Constructing Sustainability

A Study of Emerging Scientific Research Trajectories

by

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ABSTRACT

The greatest challenge facing humanity in the twenty-first century is our ability to reconcile the capacity of natural systems to support continued improvement in human welfare around the globe. Over the last decade, the scientific community has attempted to formulate research agendas in response to what they view as the problems of sustainability. Perhaps the most prominent and wide-ranging of these efforts has been sustainability science, an interdisciplinary, problem-driven field that seeks to address fundamental questions on human-environment interactions.

This project examines how sustainability scientists grapple with and bound the deeply social, political and normative dimensions of both characterizing and pursuing sustainability. Based on in-depth interviews with leading researchers and a content analysis of the relevant literature, this project first addresses three core questions: (1) how sustainability scientists define and bound sustainability; (2) how and why various research agendas are being constructed to address these notions of sustainability; (3) and how scientists see their research contributing to societal efforts to move towards sustainability. Based on these results, the project explores the tensions between scientific efforts to study and inform sustainability and social action. It discusses the implications of transforming sustainability into the subject of scientific analysis with a focus on the power of science to constrain discourse and the institutional and epistemological contexts that link knowledge to societal outcomes.

Following this analysis, sustainability science is repositioned, borrowing Herbert Simon's concept, as a "science of design." Sustainability science has thus far been too focused on understanding the "problem-space"—addressing fundamental questions about coupled human-natural systems. A new set objectives and design principles are proposed that would move the field toward a more solutions-oriented approach and the enrichment of public reasoning and deliberation. Four new research streams that would situate sustainability science as a science of design are then discussed: creating desirable futures, socio-technical change, sustainability values, and social learning. The results serve as a foundation for a sustainability science that is evaluated on its ability to frame sustainability problems and solutions in ways that make them amenable to democratic and pragmatic social action.

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"It is the active process of transforming the existent situation. Not perfection as a final goal, but the ever-enduring process of perfecting, maturing, refining is the aim in living… Growth itself is the only moral end."
– John Dewey (1920: 76)

Knowledge for Sustainability

Nearly a quarter of a century has elapsed since the concept of sustainable development emerged on the global stage with the publication of the World Commission on Economic Development's seminal report *Our Common Future*, or, as it is more commonly known, the Brundtland Report (WCED 1987). The Brundtland Report provided the oft-cited definition of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987: 43).[1] This challenge has become a central concern of the scientific community as scientists move to find ways to contribute more directly to the resolution of society's most pressing problems (Lubchenco 1998; NRC 1999). The growing urgency and complexity of many problems—from climate change and biodiversity loss to ecosystem degradation and persistent poverty and inequality—have led many scientists to call for research agendas that are problem-focused, applied and useful

[1] Though there are arguments for conceptually separating sustainable development from sustainability, they are not central to this project. As will be discussed in Chapter 2, such a difference did not emerge in my analysis. Therefore, the term sustainability is usually used here but is sometimes used interchangeably with sustainable development.

to decision-making, and approached from an interdisciplinary perspective (Kates et al. 2001; Palmer et al. 2004; Reid et al. 2010).

This dissertation focuses on one particularly prominent effort on the part of the scientific community to address the problems of sustainability—sustainability science. Sustainability science is an integrative, place-based and problem driven field with a core goal of linking knowledge to action (Clark 2007; Kates et al. 2001). It emerged from the National Research Council's (NRC) Board on Sustainable Development 1999 report, *Our Common Journey*, which reviewed the status of knowledge required to pursue a sustainability transitiosn. The NRC (1999:31) defined a sustainability transitions as occurring over the next two generations that "should be able to meet the needs of a much larger but stabilizing human population, to sustain the life support systems of the planet, and to substantially reduce hunger and poverty."

Sustainability scientists aim to support sustainability transitions by linking scientific knowledge to societal action (Cash et al. 2003; Clark and Dickson 2003). The field is both problem-oriented and "focus[ed]…on understanding the complex dynamics that arise from interactions between human and environmental systems" (Clark 2007: 1737). Carpenter et al. (2009: 1305) note that sustainability science "is motivated by fundamental questions about interactions of nature and society as well as compelling and urgent social needs" and define progress in sustainability science as those areas where "scientific inquiry and practical application are comingled." Carpenter et al. (2009) go on to stress "the urgency and importance of an accelerated effort to understand the dynamics of coupled human-natural systems." This argument is representative of a major theme in sustainability science: the fundamental understanding of the dynamics of human-environment interactions (e.g., Turner et al. 2003a,b).

