem in the 1970s—as described earlier, the scientific community offered the research program as a way to resolve some of the fundamental uncertainties about how much carbon was going where. The pattern was to continue until just a few years ago, with the demand for carbon cycle science mainly expressed as a need to reduce uncertainty for future projections of climate (USGCRP, 1989–2005). With the advent of the Kyoto Protocol, and its associated articles that provided for carbon sinks such as planting forests to offset the needed reductions from fossil fuel emissions, interest in carbon science grew stronger as an issue and became described as 'carbon management' (United Nations Framework Convention on Climate Change, 2006). Logar and Conant (this issue) describe the evolution of demand for carbon science in the agricultural sector and note recent directives from the President for carbon sink-relevant research. The 2002 U.S. Farm Bill also specifically calls out incentives for innovative projects involving producers and carbon sequestration (U.S. Department of Agriculture, 2002). This call for research, however, does not necessarily equate to demand for use of the information in decision making. As we have seen with the issue of climate change science in general, investment in prediction and characterization of the global system are not necessarily useful for current decision making and may serve conveniently as a substitute for near term, identifiable actions or prevent the generation of alternative policy options (Shackley and Wynne, 1995, 1996). The demand for knowledge to be used in decision making is strongly dependent on the policy context, and whether a policy consensus has been achieved. In the case of carbon management, such a consensus has not yet been reached in the United States, although individual cities, states, businesses, agricultural interests, non-governmental institutions and individuals are acting to deliberately manage carbon in their own contexts. This audience is likely neglected by the current focus of carbon cycle science and could be evaluated for improving the connection of carbon science to use in societal decision making in the future.

9. Alternative science policies

As we enter the era of "carbon governance", opportunities for carbon cycle science to be usable may exist in agriculture, forestry, local, state, and national government, industry, non-governmental organizations, education, and so on at a variety of scales (Dilling, in press). In order to provide usable information, however, alternate means of creating and disseminating the supply of carbon cycle science must be considered. Scholars of science–society interactions have demonstrated the weaknesses of the traditional science supply paradigm – the so-called "loading dock" strategy referred to earlier – and have persistently called for new ways of organizing the research endeavor to produce "usable" or socially robust knowledge (Cash et al., 2003, 2006; Jasanoff et al., 1995; McNie, this issue; Nowotny et al., 2001; Sarewitz, 1996; Sarewitz and Pielke, this issue; Stokes, 1997). As Nowotny et al. (2001), suggests it is critical that scientific knowledge be reliable, but in this endeavor, it is not sufficient. To be valuable for problem solving in a particular context, knowledge must also be created to be socially robust—that is, it "remains valid" even when crossing disciplines and boundaries into societal use.

Experience shows that in order to produce scientific information that is of use to others beyond the scientific community, the research community cannot merely conduct research in a societal vacuum (Herrick and Jamieson, 1995; Jasanoff, 1990; Parson, 2003; Pielke and Conant, 2003; Pulwarty and Melis, 2001; Pulwarty and Redmond, 1997; Russell, 1992; Sarewitz, 1996; Stokes, 1997). The concept of "co-production" is a useful one that has permeated much of the recent scholarship on how to achieve more usable science (Jasanoff and Wynne, 1998). Co-production is "the act of producing information or technology through the collaboration of scientists and engineers and non-scientists, who incorporate values and criteria from both communities" (Cash et al., 2006). Researchers must interact with, test, and constantly factor in the needs of real users with intentionality. Placing the user or a real use at the center of focus, rather than the resolution of scientific controversies, requires a change in mindset. It also suggests that an early step of the research program is to identify which users are to be served, with which specific problems, and over which time and space scales. An understanding of what "usable science" means to the group of intended users cannot be assumed but must be discovered through interactions with users themselves, or through their proxies such as boundary organizations (Lemos et al., 2002; Lemos and Morehouse, 2005; Ray and Webb, 2000). Then, considerations of use must be incorporated into the research strategy. Other scholars have identified criteria such as credibility, legitimacy and saliency as three critical elements that must be in place in the production of information in order for such information to be useful and incorporated into decision making (Cash, 2001; Cash and Clark, 2001).

