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Managing uncertainties: The making of the IPCC's *Special Report on Carbon Dioxide Capture and Storage*

Daiju Narita

Carbon dioxide capture and storage (CCS) is a technology that receives growing recognition because of its extremely great in mitigating climate change. However, uncertainties concerning the viability of this approach exist. With this background, the Intergovernmental Panel on Climate Change (IPCC) published a report in 2005 assessing of CCS. This article discusses the compilation process of the report, based on information collected through interviews with key participants and document research, highlighting how CCS's key uncertainties were estimated in the face of two disparate needs: scientific rigor and policy relevance.

Keywords: climate change, extended peer communities, IPCC, scientific assessment, technology uncertainty

1. Introduction

Climate change is a problem that involves a number of dimensions. Besides progress in scientific research, a noteworthy development over the last several years is a shift in perception, if not actions, of climate change as a policy problem in the United States, as exemplified by the success of Al Gore's movie and book, *An Inconvenient Truth*. This period of shift in climate change debates coincides with the emergence of a relatively obscure technology called carbon dioxide capture and storage (CCS).[1,2] This article aims to chronicle an aspect of the debates on CCS over this period of transition in discourse by focusing on the development of a Special Report compiled by the Intergovernmental Panel on Climate Change (IPCC) on this topic.

CCS is a technology that aims to reduce carbon dioxide emissions to mitigate climate change. In essence, the technology involves extracting carbon dioxide from stationary emission sources (e.g., fossil-fuel-fired power plants) and locking it semi-permanently in some natural reservoirs (e.g., depleted oil fields, underground saline aquifers, and the ocean). Since it is expected to have large potential (some estimates suggest that its total capacity is comparable with the global total carbon dioxide emissions over several decades), a growing number of climate policy analysts are beginning to regard CCS as one of the key options for solving the global climate change problem (e.g., Pacala and Socolow, 2004; Lackner and Sachs, 2005; Stern, 2007).

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CCS is a concept whose technical elements are relatively well-established in the fields of fluid separation and mining. In this sense, the biggest question with regard to its utilization is not the technical feasibility of particular engineering subprocesses but rather the long-term reliability of carbon dioxide storage – whether one can contain a large amount of gas in natural geological structures for a long period of time without leakage. A clear-cut answer for this question has not yet been obtained. At present, several commercial-scale carbon dioxide storage projects are being run across the world. While these projects provide a great amount of information on storage security, the data themselves do not warrant long-term security of CCS in an unambiguous way since their experience of operation is still about a decade at the longest (although it is possible to draw some inferences from various similar practices or general geological knowledge). As a result, some groups and individuals, mainly those outside of the researchers' community, sporadically express their concern on this point, as an environmental NGO (non-governmental organization) illustratively stated that they "have reservations about a technology that essentially sweeps carbon dioxide under the rug … leaving a problem for our descendants to solve."[3]

Under these circumstances, the IPCC released in 2005 a Special Report on CCS that partly aims to address this question of storage permanence (IPCC, 2005). Given the limited field experience of storage, this was quite an ambitious mission. Yet, in order for CCS to be taken up as an item for long-term policy planning, a clear assessment of its viability was a necessary ingredient for a CCS report.[4]

In fact, the CCS assessment project was conducted not in a political vacuum but within the delicate dynamics of climate change politics: the periods of the IPCC's CCS project and the release of the report coincided with a transition in US politics regarding climate change.[5] In a way, the IPCC's assessment of CCS was conducted under tension between science and politics.[6] This case of the CCS project poses questions: How did the IPCC manage its assessment regarding the highly uncertain and also politically sensitive question of CCS's viability? What were the expected and unintended functions of this IPCC endeavor in the context of broader policy debates on CCS? This article investigates these questions through examining the process of report-making. Specifically, this article discusses the compilation process of the report by borrowing its analytical framework from the scholarship of science and technology studies (STS), in particular one of its concepts, namely, the extended peer community. The extended peer community, a concept introduced by Funtowicz and Ravetz (1993; Ravetz and Funtowicz, 1999), emphasizes the importance of broad discussions by various stakeholders (both scientists and non-scientists) solving science policy questions subject to high uncertainties and value conflicts. This concept is further described in the next section.

The article first describes how the project of the CCS report was associated with a political goal from the beginning, namely, changing the dynamics of international climate policy negotiations. During the drafting of the report, a number of authors, on the ground of limited research evidence, opposed quantifying some key parameters concerning CCS's viability, but the group eventually made some numerical estimates on those parameters, partly driven by their recognition of the need to conform to the mission laid out by the IPCC. The political nature of the CCS project, however, does not necessarily mean that the report has become something compromising and politically biased, since the volume, in fact, ended up serving as a common ground of information appreciated by various groups, ranging from oil companies to skeptical environmental NGOs. The approach of extended peer community, which the IPCC implicitly adopted in drafting the report, is one reason for this relatively good reception of the report: the report at least reflects concerns held by well-informed groups or individuals, proponents and opponents alike. On the other hand, with the limited site-specific information in the assessment, the report has had little effect on the resolution of policy debates on how or whether CCS should be implemented in various locations in the world.

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The discussion of the paper draws on information from IPCC and external documents and interviews with 10 participants in the process (a list of interviewees is shown in the References section: in the discussion below, comments made by interviewees are kept anonymous unless the association of comments with informants' identity is contextually necessary).

2. Literature review on analytical framework

The question of the role of science in policy making has been one of the most intensely investigated in the field of STS. In the earliest works on this question, observers tended to emphasize the politically neutral quality of science, by stating that science is or should be insulated from politics (Merton, [1942] 1973; Polanyi, 1962). However, as scientific activities were seeping into socially contentious areas such as the commercial use of nuclear power and biotechnology, interactions between science and society began to be exposed to scrutiny. Weinberg (1972) depicted issues at the junction between science and society by using the term "trans-science." According to him, some scientific questions dealing with social problems, trans-scientific questions in his definition, cannot be answered by science only.[7] In scientific assessment, even if scientists rigorously observe methodological procedures, there are many factors through which their subjectivity can influence their judgment: the framing of research questions, choice of models, validating procedures such as peer review. These are not robust in a strictly scientific sense yet have significance when the results are applied to society – in fact, it is not necessarily reprehensible for scientific experts to combine their methodological thinking with their keen awareness of social problems.[8]

Funtowicz and Ravetz (1993; Ravetz and Funtowicz, 1999) discussed the intertwined nature of science and society by using the keyword "post-normal science." They point out that today's most pressing policy issues of risks and the environment often deal with high uncertainties and lack well-founded theories from which one can deduce solutions. On the other hand, those issues also often involve a sharp conflict of interests between stakeholders, often originating from different ethical views or values, and lack of common ground could lead to collective decision-making failure driven by, for example, either crude commercial interests or counterproductive protests. They argue that the resolution of those issues needs to rely on a particular type of knowledge, termed "post-normal science," as opposed to traditional science (or as they call it, "curiosity-motivated" core science). The hallmark of this concept is that it recognizes the impossibility of dissecting facts and values and also the importance of personal standpoints on those questions – for example, persons directly harmed by an environmental problem may have a more serious interest in the issue and thus a unique understanding of the problem. Funtowicz and Ravetz prescribe that the questions of post-normal science should be addressed by "extended peer communities," including not only experts in a traditional sense (scientists) but also stakeholders of the issues in general. In their words, "[o]nly a dialogue between all sides, in which scientific expertise takes its place at the table with local and environmental concerns, can achieve creative solutions to such problems, which can be implemented and enforced" (Funtowicz and Ravetz, 1993: 751).