At the core of these and similar efforts is a critical question: How can science and technology most effectively inform and foster social action for sustainability? How is knowledge to be connected to actions and decision-making that advance our visions of natural and social well-being (Bocking 2004; Jasanoff 1997)? This dissertation examines how sustainability science aims to contribute to social action for sustainability and the implications of emerging research agendas for societal discourse on sustainability. The results will help move sustainability science forward through a better understanding of how science might contribute to social outcomes more effectively. It will provide an opportunity to create more reflexive sustainability science research agendas and demonstrate the necessity of addressing the social, political and normative dimensions of sustainability in order to contribute to social action. I hope to lay the foundation for a sustainability science that is evaluated based on its ability to frame sustainability problems and solutions in ways that make them amenable to democratic and pragmatic social action.

This dissertation has three core objectives that together aim to enhance understanding of current developments in sustainability science and foster a more effective relationship between research and social action:

1. To understand how scientists are shaping emerging research agendas in sustainability science to address sustainability problems.

2. To explore the implications and potential tensions between the approach(es) taken by sustainability scientists and societal efforts to articulate and pursue sustainability goals.

3. To develop a framework for constructing a more effective role for sustainability science in fostering the development of more sustainable social outcomes.

Sustainability and scientific efforts to contribute to it are rich territory for analyzing the complex interplay between science and society and to examine how scientists are responding to twenty-first century sustainability challenges and develop a more effective role for science in pursuing sustainability goals.

This analysis has three primary outcomes. First, this project advances knowledge on how scientists are constructing research agendas that aim to contribute to the resolution of pressing social and environmental problems. I also address some of the implications, strengths and limitations of the approaches in sustainability science that emerged in the analysis. In so doing, the purpose is not to simply critique sustainability science, but to lay the foundation for a deeper dialogue amongst sustainability scientists, decision-makers and other concerned stakeholders over the role of science in sustainability and future directions for the field.

Second, this project provides insight into the implications of transforming the contested and value-laden concept of sustainability into the subject of fundamental scientific analysis. Sustainability can act as a platform for communities to articulate visions of social and natural well-being including responsibilities to nature and future generations (Norton 2005; Thompson 2010). It its broadest sense, one can view sustainability as an effort to formulate visions of the collective good. Science has, on the one hand, brought many environmental problems to the world's attention, including ozone depletion, acid rain and climate change, which have in turn become the subject of normative and political concern. On the other hand, science, in offering objective and epistemically powerful explanations of phenomena, can also constrain what is considered appropriate, legitimate or necessary discourse. By exploring these issues, this work will contribute to our understanding of the complex relationship between science and the normative dimensions of sustainability. In addition, I hope to maintain or enhance the ability of sustainability to act as a concept for articulating normative notions related to nature, social justice and future generations.

Finally, I argue that sustainability science is at a crossroads in its development where it must address the following question: How can science shift from identifying and describing problems in the biophysical realm to contributing to potential solutions in the social and political realm? It is this issue as well as the nature of sustainability problems as complex and contested that challenges the practice of sustainability science, its usefulness and role in society. This project develops a framework that pushes sustainability science toward focusing on the study and design of solutions, rather than just the identification of problems. This is a new, explicitly normative vision of sustainability science that will be more effective in advancing visions of natural and social well-being.

Before reviewing the structure of the dissertation, I briefly discuss the challenges sustainability presents to the practice and use of science in social action and how this analysis can provide an opportunity for sustainability science to address these challenges more effectively.

Challenges of Sustainability: What Role for Science?

Sustainability, in a broad sense, can be viewed as a contemporary effort to address an enduring query posed by Leo Tolstoy—"How, then, should we live?" In a search for a new path for progress, sustainability links concerns for the value(s) of nature, social justice and poverty with responsibilities to future generations It attempts to demarcate a desirable space in which humans would like to exist; a path in which society should develop in a way that limits the negative human impacts (or even seeks to produce positive impacts) on ecological support systems, reduces social injustices such as hunger and poverty, and takes a long-term, multi-generational perspective. Sustainability is a normative claim about how the world is (i.e., unsustainable) and how it *ought* to be.