Once such an orientation toward practical use takes place, the research may require radically different components, and indeed, ways of organizing. McNie (this issue) provides an extensive review of the various mechanisms used to implement improved connections between scientific knowledge production and use, such as boundary organizations. Cash et al. (2006) suggest that attention must be paid to the four functions of convening, translation, collaboration and mediation when aiming to co-produce knowledge. This type of organizational commitment differs from the more informal connections between knowledge generators and policy makers that already exist for many topic areas and that also affect the flow of information from the scientific community to policy and decision makers. For example, as described by Lövbrand (this issue), close relationships have already developed between carbon cycle scientists and policy entrepreneurs working at the international negotiating level. As Lövbrand describes, carbon cycle science in Sweden is intimately connected to policy needs at the national level, although both sides claim independence of each other. The individuals involved are definitive examples of the "knowledge broker" described by Litfin, whose ability to frame and interpret scientific knowledge is a "substantial source of political power" (Litfin, 1994, p. 4). Another possibility for connecting science to decision making is the establishment of epistemic communities. Epistemic communities are ''networks of knowledge-based communities with an authoritative claim to policy-relevant knowledge within their domains of expertise'' (Haas, 1992: as cited in Jasanoff and Wynne, 1998). Epistemic communities can play a role in representing broader views on science and technology. Communities of this type may well form around issues of carbon management, such as geologic sequestration or ocean fertilization, although those other than scientific communities are not yet highly organized in the United States. The environmental non-Governmental organization community may be performing such a role for terrestrial carbon sequestration, as for example, both World Resources Institute and the Nature Conservancy have been very active in promoting projects and accounting standards.[11]

Of course one must acknowledge the very real dilemma that both scientists and society experience over how much to ''steer'' science toward specific goals. The paradigm that emerged after World War II in the U.S. and elsewhere emphasized the autonomy of science as a reaction to the horrors of science being ''steered'' toward unacceptable ends under totalitarian regimes during the war (Merton, 1942: as cited in Nowotny et al., 2001). Merton's ideal suggested that under a functioning democratic system, science could best serve society by being unfettered and autonomous. As Nowotny et al. and others have described, such an ideal has been challenged by the realities of business-university relationships, scandals in peer-review, elite decision making on controversial technologies and increasing scrutiny of science budgets since the end of the Cold War. The promotion of ''co-production'' of knowledge and contextual or ''mode-2'' science has emerged as a response to these critiques and challenges. Advocates for such strategies do not mean to promote the usability of science in undemocratic ways—far from it. They aim to bring out into the open the underlying value commitments and priorities of society and the scientific community in the pursuit of knowledge for the public good. While such processes must naturally guard against capture by undemocratic tendencies, they are envisioned by advocates to support more democratic decision making and access to scientific knowledge, not curtail them.

10. ''Missed opportunities'' to shift the supply of carbon cycle science toward usability

Given the current paradigm and decision makers responsible for determining the supply of carbon cycle science, it is not surprising that the supply that has emerged overwhelmingly consists of basic research geared to resolving and understanding fundamental uncertainties in the carbon cycle. But what alternatives exist for ensuring that science more effectively meet societal needs? Sarewitz and Pielke (this issue) have introduced a framework for science policy research in this area, known as ''reconciling supply and demand'' for research. Situations where supply and demand are mismatched is known as a ''missed opportunity'', whether for research to serve a decision maker's need, or for a decision maker to take advantage of currently unused research. The phrase can also be thought of more broadly as those times when ''opportunities to connect science and decision making have been missed''. In its programmatic history, carbon cycle science has actually experienced at least three ''missed opportunities'' that could have been capitalized on to produce a more usable supply of information. That these were not followed up with to any degree suggests that the dominant paradigm of the past 60 years is extremely powerful and challenges have been met with effective resistance, either from the scientific community or the institutional system itself.