3. A Note on the IPCC Special Report on CCS (SRCCS)

The IPCC *Special Report on Carbon Dioxide Capture and Storage* (SRCCS) is a 431-page document consisting of nine chapters (Table 1).[9] The SRCCS discusses each component technology of CCS, namely, capture, transport, and storage, in separate chapters. Storage methods

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are reviewed in detail in three chapters, each of which corresponds to a different type of storage, i.e., underground geological storage (injection of CO_2 into underground structures such as depleted oil wells and saline aquifers), ocean storage, and others (e.g., mineral carbonization). Among these three, the largest amount of discussion is devoted to underground geological storage, reflecting its comparatively large accumulation of research data.

The SRCCS has two noticeable features. How the SRCCS made based on the two features, is described below. The first is that it gave underground storage a positive evaluation in terms of safety and security with carefully scripted language avoiding total endorsement. It states that environmental risks of underground carbon dioxide storage would be comparable with the risks of current activities of fossil fuel processing (Summary for Policymakers (SPM), 22, p. 12), and that "[o]bservations from engineered and natural analogues as well as models suggest that the fraction retained in appropriately selected and managed geological reservoirs is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1,000 years" (SPM, 25, p. 14). The second important feature is that it presented CCS's mitigation potential with concrete numbers. It says that it is likely that the total storage capacity of CCS is more than 2,000 gigatons of carbon dioxide (545 gigatons of carbon) (SPM, 18, p. 12).

4. The making of the SRCCS

Road to the IPCC assessment

CCS has been an idea held by scientists and engineers in relevant fields for over three decades (Marchetti, 1977). Concerted efforts on large-scale research and development (R&D), however, started more than a decade after the first proposal was made. It was in the 1990s that various international R&D programs on CCS began, including the establishment of the IEA Greenhouse Gas R&D Programme (IEA GHG),[10] a leading research consortium on CCS, by the International Energy Agency (IEA) in 1991. At the national level, some industrial countries, notably Norway,[11] have also engaged in R&D on CCS since the 1990s.

The IPCC's plan for an extensive review on CCS emerged along with those ongoing research efforts on the development of the technology. The precursory idea for the CCS assessment project was first pronounced in a UNFCCC (United Nations Framework Convention on Climate Change) workshop in 2000, whose purpose was to discuss measures of mitigating adverse effects falling on developing countries as a result of the fulfillment of the Kyoto Protocol.[12] CCS was brought up as a technology to relieve potential economic loss for fossil fuel

Table 1. Table of Contents of the IPCC *Special Report on Carbon Dioxide Capture and Storage*

Summary for Policymakers	
Technical Summary	
Chapter 1	Introduction
Chapter 2	Sources of CO_2
Chapter 3	Capture of CO_2
Chapter 4	Transport of CO_2
Chapter 5	Underground geological storage
Chapter 6	Ocean storage
Chapter 7	Mineral carbonation and industrial uses of CO_2
Chapter 8	Cost and economic potential
Chapter 9	Implications of CO_2 capture and storage for greenhouse gas inventories and accounting

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producers under global climate policy. After undergoing higher level meetings, the decision requesting the IPCC to compile a technical paper on CCS was formally authorized by the UNFCCC's member governments at its 2001 general conference in Marrakesh, Morocco.

In response to the invitation by the UNFCCC, the IPCC formally started with its deliberation about the CCS report. In IPCC negotiations, the plan for a CCS report first appeared in the session in Geneva, Switzerland, in April 2002. Since the IPCC is an independent body, the Panel had the freedom to ignore, or at least delay, the response to the UNFCCC's invitation. In fact, the IPCC had already made a short assessment of CCS: its Third Assessment Report (TAR), which had just been completed in 2001, discussed CCS with a three-page review among an array of potential mitigation technologies for climate change. The IPCC, however, chose to take it as an item within a fairly short interval, following the invitation, even if it was unprecedented to make a comprehensive report specifically dealing with a single technology. Bert Metz, a co-chair of the IPCC Working Group III (responsible for issues related to climate change mitigation, see Figure 1) who introduced this item in the IPCC discussion, points out a few reasons why he, in consulting with his colleagues in the IPCC Bureau (i.e., chairs and vice-chairs of IPCC's main body and working groups, see Figure 1), brought up this item at the discussion. The first reason was purely logistical: the IPCC had managerial capacity to begin the project at that point since it was soon after the completion of TAR.

The second reason was that they thought that it was useful for the IPCC to provide a common ground for future policy debates on CCS, as the IPCC Bureau members perceived that CCS was an emerging technology and was becoming a divisive issue for environmentalists and energy experts. As Metz puts it:

> It [CCS] was new. There were a lot of new publications, and there was a lot of debate also about people who like this very much and people who hate it. In such a situation, a solid assessment report by the IPCC could help regarding scientific basis for further debate. And that's also how IPCC reports function. They helped provide a common ground for decision making by establishing a balanced picture of the scientific facts. So, the fact that it was a controversial thing certainly added to the decision to undertake this.

The IPCC system is a platform internalizing such a potential division, as the authors for its reports are deliberately selected to reflect diverse social backgrounds (e.g., NGOs, energy

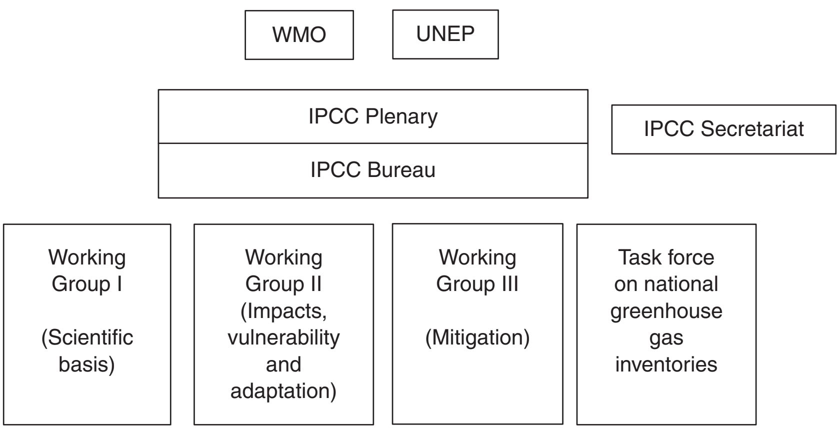

Figure 1. Organizational structure of the IPCC.