The fact that the definition of and usefulness of sustainability as a concept or discourse remains contested has led many to contend that it is bereft of meaning, a utopian ideal or has come to be defined as a technological problem (Allenby 2005; Beckerman 1994; Daly 1996; Worster 1993). This contestation is in fact one of its primary strengths: its ability to act as an open conceptual or linguistic framework within which communities and stakeholders can articulate a range of often competing visions of well-being (Jamieson 1998; Norton 2005). Sustainability is also political as competing visions are defined and contested (Davison 2000; Jacobs 1999).

Norton (2005) argues that sustainability is a value-laden concept. In this sense, sustainability science is not unlike conservation biology in that it is normative and mission-oriented. In the case of sustainability, however, the normative dimensions are particularly complex and potentially conflicting due to the plurality of ways in which humanity interacts with and values the environment and the future. While Norton (2005) has laid out a schematic definition of sustainability with a focus on obligations to future generations, adaptive management, and democratic deliberation, there has been little research done to examine how science is both responding to and shaping sustainability.

Science not only produces beliefs about how the world is, but also how it *ought* to be (Jasanoff 2004; Latour 1993). As scientists describe social or ecological dynamics, they also influence beliefs about what dynamics are sustainable—what society *ought* to do in order to be sustainable. Scientists may attempt to respond to the societal discourse on sustainability by researching problems identified by society as important. How sustainability science influences the social, political and normative dimensions of sustainability may render the concept of sustainability and the problems it encapsulates more or less tractable in terms of social action.

In examining how sustainability scientists are constructing research agendas for sustainability, Gieryn's (1995, 1999) notion of boundary work is useful. Gieryn (1999) argues that boundaries between science and non-science are constantly drawn and redrawn, allocating the epistemic authority of science and demarcating it from non-science. Jasanoff (1987, 1990) also uses boundary work to analyze the ever-shifting border between science and politics. A sustainability transition, however defined, will be a social, cultural and political process (Miller et al. 2009). This dissertation contributes to our understanding of how sustainability scientists imagine their field contributing to this process and how a more effective role for science might be developed.

Chapter Layout

Following this introduction, the dissertation proceeds in four chapters. Chapter 2 reports the results of 28 in-depth interviews conducted with leading sustainability scientists throughout the world between June 2009 and January 2010. This chapter also draws from a content analysis of the relevant literature in sustainability science, examining how scientists are constructing research agendas for sustainability. More specifically, it addresses three core questions: (1) How do sustainability scientists define and bound sustainability?; (2) How and why are various research agendas being constructed to address these notions of sustainability?; and (3) How do scientists see their research contributing to societal efforts to move towards sustainability?

Based on the results from Chapter 3, Chapter 2 explores the tensions that arise between the approach of sustainability scientists and societal efforts to articulate and pursue sustainability goals. Chapter 2 addresses three sets of questions: (1) How does sustainability science address the normative commitments of the sustainability discourse? What are the implications for science and for societal understandings of sustainability?; (2) What are the epistemic challenges posed by sustainability problems? How does sustainability science address these?; (3) What are the barriers to and opportunities for linking knowledge with action for sustainability? How does sustainability science as a field address these issues? The purpose of this analysis is to illuminate these often hidden tensions so that future sustainability science research efforts might navigate them more effectively and contribute to positive social outcomes.

Given the analyses presented in the first two chapters, Chapter 4 argues for a new direction in sustainability science, putting forth a model of sustainability science as a science of design (Simon 1996), developing new core objectives for the field centered on the creation of sustainable solutions and support of deliberation over the meaning and goals of sustainability. It also develops a set of design imperatives for sustainability science that aim to overcome the limitations of other approaches and focus research on the generation of positive, more sustainable, social outcomes. Following these new objectives and design imperatives, in Chapter 5, my co-author, Arnim Wiek, and I propose four research pathways for the future of sustainability science: (1) creating and pursuing desirable futures; (2) mapping and deliberating sustainability values; (3) fostering socio-technical change; and, (4) enabling social learning. These four areas are designed to move sustainability science beyond research on problems in coupled human-natural systems to focus on the exploration of potential solutions.

As Jamieson (1998: 191) aptly notes, "What is needed are simple and compelling stories that show us how to practically participate in creating the future in our daily lives, and how to engage in ongoing dialogue with others about how our everyday actions help to produce global realities." Science alone cannot *make* future to happen; yet, it can help us identify the potential implications of such futures and their plausibility. As various research agendas for sustainability continue to emerge and develop, this project offers an opportunity to consider how science is informing and shaping societal efforts to pursue sustainability and an avenue for a more broadly reflexive and deliberative research program for sustainability regarding how knowledge is appropriated and the public purposes it serves.