The first missed opportunity was experienced within the early DOE planning and implementation of a carbon cycle research program. Within the ''Carbon Dioxide, Environment and Society'' program that encompassed carbon cycle research, program plans had outlined a research strategy that included research on the ''ameliorative or adaptive strategies and technologies'' and ''assessment of the environmental and social costs and benefits'' for the effects of increasing atmospheric carbon dioxide concentrations (US DOE, 1979b, p. 112). A workshop on the environmental and societal consequences of a possible CO_2-induced climate change specifically included experts on the use of scientific knowledge in decision making, and recommended steps be taken to include such research in the program (US DOE, 1980a). Small amounts of funding (approximately 8% of the entire DOE carbon dioxide and climate budget—and no other agency funded such research) were allocated to research dealing with options, decision making, assessments and institutional choices in FY1980 (US DOE, 1981). The director of the Carbon Dioxide and Climate Division at that time, Dr. David Slade, was also personally interested in more than the basic science conducted within his program. As he muses in his introduction to a workshop report from 1980; ''. . .perhaps it would be more useful if we would design fossil fuel use strategies that would permit us to manage release rates of CO_2 so as to keep the CO_2 concentrations at ''acceptable levels''. . . do we know enough to about the carbon cycle now to develop a . . . management strategy that would limit atmospheric concentrations of CO_2 to some predetermined level? If the answer is no, . . . is our research program properly directed to obtain it? What should we be doing that we are not now doing?'' (US DOE, 1980b, p. xiii). However, by 1983, Dr. Slade had been removed from his position, and the boundaries of the program retreated to the familiar carbon cycle science and climate dynamics basic research separated from human decision making or policy. According to a program manager familiar with the history, Dr. Slade's foray into linking to intended end users was seen as an ''experiment'' that ''did not go over very well''. After that time, the guidance from the agency was ''even more strong: just focus on the science''. The program did go on to produce several ''State of the Art'' reports summarizing the state of the science, and funded international scientific committees and those at the National Research Council, but reports and assessments remained the extent of engagement with the public. Clearly, then, there are legitimate fears of attempting to make more direct connections between those who might use research information and the production of that information supply. In

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[11] For example http://climate.wri.org/carboncapture-project-226.html and http://www.nature.org/initiatives/climatechange/work/ (accessed August 1, 2006).

any event, the opportunity to perhaps shift the supply of carbon cycle science was missed.

The second missed opportunity occurred as part of the planning for the National Climate Program in 1980, of which DOE was a major participant. The National Climate Program Act (PL 95-367) that established the program, emphasized the fact that information existed that could potentially help in decision making, but was not being used: ''information regarding climate was not being fully disseminated or used, and Federal efforts have given insufficient attention to assessing and applying this information''. A full program of assessments, basic and applied research, monitoring, climate forecasting, and so on, was authorized. Congress highlighted the need to have the program deliver more than just research. As stated by Mr. Brown in a Hearing about the implementation plan put forward by the agencies: ''an essential feature of that planning process was to bring potential users of climate knowledge into the program design at the earliest stage, both to promote the education of those users as to what is available and to insure that programs were designed not merely as interesting research programs, but to fulfill real needs of society'' (House Committee on Science and Technology, 1979, p. 2). A similar dissatisfaction with the plan was stated by Mr. Walker, ''one of the things that I have learned on this Committee [the Committee on Science and Technology] is that the end result of virtually all research is that more research is needed'' (House Committee on Science and Technology, 1979, p. 21). He also asked pointedly whether the services and use aspect of the plan would get significant resources within the first 5 years (it was a very minor percentage of the program). Within the larger recessionary context of the early 1980s, this national program never came to fruition as envisioned and so the concerns of the Congressmen were never adequately addressed.

The third missed opportunity came in the implementation of the U.S. Global Change Research Program, of which carbon cycle science is a major component. The 1988 NRC document that laid the priorities out for the program contained a chapter that explicitly called out the human dimensions of global change. While much of this section emphasized social science research that may or may not have been any more usable in decision making, the section did acknowledge that ''management is not the same as prediction or even understanding'' (NRC, 1988, p. 168). It further went on to state that ''management can be improved despite the enormous uncertainties and downright ignorance that will continue to make detailed predictions illusory. A central question is whether we are in fact improving our management of environmental change, and, if so, which forms of social action are most effective in what situations... [I]ncreasing the range of management options, and characterizing their likely performance, should be a central focus for invention, imagination and research applied to the human component of global change''. A further section made explicit recommendations about how to make ''knowledge about global change useful as a guide to human actions'' (NRC, 1988, p. 180). The section also suggested that involving organizations directly responsible in performing assessments would be necessary in order for this research to influence practice. In other words, even for those engaged in research on how to do usable science, it would help to involve the potential users to have a greater chance those users might actually use the results.