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industries, regional differences) as well as academic merits. Here, one can observe that in dealing with a science policy question with high decision stakes, decision-makers in the IPCC implicitly followed the logic of Funtowicz and Ravetz's emphasizing of the virtue of extended peer communities. What is particular about the IPCC framework is, however, that such considerations of extended communities are rather inconspicuously inserted under the appearance of a pure scientific body composed by specialists, which is consistent with a more traditional positivist view of science policy making. Indeed, a concern such as Metz's described above was never clearly pronounced in the IPCC's official discussions, while the IPCC's management team found it necessary to recruit authors from both skeptical NGOs and keen industries in order to address the concern.

As for the initiation of the CCS assessment, a more outright political factor was also behind. Metz points out that, in the IPCC negotiations, a comprehensive assessment of CCS had been an issue for a fairly long period of time, being strongly championed by some countries including the US, Australia, and Canada, in addition to Saudi Arabia. For those countries, all of which have strong domestic coal or oil interests, CCS is a way to sustain their way of economy, and thus they wanted the IPCC to promote CCS by making a detailed assessment. On the other hand, at that time, it was widely perceived that the above-listed countries were resistant to reacting to climate change in the political arena. For example, it was the year 2001 when President Bush announced the US's rejection of the Kyoto Protocol. Metz recalls that "there had been a lot of resistance from fossil fuel-producing and -exporting countries, in particular against taking aggressive actions on climate change because they feel their interests are harmed." He also recollects that he and his colleagues thought that making a report on CCS was expected to show an escape route for the stalemate in the international climate change policy at that time. In his words:

> [CCS] had a potential of finding a way out of that problem, by adding something to fossil fuel use, coal, even more so than oil. That would enable to continue [using] fossil fuels while solving climate problems. It was also an interesting aspect of the potential to change the dynamics of the discussion, and actually, when it was released, it was exactly what happened. It was strongly supported by Saudi Arabia and the big coal-producing countries, and given that we get rid of fossil fuel quickly anyway, this helped change the dynamics of discussions. This was one of the considerations. I personally but also others supported this idea because we felt it would help a broader political discussion.

Indeed, the significance of fossil fuel industries, especially oil companies, was an important factor in the debate on CCS. Without CCS, reduction of carbon dioxide emissions almost inevitably entails reduced use of fossil fuels, the source of revenues for the firms. Because of this, with their large economic presence, the fossil fuel industries, notably the oil industry, played an influential and complex role in the past debates of climate change policy (e.g., Rowlands, 2000; Skjaerseth and Skodvin, 2001; Levy and Kolk, 2002; Levy, 2005; Stephens, 2006; Pulver, 2007; Tjernshaugen, 2008). On the one hand, the fossil fuel industry has been a visible opponent of climate change policy.[13] On the other hand, however, the oil companies have not been knee-jerk objectors merely campaigning against climate change policy, either. As mentioned earlier, the largest oil companies were benefactors for CCS research, although, at least for some, it was hardly at the center of their corporate agenda (Tjernshaugen, 2008). More importantly, there has been some spectrum in strategies on the climate change problem within the oil industry as well. While the multinational oil companies more or less unilaterally had opposed any tangible climate change policy up to a certain point of time, the coalition was broken when BP publicly acknowledged the necessity of actions against climate change

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in May 1997. Since then, despite their shared basic interest to defend the core business of oil production, their corporate strategies have not been uniform across firms, with a group recognizing the need for some actions at one end and a group of more steadfast opponents at the other. For the former group, CCS is a concept giving them logical consistency between their need to keep their main source of revenues and their public position embracing the challenge of climate change (Tjernshaugen, 2008). In this context, the IPCC's extensive review on CCS could become a driver to tip the balance for the industry towards joining the endeavor of climate change mitigation by legitimizing their core business, that is, fossil fuel extraction.

In sum, the CCS report was conceived to respond to two kinds of need in a political sense. First, it was to produce a reference for well-informed participants in environmental policy discussions, proponents and opponents alike, about CCS. Second, it was to indicate a potential solution for the deadlock in international climate change policy, one that would not alienate fossil fuel interests but was inclusive of them. The report was constructed to accommodate those objectives, and earned a fairly good reception by disparate groups of people in the debate. Meanwhile, implicitly, assessment of potential application in specific locations (countries) was beyond its scope. The report ended up somehow lacking localness, especially in the context of application to developing countries, although ironically, as mentioned above, CCS was originally discussed as a way to prevent adverse economic effects on developing countries in the UNFCCC debate.

Beginning of the SRCCS preparation

As discussed earlier, the 2002 Geneva meeting produced a plan for an exploratory workshop on the issue, which took place in November 2002 in Regina, Canada. The actual process of report preparation began after the formal decision to compile the report, made at the IPCC meeting in February 2003 in Paris. The preparation of the document was coordinated by the Panel's Working Group III with the chairmanship of Ogunlade Davidson, a Sierra Leone national, and Bert Metz from the Netherlands. The report itself was written by more than 100 authors who were nominated by the IPCC's member governments or international organizations and chosen by the IPCC Bureau, a 30-member board consisting of chairs and vice-chairs of the IPCC's main body and working groups.

The tasks of the drafting process were to a large extent managed by two coordinating lead authors for each of the nine chapters of the report (in practice, there also existed additional coordinating lead authors for cross-cutting themes across chapters, such as risk and regulatory issues). Drafts were assembled and reviewed within the whole author team, and then they were subjected to extensive review involving more than 200 individuals ranging from outside scientists to government representatives. The review does not ensure total consensus among authors and reviewers. Its process, however, is governed by the IPCC's well-codified standards, and the authors need to address every comment by observing its internal rules (at the end, the IPCC "accepts" the report, meaning that it confirms that the report reflects the balance of views, even though every piece of the content may not be perfectly consistent with each other).

Contentions over uncertainty

Estimation of leakage

As already described, the actual drafting of the report was conducted on a chapter-by-chapter basis under the supervision of coordinating lead authors. While each of the nine chapters of

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the report faced some difficult questions in their drafting process, it was Chapter 5 (underground geological CO_2 storage) that addressed the core policy question about the viability of CCS technology – whether it is possible to store a large amount of CO_2 in natural locations semi-permanently with available technology. This was one of the questions that 37 individuals (coordinating lead authors, lead authors, contributing lead authors, and review editors) were requested to examine in Chapter 5. By the IPCC's rule stipulating that the composition of authors must reflect "a range of views, expertise and geographical representation,"[14] the team of those 37 authors and editors varied in their background. The group explicitly included some people who are aligned with particular economic interests, notably experts from the oil industry. On the other hand, the author body also incorporated NGO members whose stance toward CCS is not positive. All of them, however, were asked to participate in an individual capacity and were supposed to make a contribution on the basis of their expertise.