Chapter 2

CONSTRUCTING SUSTAINABILITY:

AN ANALYSIS OF EMERGING SCIENTIFIC RESEARCH TRAJECTORIES

Introduction

The idea of sustainability cannot be adequately understood without giving special attention to the role of science in shaping how we understand it. The ability of scientific knowledge to contribute to sustainability has been an issue of high priority in the scientific community since at least the 1972 United Nations Conference on the Human Environment in Stockholm and the establishment of the UNESCO Man and the Biosphere Program in 1977. Much of the academic research on sustainability has focused on the ecological dynamics underlying environmental sustainability (Palmer et al. 2004), the economic constraints and requirements for sustainability (Pezzey and Toman 2002), and engineering solutions to problems associated with the production and consumption of natural resources (Frosch 1999). The last decade has seen the emergence of sustainability science, an interdisciplinary, problem-oriented field aimed at understanding the fundamental dynamics of coupled human-natural systems and contributing to societal efforts to move towards sustainability (Clark 2007; Clark and Dickson 2003; Kates et al. 2001; Levin and Clark 2010; Matson 2009).

How scientists, and in particular sustainability scientists, grapple with the deeply social, political and normative dimensions of both characterizing and pursuing sustainability has implications for science, its relationship with society and for the way sustainability is understood in society. As Miller et al. (2009: 5) note, "the sustainability challenge is largely about how human societies in the 21st century choose to build, maintain, and reform the socio-technological systems of the future." This chapter examines the emerging research trajectories in sustainability science and the ways in which they affect societal understanding of sustainability and the relationship between science and decision-making for sustainability. It is based on extensive interviews with leading sustainability scientists as well as a content analysis of the relevant literature.

The analysis focuses on three core issues in the construction of sustainability science research agendas: (1) how sustainability scientists define and bound sustainability; (2) how and why various research agendas are being constructed to address these notions of sustainability; (3) and how scientists see their research contributing to societal efforts to move towards sustainability. The purpose of this analysis is to explore the issues associated with scientific knowledge at the interface between science and sustainability in the scientific discourse. It is hoped that doing so will create the opportunity for a more reflexive and open sustainability science.

The chapter begins with a brief overview of the emergence of sustainability science and a discussion of the analytical approach taken which uses the concepts of co-production (Jasanoff 2004a, 2005; Latour 1993) and boundary work (Gieryn 1983, 1999) from science and technology studies (STS). These concepts are used to explore how scientific efforts justify appropriate research programs, manage the relationship between scientific knowledge and societal action, and shape the ways society understands sustainability. An explanation of the methodological approach follows along with a discussion of how sustainability science has been defined for this analysis. This is followed by the results of the interviews and literature review with a discussion focused on the how sustainability scientists are defining their field, their research priorities and the ways in which this research will contribute to society. The chapter concludes with a discussion of the implications of various forms of boundary work for sustainability science.

Science and Sustainability

First coined in 1982 at the International Union for the Conservation of Nature (IUCN) World Parks Congress in Bali, the term "sustainable development" was an attempt by conservation biologists and practitioners to integrate the goals of conservation with development, particularly in the developing world. Science, and more specifically the then-emerging field of conservation biology, was viewed as crucial to both revealing the societal and environmental benefits of conservation (what are now referred to as ecosystem services) and providing knowledge to assist in the management of protected areas (Soulé 1985).

While the concept can be traced back further to the 1980 World Conservation Strategy and the 1972 Stockholm Conference on the Human Environment, sustainable development gained wide recognition and caché with the World Commission on Economic Development's 1987 publication of *Our Common Future*, or, as it is commonly known, the Brundtland Report. The Brundtland Report famously defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987: 43). While it made clear the importance of the role of technology, social organization and political action,[2] it relied heavily on and carved out a significant role for science in the pursuit of sustainable development. The Brundtland Report framed sustainable development as something that would be made possible by the power of global ecology to inform society's decisions and strategies (Jasanoff 1996). Jasanoff (1996: 185-186) continues, arguing that the Brundtland Report's idea of sustainable development and "…the indefinite survival of the human species could be assured through a universally acceptable marriage between scientific knowledge and rational stewardship."