These sections appear to recognize that prediction, reducing uncertainty, and otherwise performing basic research may have little relevance to producing information useful for management of environmental problems—a direct challenge to the notion of the ''linear model'' paradigm. Unfortunately, these details did not make it into the ''Summary of Recommendations'' at the beginning of the report. The next NRC report ''Research Strategies for the U.S. Global Change Research Program'', did not highlight decision making or use of information in any way, focusing instead on modeling, satellite systems, and process research that included humans to be studied as far as how they affected the Earth system (NRC, 1990). As before, however, when Congress turned its attention to the USGCRP in its early years, the lack of attention to ''usable science'' earned the program sharp criticism (Pielke, 1995). These missed opportunities suggest that it is very difficult to challenge the dominant paradigm, as the scientific culture, institutions and incentives all act to maintain the status quo.

Nonetheless, small changes within individual agencies have been visible over the past decade. At NSF, a second criterion for judging proposals was introduced, intended to highlight the relevance of the proposed research for ''broader impacts'' to society. NASA has introduced a new Applied Sciences emphasis, attempting to connect their research products to various decision support systems in agriculture, security, water resources, and so on (NASA, 2002). And in NOAA, experiments in co-production of knowledge have been launched in the Regional Integrated Sciences and Assessments program. Much of what has been learned about ''usable'' earth science information has come from studies in the seasonal to interannual climate forecasting arena (e.g. Lemos et al., 2002; Lemos and Morehouse, 2005; NRC, 1999, 2005; Pulwarty and Redmond, 1997). Whether these small, pilot activities survive the pressure from the more dominant institutional paradigm remains to be seen. The USGCRP, now organized into the U.S. Climate Change Science Program, appears now to be even more strongly stating an interest in providing decision support, but there is no indication that the program will organize itself to do so by transforming its research strategy (U.S. Climate Change Science Program, 2003b).

The carbon cycle science program as a whole has not asked the question of how their research could be more usable. Some of the obvious questions include those of scale—does a carbon budget at a global or continental or even regional scale provide useful information? To whom? Is there information that a city manager interested in reducing a city's carbon emissions footprint might need? Where can she look? How about a business looking for ''the straight scoop'' on options for the future? What is the responsive domain of publicly funded carbon science versus privately funded knowledge brokers? There are pockets of activity within the Department of Agriculture that are studying carbon sequestration on agricultural lands and in forests, but the degree to which users are involved is variable (Logar and Conant, this issue). A few projects on carbon management have also been funded through the NASA Applied Sciences program and the North American Carbon Program, and may yield some insight into more effectively meeting decision makers' needs for carbon information. For the most part, however, the carbon program has not yet engaged the question on how to make science more usable, and for which users, at what scales.

11. A future opportunity?

As individuals and nations grapple with decisions to mitigate and adapt to climate change in the future, there is increasing interest in deliberate management of the carbon cycle. It would seem at first glance that carbon cycle science is an area of research that has enormous potential for use in societal decision making. However, carbon cycle science in the United States for the most part is not currently configured to be able to discern what might be of interest to decision makers in various sectors and to organize to meet those needs effectively. The evidence suggests that most of the decisions about scientific funding for the carbon cycle are still made in response to scientific priorities without a great deal of linkage to the needs of decision makers outside the scientific community. Without a deliberate strategy to conduct usable science, the supply of carbon cycle science will always be primarily designed to investigate the basic uncertainties and scientific frontiers of the field, without regard to the broader societal interest or need. While no-one advocates for doing away with curiosity-driven research, it is well-recognized that such research is no substitute for science that is intended to provide socially robust knowledge. Carbon science therefore must seriously consider how to best organize and create new, additional strategies if indeed it is serious about knowing how to "best support improved public debate and decision making in the near term".

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