One of the potential challenges for the author team of Chapter 5 was that the research field of CCS was so new that the authors do not share a sufficient knowledge base to conduct a review together. Sally Benson, one of the two coordinating lead authors for Chapter 5, recalls that, at the beginning of the project, "they [the authors of the report] didn't know each other" because "everyone was a technical specialist in the area but with varying degrees of direct experience [on CCS]." In fact, an expert body for academic communication on this topic was just emerging at that time. The International Conference on Greenhouse Gas Control Technologies (GHGT), a biannual conference on greenhouse gas control technologies, currently a primary academic platform for CCS researchers, began playing the role relatively recently.[15] Meanwhile, research activities were extremely uneven in a geographical sense, especially with respect to large-scale field practice of CO_2 storage. As a natural consequence, some of the authors of the chapter did not have any prior first-hand research experience in CCS at the beginning of the drafting process.

Given the contentious nature of the issues they were requested to examine, this lack of a core academic group on CCS research could have impaired the assessment of the chapter. However, this proved not to be a major hindrance for discussions among the Chapter 5 team since a dominant number of authors were trained as geologists or were in relevant disciplines and they shared professional norms (recall Benson's account, "everyone was a technical specialist"). Even though the authors' affiliation varies greatly (from oil companies to hard-core environmental NGOs), there was no fundamental disagreement about what constitutes valid literature (they primarily used peer-reviewed articles) and how scientific claims should be validated. In fact, all the interviewees who were involved in Chapter 5 agree that authors acted as scientists, not as representatives of their home institution: in other words, they did not see in the members a fundamental difference in the way they utilized data and constructed arguments. In a way, a background of geology served as a lynchpin of the whole assessment enterprise. It prevented discussions among authors from being torn apart. On the other hand, one could also argue that this shared background of geology might have set an underlying tendency towards optimism on the technology – after all, researchers on CCS could have benefitted from increased public attention to CCS (as one interviewee puts it, "I don't think that completely biased information has gotten through the reviewers very easily, but certainly the undercurrent of the whole thing was quite pro-CCS, just given the group of people that was there"). Even Gabriela von Goerne, a Chapter 5 author and also an activist of Greenpeace, who opposes CCS used as an excuse to continue the intensive use of fossil fuel, describes geological CCS as a good research topic for geologists, saying, "I'm not interested in making this happen, but [I want] to know and learn more about what happens in a geological formation if you put CO_2 in there, what reactions are taking place, what kind of

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mixture, etc. … I think it's of course a great interest for a lot of researchers, too." (She was originally trained as a geologist as well.) In this sense, there was certainly a factor that could prevent this author team from making an outright negative assessment of the viability of geological CO_2.

The relative homogeneity of authors as geologists, however, did not mean that all discussions went on amicably. As noted earlier, one of the major questions for the report was assessment of permanence of underground CO_2 storage. Given the very limited field experience, this was in some sense an unanswerable question – it was not straightforward to draw conclusions about the security of underground storage from existing scientific evidence. Still, the authors did not have the freedom to be agnostic about this question as this was one of the issues that policymakers were most interested in. Metz, co-chair of Working Group III, points out that "the issue is how much can you store and how sure can you be that it stays where you put it: these are absolutely essential for policymaking." He recalls that the IPCC management team "made really clear we need some statement that is meaningful" on this issue.

To be sure, while no direct observational evidence guarantees the permanence of storage, there is some soft information supporting possible long-term security of CO_2 storage. Underground storage has multiple natural trapping mechanisms whose efficacy is proven by natural trapping of oil and natural gas. In addition, current evidence of large-scale CO_2 storage operation, however limited, shows a positive track record on this point.

A real difficulty lies in going one step further than constructing the above general logic: how to *quantify* security of underground carbon storage. On the one hand, it is geologically unreasonable to claim that stored carbon dioxide would be securely sealed *forever* (i.e., in a geologic time scale, practically anything is impermanent). On the other, the scientists did not have any data showing that stored carbon dioxide in fact escaped from existing field sites. Indeed, leakage of carbon dioxide from reservoirs is most likely to happen as discrete events,[16] rather than as continuous ones, and that makes quantification of events even more difficult.

Eventually, the author team of Chapter 5 decided to adopt an expert elicitation method, that is, an approach taking an anonymous questionnaire for members about their best guess (subjective evaluation) and figuring out the most representative numbers among their answers. Expert elicitation processes are a widely utilized method for scientists and engineers to estimate a value without direct observational data,[17] and in the end, the Chapter 5 team as a whole managed to accept the application of this approach to their issue (this is another example of how shared academic experience helped the authors not to be totally split). However, during the course of the discussion, there were objections to the validity of quantitative estimates on this issue – some members believed that it is impossible to quantify leakage given their state of knowledge. Von Goerne, the author from Greenpeace, calls the elicitation process "what I don't like" and stresses that "it says nothing to my eyes." She says that she was concerned that such a subjective estimate was going to be employed liberally by proponents of CCS: in her words, "I was scared because I thought if we did it [presenting quantitative estimates], then this would be used everywhere."[18] However, she eventually let the estimates be published and instead began to inform outsiders of how the estimate was produced, when participating in meetings. In any event, the dilemma of making a judgment with relative scarcity of data is reflected in the final statement of the report. Whereas the statement is at first sight a clear quantitative assessment about security of underground storage with specific numbers (as quoted earlier in this article, SPM 25, p. 14 of SRCCS), it is in fact weakened in a subtle but important way: adding that the estimate is valid for "appropriately selected and managed geological reservoirs". This makes the entire statement a "truism"

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(because the statement includes no definition of what “appropriately” means), according to one interviewee.

Quantification of potential storage capacity

Another major disagreement among the authors of Chapter 5 was one related to quantitative estimates of global storage capacity of CO_2. A number of interviewees note that the discussion on this issue was in fact more contentious than that on security – one interviewee says that the discussion on capacity estimates “almost broke up the report.” Still, this was another topic of which policymakers needed a clear, useful assessment, and accordingly, the IPCC management team pushed them hard to come up with one. On this issue, the biggest problem was limited geographical contexts of existing estimates. At the time of drafting, fairly detailed assessment of storage capacity existed for several regions in the developed world, but estimates were practically absent for the developing world. Specifically, according to the report’s own text, “[c]ountry- or basin-specific capacity estimates are available only for North America, Western Europe, Australia and Japan,” while “[g]lobal capacity estimates have been calculated by simplifying assumptions and using very simplistic methods and hence are not reliable” (SRCCS, Section 5.3.7, p. 221). The question was then whether it was possible for the Chapter 5 authors themselves to extrapolate the existing data for specific regions to the whole world. Some members felt that extrapolation was not scientifically valid, and refused to make quantitative estimates accordingly. Other members argued that they were obliged to write something quantitative since some figures did exist at least for some regions. Benson, one of the coordinating lead authors for Chapter 5, recalls, “Certain people thought they were being asked to say things they didn’t feel they could say and justify. There were other people like me saying, let’s just do a good job describing what we do know and what we don’t know because that’s the job of the IPCC. It’s gotten to be very contentious.” The debate between the two camps was contentious and long, but finally, they reached a compromise.[19]