Fast-forwarding to the turn of the century, the National Research Council's (NRC) Board on Sustainable Development 1999 report, *Our Common Journey*, reviewed the status of the knowledge and know-how needed to embark on a sustainability transition. The Board defines a sustainability transition as occurring over the next two generations that "should be able to meet the needs of a much larger but stabilizing human population, to sustain the life support systems of the planet, and to substantially reduce hunger and poverty" (NRC 1999: 31). Such a transition is possible but requires "significant advances in basic

[2] After defining sustainable development, the authors continue, noting that while it does imply limits, they are "not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities. But technology and social organization can be both managed and improved to make way for a new era of economic growth" (WCED 1987: 8).

knowledge, in social capacity and technological capabilities to use it, and political will to turn this…into action" (NRC 1999: 7).

It is out of this context that the field of sustainability science is emerging. The NRC report proposed the development of a "sustainability science" that is place-based and problem-driven, integrating knowledge from different disciplines (particularly the biological, geophysical, social and technological), across geographical and temporal scales, and between scholarship and practice. The concept began to gain significant traction in academic circles with the publication of "Sustainability Science" in *Science* (Kates et al. 2001). Kates et al. (2001: 641) defined sustainability science as a new field that seeks "to understand the fundamental character of interactions between nature and society" and enhance "society's capacity to guide those interactions along more sustainable trajectories." Kates et al. (2001) and others (Cash et al. 2003; Matson 2009; NRC 1999) are quick to point to the normative reasons why such a research agenda is important—meeting human needs, especially for those living in poverty, while preserving the Earth's life support systems for future generations—and emphasize the necessity of linking knowledge to social action.

In each of these developments, science has been positioned as a key component to society's ability to move towards sustainability (however defined). So too has science been shaped by the problems and concerns associated with sustainability. Science, in other words, shapes and is shaped by sustainability. They co-produce one another (Jasanoff 2004a, 2005; Latour 1993). As Jasanoff (2005: 19) notes, "the products of the sciences, both cognitive and material, embody beliefs not only about how the world *is*, but also how it *ought* to be. Natural and social orders…are produced at one and the same time." As scientists move to conduct research relevant to sustainability, they, in part, define sustainability. In selecting theories and problems for sustainability science, scientists shape the concept of sustainability in society more broadly. Motivated by a desire to produce useful knowledge and a belief that access to the necessary knowledge will result in better decisions (Bocking 2004; Kinzig 2001; Lubchenco 1998; Palmer et al. 2005; Raven 2002) as well as a need to seek out the latest sources of funding (Braun 1998), scientists often pursue research priorities that respond to pressing problems. The ways in which scientists construct the research agenda(s) for sustainability science will have implications for both the ability of the field to provide useful knowledge and for how sustainability is constituted in society. Science and technology studies scholars are well positioned to offer an analysis of this coproduction as well as how boundary work is shaping sustainability science and its relationship to society.

Though critiqued as inoperable, overly ambiguous or simply promoting the status quo (Jamieson 1998; Marcuse 1998; Mebratu 1998; Worster 1994), sustainability might also be viewed as an effort to represent and articulate visions of social and natural well-being. Any effort by society to progress towards such a vision(s) will be an intensely social and political process. In this context, the concept of coproduction is particularly useful for two reasons. First, the coproductionist lens allows for an examination into how the social, political and normative dimensions of sustainability are understood, articulated, bounded and settled by sustainability scientists. The concept of boundary work (Gieryn 1983, 1995, 1999) is also useful here. Gieryn (1999: 4) defines boundary work as "the discursive attribution of selected qualities to scientists, scientific methods, and scientific claims for the purpose of drawing a rhetorical boundary between science and some less authoritative residual non-science." For the purpose of this analysis, the concern is not on boundary work as the expulsion of rival authorities; rather, the focus is on the construction of epistemic authority through scientific discourse and knowledge and how sustainability scientists deploy this authority to control discussions of research goals and demarcate social, political and normative discussions as either settled or beyond the scope of their claim-making territory.

Second, coproduction holds the potential to lend insights that can assist in the normative guidance of the development of sustainability and the role of science within it. As Jasanoff (2004b: 278-279) explains, "It is also at this moment of flux that processes of co-production are most influential in setting the stage for future human development… Once the resulting resettlements are normalized (social order) or naturalized (natural order), it becomes difficult to rediscover the contested assumptions that were freely in play before stability was effected." Coproduction can enable a more critical interpretation of how sustainability is being constituted and how it might be reconstituted. As the quote above demonstrates, this is especially crucial at this point in both the development of sustainability science as it becomes the focus of academic journals, research and education institutions and funding agencies as well as the continual evolution of sustainability in societal discourse.

The point of departure for this analysis is itself an openly normative one—sustainability is a valuable concept that may allow communities and society writ large to articulate and represent visions of human and natural well-being. Sustainability offers the potential for constructing a new and improved discourse for discussion of environmental problems because it is both descriptive and evaluative (Norton 2005). As Norton (2005) argues, it is a “thick” concept that can encapsulate a great deal of information about how humans interact with the environment and present that information in a way that is transparent, important to widely held social values and help move communities toward adopting more sustainable practices.

The purpose of this analysis is threefold. First, it seeks to understand and interpret how science and sustainability are coproducing one another at the level of scientific discourse. Second, in so doing, it aims to ensure that the social, political and normative discussions continue to be a part of sustainability and are not bounded and settled malapropos by science. This analysis is a step to ensure that sustainability does not become “scientized” – that is, when debates over science substitute for debates over values (Sarewitz 2004). Finally, the results of this analysis will contribute to more open discussions and form the foundation of a more reflexive science for sustainability—one that appreciates and accedes to the social, political and normative dimensions inherent in the articulation and pursuit of visions of sustainability. This will foster a deeper and lasting conversation about what the most effective role is for science relative to the values and goals of sustainability as set by society.

Investigating Sustainability Science

Defining Sustainability Science

The first challenge in examining sustainability science is that, like sustainability, it is broad and contested. For the purposes of this study, sustainability science is defined as emerging from human-environment and coupled human-natural systems research in the natural sciences, especially ecology, biogeochemistry, and earth systems science as well as geography. Sustainability science first emerged from the NRC (1999) report and became more established as a viable research program with Kates et al. (2001). Clark (2007) marked another important point in the development of the field with the establishment of a section devoted to sustainability science in the *Proceedings of the National Academy of Sciences*. In an editorial introducing the section, Clark (2007: 1737) characterizes sustainability science as a field similar to health science or agricultural science – “a field defined by the problems it addresses rather than by the disciplines it employs.” Sustainability science, argues Clark, seeks to facilitate a transition toward sustainability.

While it is a broad and evolving field at this point, several characteristics identify sustainability science including fundamental research with a place-based focus on coupled human-natural systems from an interdisciplinary, problem-driven perspective (Cash et al. 2003; Clark and Dickson 2003; Kumazawa et al.

2009). Turner et al. (2003a), for example, apply a vulnerability framework[3] to the analysis of three coupled human-environment systems case studies including the Southern Yucatán peninsular region surrounding the Calakmul Biosphere Reserve. The authors view vulnerability as residing "in the condition and operation of the coupled human-environment system, including the response capacities and system feedbacks to the hazards encountered" (Turner et al. 2003a: 8080).

Another example of coupled systems research in sustainability is the work of Matson and colleagues on the Yaqui Valley in Sonora, Mexico. Matson et al. (2005) examine a system in which they seek to understand transitions underway as a result of population growth, urbanization, land use change and changes in the region's water regime. In these and other studies, sustainability science is being defined as an interdisciplinary field that seeks to understand the coupled human-environment dynamics underlying many pressing environmental problems (Carpenter et al. 2009; Ostrom 2007; Turner et al. 2003a).

As the research agendas for sustainability have developed so too have the programmatic elements of a growing scientific field including the establishment of research and education institutions and dedicated academic journals. Much of the activity in institutionalizing sustainability science has been centered around the American Association for the Advancement of Science (AAAS) Forum on Science and Technology for Sustainability, the Roundtable on Science and

[3] Vulnerability is defined as "the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressor" (Turner et al. 2003b: 8074).