One can see in the above anecdotes some elements of co-production in Jasanoff’s (1990, 1991, 2004, 2005a, 2005b) sense. The overall framework of this report project, such as its outlined mission, time frame, and management structure, was essential for the scientists to reach these numerical assessments of storage security and capacity. It would be fair to say that the outcome would look totally different if this exercise were performed on a different intellectual platform (e.g., a peer-reviewed academic journal) – it is likely that precise quantitative estimates as seen in the IPCC report would not be obtained in, given the wide spectrum of opinions among scientists. Estimates of uncertainty embody some ambiguity exactly because the things they estimate are uncertain. This leaves the observer a question – what do the estimated uncertainties really mean? In the case of the CCS report, it would be unfair to say that the results were politically distorted: at least in the debate of storage capacity, authors generally witness that their division did not reflect their difference in institutional background (e.g., oil companies and environmental groups), but rather a difference in personality (some are more circumspect, flexible, etc.) or their way of scientific reasoning. However, at the same time, the IPCC management team repeatedly asked the Chapter 5 authors that they should produce some clear statements for the two key questions (as seen in Metz’s remark shown earlier in this section), and even without the IPCC’s explicit request, these points were clearly perceived by many authors as part of their mission. Meanwhile, the framing of the CCS project was strongly conditioned by the context of the overall political scene of climate change negotiations – as previously described, this report was meant to be useful for tipping the balance of international debates on climate change policy. In this sense, the way uncertainties were described in the report was deeply influenced by the political context of this project, even if there was no outright political manipulation.

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5. Discussion and conclusion

Assessment of the SRCCS project: The perspective of the extended peer community

Despite contentions during the drafting process, it would still be fair to say that overall, the project ended up a success – at least in the sense that the report has become something that is able to fulfill its expected functions described earlier. First, the document has become a convenient reference as it covers a wide variety of aspects of CCS (technical descriptions of component technologies, costs, risk, etc.) in a single volume. Many see it as a valuable achievement – even Greenpeace's von Goerne, who opposes CCS as an excuse to continue the intensive use of fossil fuel and also feels dissatisfaction with the way the author team made quantitative assessments, regards the volume as a "good report" as it is informative for NGO activists (and in fact useful for them as well, because, in her account, there are "so many issues that I can use, for example, the cost estimates. In the discussion in Germany, [some people say] CCS is cheaper than renewables, and we can put, look at these numbers, tell me what is cheaper here, it is costly").[20] The IPCC's inclusive approach, getting both proponents and opponents on board, in fact helped create a common ground of information drawn on by a range of climate change policy stakeholders.[21] Meanwhile, the report's publication was also well-timed in terms of its second, more political and implicit objective discussed earlier – changing the dynamics of climate change politics. It is beyond the scope of this article to assess whether or how the SRCCS had a political impact on the shift of US climate policy, but one could at least indicate that the preparation and release of the SRCCS took place in a timely manner in the context of changing US politics.[22]

The platform of the CCS assessment served as an extended peer community in Funtowicz and Ravetz's sense, even if it is important to note that it only concerns the expected mission of the report and not the resolution of a whole range of political and social issues regarding CCS. The assessment of CCS technology is a quintessentially post-normal scientific question: extremely uncertain, concerning conflicts of interests and also of values (e.g., affinity with business thinking or discomfort with manipulation of nature), but involving some urgency. Thus, deliberation on the issue should be carried out by a diverse group of people with disparate positions, interests, and values, and the CCS project was conducted by implicitly taking this approach.

In relation to the extended peer community nature of the CCS project, several specific factors could explain its success. The first would lie in the IPCC system itself. It invites various groups of people to be authors for its reports, and drafts are examined by numerous outside scientists and government representatives in a well-codified fashion. One could also argue that it was not only the IPCC system itself but also the legacy it had built over time that was instrumental in the course of assessment. A general trust towards the system might have helped attract diverse people to the process, especially NGO members.[23]

Second, at least for Chapter 5, which dealt with some of the central questions for the report, shared intellectual background among the authors (geology) had an effect. Despite the controversial nature of the topic (and debates were very contentious), the discussions maintained focus in part because they had general agreement on the methodology of deliberation. At the same time, it might be the case that the dominance of geologists in the author team shaped the underlying partiality towards an optimistic assessment of CCS.

Third, there was a general sentiment that climate change was a serious, urgent problem among those who might have a negative perception about CCS such as some NGO participants. Even though CCS was not an idea that everybody could be comfortable with (because of its association with fossil fuel use or industry), blocking, obfuscating, or diminishing the

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report was not an option as doing so would not help solve the climate change problem as a whole. This also explains the relatively positive reception of the report by outside NGO activists. David Hawkins, a review editor for Chapter 5 who is from an NGO (Natural Resources Defense Council), observes:

> I have not seen any attacks on the report. I haven't seen any even from the NGOs that were pretty critical of CCS. I'm speculating that one factor that might have contributed to that is that the environmental NGOs that might be tempted to consider attacking the report as a biased document tend to be groups very serious about global warming. They worry about global warming, and they believe the IPCC is a very important institution in getting the world to understand the importance of dealing with global warming. So it wouldn't be very sensible for them to attack the IPCC report as biased and one-sided because this would tend to undermine the credibility of the institution.[24]

Fourth, while CCS is an important method for survival of the fossil fuel industry in the future, proceeding with CCS does not result in current, immediate profits for fossil fuel companies. This is in contrast with a controversy that erupted in Germany about genetic engineering, where environmentalists questioned both the safety of the technology and the direct profits it brings to transnational agribusiness, which supposedly would monopolize agriculture in developing countries through the sale of genetically modified crops (Gottweis, 1995). By contrast, in the case of CCS, general concerns about the effectiveness of the technology were not yet mixed with the issue of corporate domination, and thus it did not alienate people who were skeptical of corporate interests from the assessment and the outcome of the assessment report.

The SRCCS and public consensus building on CCS policy: A peer community not extended enough?

The evaluation of the report would differ somewhat if looked at from a different angle. The IPCC's assessment of CCS was an unconventional project among the reports previously compiled by the Panel; the authors assessed a particular technology. Ordinarily, the spread of a technology takes place gradually. In many cases, implementation of technologies does not need endorsement by authoritative technical bodies, especially by international bodies with some legal status such as the IPCC. Problems associated with the use of technologies, such as the safety of nuclear power and ethical soundness of genetic engineering, are contested and settled through long-term public debates often reflecting a particular national culture of politics (e.g., Jasanoff, 2005b). A potential function of the IPCC's assessment on CCS could have been to expedite this lengthy process of public consensus building. For example, one potential conflict with regard to CCS was that between the oil industry and the public: CCS may be a key element for future corporate strategy for the former, whereas it could invoke skepticism about safety for the latter.

As discussed in the previous section, the SRCCS project aimed to give a frame for debates by potentially clashing groups (e.g., skeptical environmentalists and fossil fuel interests), and in this respect, the IPCC system was effective. Hawkins's quote cited above indicates that the IPCC platform itself had a certain power for its messages to be adopted by a broader range of people, and the assessment was also carefully conducted so as to sustain the Panel's legitimacy. However, in the case of the SRCCS, such influence by the IPCC remained in the realm of "global policy elites" in Fogel's (2004) sense – it may have an effect on international political negotiations but not at more local levels involving actual stakeholders. In

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fact, it is fair to say that the SRCCS did little about public consensus building regarding how or whether CCS should be implemented in the respective localities. As already mentioned, the report, by and large, lacks data on developing countries, who might be major beneficiaries of CCS (such as China and India, who are building coal-fired power plants at a rapid pace), and also the assessment discusses little about the specificity of potential application of CCS. It is pertinent that the authors of Chapter 5 chose to add the words "appropriately selected and managed" to the numerical assessment of CO_2 storage security.[25] This expression in effect detaches the statement from the local context (in the sense that the report did not explore the question of which specific locations of the world are "appropriate"). In other words, the SRCCS has done little about building a consensus or shaping perception about CCS as a practical tool to be used in policy. To be fair, however, a different way to put it is that the SRCCS stayed away from a potentially dangerous role of technocratic standard-setter meddling in practical dimensions on operations of CCS. As some observers criticized in the case of the implementation of the Clean Development Mechanism (CDM) under the Kyoto Protocol (e.g., Fogel, 2004; Lohmann, 2005), such top-down technocratic execution of climate change policy could easily miss important features of local applications and also could be problematic in terms of distribution of power.

Indeed, while the CCS report might have affected the overall direction of climate change politics, the publication of the report has hardly been a determining factor for actual implementation of CCS itself. Right after the release of the report, the UNFCCC started deliberation on whether it approves three CCS methodological proposals as part of the CDM, two of which involve applications to fossil fuel combustion or processing facilities in Vietnam and Malaysia (Proposals NM0167 and NM0168). However, the proposals were not approved at its Nairobi meeting in 2006 because of the opposition of developing countries, whose reason for disagreement was partly that CCS is still *too uncertain* [26] – a claim that the IPCC tried to play down with careful language.[27]

In this sense, though the IPCC had made an assessment of CCS in the use of its careful review mechanism, public consensus building about this technology had merely begun. There remain steps ahead towards making a socially robust policy on CCS.

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Notes

1 Sometimes also called *carbon* capture and storage or carbon capture and *sequestration* (also CCS).
2 A concise general summary on the history, political contexts, and interests regarding CCS is given by Stephens (2006).
3 Friends of the Mountains, "Letter to the NRDC" on 26 September 2005. This line is quoted by *The Economist* ("Endangered Species; The Environmental Movement," 18 February 2006).
4 Though in a different context, Cook (2007) also discusses the highly public nature of scientific activities regarding CCS.
5 In 2001, President Bush expressed a position that the US government would withdraw from the Kyoto Protocol, the existing global framework addressing reduction of greenhouse gas emissions, in accordance with a decision

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supported by 95 out of 100 members in the Senate. The objection by the administration was unequivocal and firm at least at the official level, as it asserted not only that the Kyoto targets were unfair, but that human influences on climate change were not scientifically proven in the first place. However, by the year 2007, the US government clearly passed the stage of this climate change dismissal. For example, in the context of climate change mitigation, its president has stated a plan to reduce domestic gasoline consumption with a quantitative target.

6 Previous studies that discussed the Panel's workings and structure include the following: Boehmer-Christiansen (1994); Agrawala (1998); Edwards and Schneider (2001); Miller (2001); Siebenhüner (2006).

7 Weinberg draws on the example that scientists assess biological effects of very low-level radiation through high-level dose experiments by holding the assumption of linear physiological response to radioactivity. Direct experiments (low-dose experiments) are not practical because they necessitate the use of an unrealistically large number of mice (8 million mice) in order to produce statistically significant results. He argues that the assumption of linearity itself, however, cannot be verified by experiments, and that it is up to scientists' personal judgment additional to direct implications of research data.

8 The research on stratospheric ozone decomposition, which served as the basis for the prohibition of CFC use and also led to the awarding of three scientists the Nobel Prize in chemistry in 1995, would be an example of such a combination.

9 The report is one of the IPCC's Special Reports, which is "an assessment of a specific issue and generally follows the same structure as a volume of an Assessment Report" in IPCC terminology (IPCC, *Procedures for the Preparation, Review, Acceptance, Adoption, Approval and Publication of IPCC Reports*, Section 2). Note that Special Reports are prepared separately from Assessment Reports.

10 Currently, the members of the IEA GHG comprise 17 countries (all of them are OECD members, except India and Venezuela), the European Commission, OPEC, and 17 multinational industry sponsors (including some of the largest petroleum companies such as BP, Chevron, ExxonMobil, Shell, and Total) (according to the IEA GHG website: http://www.ieagreen.org.uk/, accessed 22 February 2008).

11 Norway hosted the first commercial-scale project on geological CO_2 storage for the purpose of CO_2 emission reduction. The project started in 1996 at Sleipner, a gas field in the North Sea about 250 km off the coast of Norway. Statoil (now StatoilHydro), a natural resource company whose shares are mostly owned by the Norwegian government, has run the project.

12 The need for research and for the use of CCS was an idea mentioned by participants, along with the promotion of technology transfer, economic diversification of developing countries through extensive foreign direct investment, and energy efficiency improvement. ("21. The following measures were mentioned by participants as possible options … (e) Enhancing research, development and use of advanced fossil-fuel technologies that sequester or reduce carbon dioxide emissions," UNFCCC SBI and SBSTA "Implementation of article 4.8 and 4.9 of the convention (decision 3/CP.3 and articles 2.3 and 3.14 of the Kyoto Protocol). Note by the Chairman of the Subsidiary Bodies," 4 April 2000, p. 6.)

13 For example, major oil companies were prominent members of the Global Climate Coalition, a lobbying group having influenced debate on the Kyoto Protocol in 1997 in downplaying the danger of climate change. Another oft-criticized example of their attitude toward climate change is ExxonMobil's past record of generous donation to the Competitive Enterprise Institute, an American conservative think-tank eager to find counter evidence on climate change.

14 IPCC, *Procedures for the Preparation, Review, Acceptance, Adoption, Approval and Publication of IPCC Reports*, Section 4.2.2.

15 In 1998, CCS was not yet a dominant topic discussed in the conference: only 64 out of 201 papers (those compiled in the proceedings) were CCS-related, in other words, a majority of papers discussed other greenhouse gas control technologies such as energy efficiency improvement. In 2000, this figure jumped to 88 out of 215, and in 2002, 171 out of 307 (in Benson's expression, "really only in about 2000, people started coalescing and popping up"). In 2004, the GHGT practically became an academic forum specifically for CCS researchers (334 out of 375 papers were CCS-related).