Technology for Sustainability Program at the National Academy of Sciences, the Initiative on Science and Technology for Sustainability sponsored by the International Council of Science as well as a series of workshops including, most recently, "Toward a Science of Sustainability" sponsored by the National Science Foundation. Research and education programs and centers are rapidly emerging. These include, but are certainly not limited to, the Global Institute of Sustainability and School of Sustainability at Arizona State University, the Center for Interactive Research on Sustainability at the University of British Columbia, Sustainability Studies at Lund University (Sweden), the Sustainability Science Program in the Center for International Development at Harvard University, and the Graduate Program in Sustainability Science at the University of Tokyo. Several academic journals have emerged including the *Proceedings of the National Academy of Sciences* Sustainability Science section, *Sustainability Science*, *Current Opinion in Environmental Sustainability*, and *Sustainability: Science, Policy and Practice*.

There are of course other areas of research that directly address sustainability including industrial ecology (Graedel and Allenby 2006), economics (Perrings 2006; Solow 1991), especially ecological economics (Costanza and Patten 1995; Daly 1996), and others (Dyllick and Hockerts 2002; Ruttan 1999). This study does not address these areas directly as it is not a survey of academic efforts addressing sustainability; instead, it focuses on sustainability science as defined above and as a major scientific effort to bring scientific knowledge to bear on sustainability problems. It does, however, identify and examine several areas outside of the mainstream of sustainability science as defined above in order to highlight how approaches to these issues vary and how boundaries are (and might be) drawn differently. The shape of scientific research and the knowledge it produces whether in sustainability science or any other field is not *a priori*. Coproduction and boundary work are social processes that are constructing scientific discourse, practice and knowledge and sustainability in specific and contextual ways. Furthermore, in defining sustainability science in this way, this analysis is itself performing an act of boundary work. This is done in order to focus the analysis in a broad, yet important, area of research, and to show how a developing field might shape the discourse on sustainability.

Methodology

The methodological approach follows Takacs' (1996) pioneering study of conservation biologists and biodiversity. Through interviews with leading figures in conservation, Takacs examines how they have shaped and promoted the concept of biodiversity, including its normative character. In a similar fashion, the present analysis provides a rich description of emerging research agendas in sustainability science and how scientists envision the knowledge produced by the field contributing to society.

In-depth interviews were conducted with 28 key researchers in sustainability science between June 2009 and January 2010. Interview subjects were identified through their involvement in important developments in the sustainability science literature, association with sustainability research programs and by key informants. As mentioned earlier, several researchers that are outside of the mainstream sustainability science community were interviewed in order to get alternative perspectives on this developing research area. Interviews began with several preset questions and topics but allowed for flexibility according to the research interests and perspective of the interview subject. Interviews were conducted in person when possible and over the phone in select cases. Interviews were conducted in English and ranged from 45 minutes to 1.5 hours in length.[4]

In addition to the interviews, a literature review of the leading journals, reports and papers in the field was performed. Journals analyzed included the *Proceedings of the National Academy of Sciences*, *Science, Nature, Sustainability: Science, Policy and Practice, Sustainability Science*, and *Current Opinion in Environmental Sustainability,* as well as select papers in other journals. Activities sponsored by the AAAS, the National Academy of Sciences and the National Science Foundation have been critical in establishing a research agenda for the field. Workshop reports and other outcomes from these activities were analyzed as well.

Constructing Sustainability Science

The remainder of this chapter discusses the results of the interviews and content analysis of the literature. The analysis focuses on the scientific discourse and examines three main questions: (1) how sustainability is defined by scientists, (2) how research agendas are being constructed to respond to sustainability, and (3) how scientists envision knowledge contributing to societal efforts to move towards sustainability. Examining how scientists aim to contribute to

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[4] See Appendix I and II for a list of interview subjects and the interview protocol, respectively.

sustainability efforts and how they attempt to translate knowledge into action can provide insight into how scientists might shape research agendas and their relationship to society going forward. For each of these questions, responses and analyses are grouped into themes that emerged in the interviews and literature review that serve to illustrate varying approaches to and implications for sustainability science. It is important to note that the following discussion does not attempt to group individual scientists as adhering to certain definitions; instead, the point is to analyze and discuss various definitions of sustainability that are motivating the development of research agendas and influencing the development of the sustainability discourse.

Defining Sustainability

In discussions on sustainability there is one question that is inevitably raised – "What is sustainability?" Follow up questions typically attempt to ask what is being sustained, for whom it is to be sustained, and for how long the good or process in question is to be sustained. The answers to such questions are anything but trivial, particularly in the context of sustainability science, and are value-laden (Norton 2005). As Beck (1992: 174) observes, "…which interests they [scientists] select…on whom and what they project the causes, how they interpret the problems of society, what sort of potential solutions they bring into view – these are anything but neutral decisions."