16 Such discrete leakage events are documented for analogous engineering systems, such as natural gas storage (SRCCS, p. 245).

17 Permissibility of expert elicitation in IPCC assessment processes has been somewhat ambiguous, at least at the time of the CCS assessment. As a rule, the IPCC does not engage in new research, and every piece of information it presents should be in principle substantiated by peer-reviewed literature or other verified outside data sources. In this sense, strictly speaking, generating new numbers through expert elicitation could be seen as a violation of IPCC codes, and in fact, one interviewee notes that the use of expert elicitation was discouraged at the time of drafting. On the other hand, the need for clarifying the status of subjective evaluation in IPCC assessments had been recognized in the IPCC's community even before the beginning of the SRCCS project, and one of its official documents (Moss and Schneider, 2000) had in fact already discussed the usefulness of various

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methods of subjective uncertainty estimation (including expert elicitation) in great detail. Reflecting this ambiguous status of methodology (i.e., it was unclear that expert elicitation was part of the standard procedures that do not need a particular justification on methodology), the SRCCS is not explicit about the use of expert elicitation in its text. This is another focus of criticism by von Goerne, who says, "I think it would have been probably better to have a footnote and explain to the reader how this assessment had been undertaken." However, the report ended up being published without such a footnote. Jasanoff (1990: 108) discusses a dispute similar in nature (over methods of quantification) that is observed in the case of the US government's assessment of the health effects of ozone.

18 One can observe that her concern mirrors the tendency of democratic societies to use quantification in order to soften the appearance of administrative discretion in political decision-making and defend policy decisions from external criticisms (Ezrahi, 1990; Jasanoff, 1991; Porter, 1995; Miller, 2005).

19 In Benson's words:

> For coal, we ended up biasing strongly toward what might be economical, which is not what you call theoretical capacity, but more economic capacity. For saline aquifers, we tried to create a lower bound with which there was a high degree of certainty. But for the upper bound, we just ended up putting up 10^4. We didn't say 10,000 [because the former makes the estimate less specific]. We also had a little caveat that this is highly uncertain. So that was the compromised position in the end.

20 This remark hints that the CCS assessment might be serving as a boundary object as described by Star and Griesemer (1989), in the sense that the product is embraced by different audiences in different ways but is yet robust enough to maintain a common identity across those groups.

21 Subsequently, it could promote social-technical debates on CCS, which would be another positive point.

22 As already mentioned in the Introduction, the preparation and release of the CCS report coincide with the period of a shift in US policy regarding climate change. CCS has been clearly a subject for which the US government could show some support: examples are the US's hosting of the inaugural meeting of the Carbon Sequestration Leadership Forum, an international initiative on the development of CCS, and the launch of the FutureGen project, a US-initiated large-scale energy research project involving CCS. *An Inconvenient Truth*, which promoted public awareness of climate change across the nation, delivers its message in an encouraging tone, not overly demonizing the American lifestyle itself, and CCS is a crucial component in the solution that the documentary recommends.

23 As in Lahsen's (2007) case, dynamics for the opposite direction could have also existed: the involvement of diverse people may have built trust towards the IPCC system in general. It should be noted, however, that the participants in the CCS assessment were not necessarily well experienced in the IPCC procedures at the start of the project since CCS was a relatively new item in the climate change debate.

24 This comment echoes Wynne's (1996) argument that the contexts (institutional settings) of knowledge have as much importance as knowledge itself in its social acceptance.

25 SPM, 25, p. 14. The entire quote is shown earlier (see §3).

26 Pronounced by the Alliance of Small Island States (AOSIS). See *Earth Negotiation Bulletin*, Vol. 12, No. 318, Monday, 20 November 2006.

27 In the developed world, debates on implementation of CCS are in progress, and they might be partly seen as a response to the publication of the Special Report. One of the recent developments on this point is that the European Commission made a proposal in January 2008 about the utilization of CCS within the EU (*Proposal for a Directive of the European Parliament and of the Council on the geological storage of carbon dioxide and amending Council Directives 85/337/EEC, 96/61/EC, Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC and Regulation (EC) No. 1013/2006*).

References

By courtesy of the Technical Support Unit of the IPCC's Working Group III, the author had unlimited access to primary documents of report drafts, review comments and responses, and some written communications within the author team. Below is the list of other references that were drawn on in this article.

Agrawala, S. (1998) "Structural and Process History of the Intergovernmental Panel on Climate Change," *Climatic Change* 39: 621–42.

Boehmer-Christiansen, S. (1994) "Global Climate Protection Policy: The Limits of Scientific Advice, Part 1," *Global Environmental Change* 4(2): 140–59.

Cook, P.J. (2007) "Public Science, Society, and the Greenhouse Gas Debate," in J.M. Porter and P.W.B. Phillips (eds) *Public Science in Liberal Democracy*, pp. 84–110. Toronto: University of Toronto Press.

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Edwards, P.N. and Schneider, S.H. (2001) "Self-Governance and Peer Review in Science-for-Policy: The Case of the IPCC Second Assessment Report," in C.A. Miller and P.N. Edwards (eds) *Changing the Atmosphere: Expert Knowledge and Environment Governance*, pp. 219–46. Cambridge, MA: MIT Press.

Ezrahi, Y. (1990) *The Descent of Icarus: Science and the Transformation of Contemporary Democracy*. Cambridge, MA: Harvard University Press.

Fogel, C. (2004) "The Local, the Global, and the Kyoto Protocol," in S. Jasanoff and M. Long Martello (eds) *Earthly Politics: Local and Global in Environmental Governance*, pp. 103–25. Cambridge, MA: MIT Press.

Funtowicz, S.O. and Ravetz, J.R. (1993) "Science for the Post-normal Age," *Futures* 25(7): 739–55.

Gottweis, H. (1995) "German Politics of Genetic Engineering and its Deconstruction," *Social Studies of Science* 25(2): 195–235.

IPCC (2005) *IPCC Special Report on Carbon Dioxide Capture and Storage*. Cambridge: Cambridge University Press.

Jasanoff, S. (1990) *The Fifth Branch: Science Advisers as Policymakers*. Cambridge, MA: Harvard University Press.

Jasanoff, S. (1991) "Acceptable Evidence in a Pluralistic Society," in R. Hollander and D. Mayo (eds) *Acceptable Evidence: Science and Values in Hazard Management*, pp. 29–47. New York: Oxford University Press.

Jasanoff, S. (2004) "Ordering Knowledge, Ordering Society," in S. Jasanoff (ed.) *States of Knowledge: The Co-Production of Science and Social Order*, pp. 13–45. London: Routledge.

Jasanoff, S. (2005a) "Judgment under Siege: The Three-Body Problem of Expert Legitimacy," in S. Maasen and P. Weingart (eds) *Democratization of Expertise? Exploring Novel Forms of Scientific Advice in Political Decision-Making*, pp. 209–24. Sociology of the Sciences Yearbook, Vol. 24. Dordrecht: Springer.

Jasanoff, S. (2005b) *Designs on Nature: Science and Democracy in Europe and the United States*. Princeton: Princeton University Press.

Lackner, K.S. and Sachs, J.D. (2005) "A Robust Strategy for Sustainable Energy Use," *Brookings Papers on Economic Activity* 2: 215–84.

Lahsen, M. (2007) "Trust through Participation? Problems of Knowledge in Climate Decision Making," in M.E. Pettenger (ed.) *The Social Construction of Climate Change: Power, Knowledge, Norm, Discourses*, pp. 173–96. Aldershot: Ashgate.

Levy, D.L. (2005) "Business and the Evolution of the Climate Change Regime: The Dynamics of Corporate Strategies," in D.L. Levy and P.J. Newell (eds) *The Business of Global Environmental Governance*, pp. 73–104. Cambridge, MA: MIT Press.

Levy, D.L. and Kolk, A. (2002) "Strategic Responses to Global Climate Change: Conflicting Pressures on Multinationals in the Oil Industry," *Business and Politics* 4(3): 275–300.

Lohmann, L. (2005) "Marketing and Making Carbon Dumps: Commodification, Calculation and Counterfactuals in Climate Change Mitigation," *Science as Culture* 14(3): 203–35.

Marchetti, C. (1977) "On Geoengineering and the CO_2 Problem," *Climatic Change* 1(1): 59–68.

Merton, R.K. ([1942] 1973) "The Normative Structure of Science," in *The Sociology of Science: Theoretical and Empirical Investigation*, pp. 267–78. Chicago: University of Chicago Press.

Miller, C.A. (2001) "Challenges in the Application of Science to Global Affairs: Contingency, Trust, and Moral Order," in C.A. Miller and P.N. Edwards (eds) *Changing the Atmosphere: Expert Knowledge and Environment Governance*, pp. 247–86. Cambridge, MA: MIT Press.

Miller, C.A. (2005) "New Civic Epistemologies of Quantification: Making Sense of Indicators of Local and Global Sustainability," *Science, Technology and Human Values* 30: 403–32.

Moss, R.H. and Schneider, S.H. (2000) "Uncertainties in the IPCC TAR: Recommendations to Lead Authors for More Consistent Assessment and Reporting," in R. Pachauri, T. Taniguchi and K. Tanaka (eds) *Guidance Papers on the Cross Cutting Issues of the Third Assessment Report of the IPCC*, pp. 33–51. Geneva: World Meteorological Organization.

Pacala, S. and Socolow, R. (2004) "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science* 305: 968–72.

Polanyi, M. (1962) "The Republic of Science," *Minerva* 1: 54–73.

Porter, T. (1995) *Trust in Numbers*. Princeton, NJ: Princeton University Press.

Pulver, S. (2007) "Making Sense of Corporate Environmentalism: An Environmental Contestation Approach to Analyzing the Causes and Consequences of the Climate Change Policy Split in the Oil Industry," *Organization Management* 20(1): 44–83.

Ravetz, J. and Funtowicz, S. (1999) "Editorial: Post-Normal Science – An Insight Now Maturing," *Futures* 31(7): 641–6.

Downloaded from pus.sagepub.com at Universitaetsbibliothek Kiel on November 24, 2010

Rowlands, I. (2000) “Beauty and the Beast? BP’s and Exxon’s Positions on Global Climate Change,” *Environment and Planning C* 18(3): 339–54.

Siebenhüner, B. (2006) “Can Assessments Learn, and If So, How? A Study of the IPCC,” in A.E. Farrell and J. Jäger (eds) *Assessments of Regional and Global Environmental Risks: Designing Processes for the Effective Use of Science in Decisionmaking*, pp. 166–86. Washington DC: Resources for the Future.

Skjaerseth, J.B. and Skodvin, T. (2001) “Climate Change and the Oil Industry: Common Problem, Different Strategies,” *Global Environmental Politics* 1(4): 43–64.

Star, S.L. and Griesemer, J.R. (1989) “Institutional Ecology, ‘Translations’ and Boundary Objects: Amateurs and Professionals in Berkeley’s Museum of Vertebrate Zoology, 1907–39,” *Social Studies of Science* 19: 387–420.

Stephens, J.C. (2006) “Growing Interest in Carbon Capture and Storage (CCS) for Climate Change Mitigation,” *Sustainability: Science, Practice and Policy* 2(2): 4–13.

Stern, N. (2007) *The Economics of Climate Change: The Stern Review*. Cambridge: Cambridge University Press.

Tjernshaugen, A. (2008) “Oil Companies and CO_2 Storage,” Paper prepared for presentation at the ISA’s 49th Annual Convention, “Bridging Multiple Divides,” San Francisco, CA, 26 March. URL (accessed 18 June 2008): http://www.allacademic.com/meta/p252269_index.html

Weinberg, A.M. (1972) “Science and Trans-Science,” *Minerva* 10: 209–22.

Wynne, B. (1996) “Misunderstood Misunderstandings: Social Identities and Public Uptake of Science,” in A. Irwin and B. Wynne (eds) *Misunderstanding Science? The Public Reconstruction of Science and Technology*, pp. 19–47. Cambridge: Cambridge University Press.

Interviews

Jason Anderson (Head, Climate Change Program, Institute for European Environmental Policy), a lead author for Chapter 5, 18 December 2007, at the Institute for European Environmental Policy, Brussels, Belgium.

Sally Benson (Professor, Stanford University), a coordinating lead author for Chapter 5, 26 October 2007, interview conducted in New York City.

Peter Cook (CEO, Cooperative Research Center for Greenhouse Gas Technologies, Australia), a coordinating lead author for Chapter 5, 11 November 2007, phone interview.

Ogunlade Davidson (Professor, University of Sierra Leone), Co-Chair, IPCC Working Group III, 30 January 2008, phone interview.

Heleen de Coninck, Technical Support Unit, IPCC Working Group III, 21 September 2007, at Princeton University, Princeton, New Jersey.

David Hawkins (Director, Climate Center, the Natural Resources Defense Council), a review author for Chapter 5, 12 October 2007, at the Natural Resources Defense Council, Washington DC.

Olav Hohmeyer (Professor, University of Flensburg, Germany), a lead author for the report (for Chapter 6) and a German delegation member for IPCC negotiations, 23 November 2007, at the University of Flensburg, Germany.

David Keith (Professor, University of Calgary), a lead author for Chapter 5 and a cross-cutting coordinating lead author, 15 January 2008, phone interview.

Bert Metz, Co-Chair, IPCC Working Group III, 17 December 2007, at the Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.

Gabriela von Goerne (Greenpeace Germany), a lead author for Chapter 5, 21 November 2007, at Greenpeace Germany, Hamburg.

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