The purpose of examining scientists' definitions of sustainability is not to refute or endorse one or another. In fact, during the course of the interview, some scientists discussed and even endorsed multiple and sometimes conflicting definitions. Definitions of sustainability serve as an important point to analyze its coproduction and the performance of boundary work. Importantly, each of the definitions involves normative notions of sustainability but with varying emphases and implications. How do scientists define sustainability? To what extent do scientists address these value-laden questions related to sustainability? How might this influence how society comes to define sustainability? What are the implications for the role of science in the sustainability discourse? How do they envision their research contributing to it? These are the questions that will be addressed in the following discussion.

Three themes emerged in discussions on the meaning of sustainability: *universalist sustainability*, *procedural sustainability* and *ambiguous sustainability*. Each theme will be discussed in turn along with a discussion of the different ways in which boundaries are drawn and implications for the coproduction of sustainability. This is not the result of an exhaustive survey of sustainability definitions in the literature. These are themes that have emerged through the interviews and the analysis of the literature on sustainability science.

Universalist Sustainability. Many of the interview subjects and much of the literature refer, perhaps not unsurprisingly, to one of two definitions – those put forth by the WCED and the NRC report, which were discussed earlier. Parris and Kates (2003: 8068), for example, define a transition to sustainability as "stabilizing world population, meeting its needs and reducing poverty and hunger while maintaining the planet's life support systems." Similarly, a report from the Third World Academy of Sciences (Hassan 2001: 70) defines sustainability as “meeting current human needs while preserving the environment and natural resources needed by future generations.” Carl Folke sums this perspective up nicely: "How can we develop and continue to improve human well-being and our life as a species on [this] planet…? That’s really what sustainability is about for me."[5] I refer to this set of definitions as *universalist (or thin) sustainability* -- meeting human needs, both now and in the future, without degrading the planet’s life support systems.

Political theorist Michael Walzer (1994) uses “thin morality”[6] or “moral minimalism” to describe concepts that encourage widespread agreement but do not substantively translate to the level of individual behavior changes nor do they conflict with more contextual notions of what is moral or desirable. Thin morality is universalist. Walzer notes that virtually every human society can agree that the idea of justice is one worth pursuing; however, what justice looks like in various places or contexts can be very different and even conflicting. This does not mean that thin or morally minimal descriptions of justice are meaningless or morally shallow. Instead, thin morality can assume a deeply compelling character as it consists of moral notions on which all can agree. It is this universalism that has allowed thin sustainability to gain traction in both science and society. As Thomas

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[5] Carl Folke. Interview. 30 September 2009.

[6] Walzer borrows this term from Geertz’s (1973) “thick description.” Walzer’s (1994: xi) aim, however, is not to present a thick description of moral argument but to refer to argument that is thick—“richly referential, culturally resonant, locked into locally established symbolic systems or network of meanings.”

Parris notes, the NRC definition "was chosen… intentionally as a minimalist definition. It's the part that everybody can agree on."[7]

Thin sustainability can be viewed broadly as an effort to reconceptualize the relationship between humans and the natural environment. As Clark and Dickson (2003: 8059) argue, "the challenge of sustainable development is the reconciliation of society's development goals with the planet's environmental limits over the long-term." Jill Jäger (2009), in a review of sustainability science in Europe, defines sustainability as rethinking the interactions between nature and society, the global and the local. F.S. (Terry) Chapin III understands sustainability as "more of a calling on ethics and a sense of responsibility to the planet, a sense of responsibility to future generations that is going to have more influence over a broad range of citizens and a broad range of cultures."[8] Chapin et al. (2009: 2) expand on this with a call for ecosystems stewardship to "sustain the capacity to provide ecosystem services that support human well-being under conditions of uncertainty and change." Paul Raskin views sustainability "in its widest sense, as raising questions about the nature of human culture and institutions, and the way we interact with each other and the earth over the coming decades."[9] Similarly, for James Buizer, sustainability "is putting humans back into…[the] natural system…[and] looking for harmony and balance."[10]

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[7] Thomas Parris. Interview. 8 July 2009.

[8] F.S. Stuart Chapin III. Interview. 30 September 2009.

[9] Paul Raskin. Interview. 17 December 2009.

[10] James Buizer. Interview. 29 January 2010.

It is worth highlighting that each of these definitions is anthropocentric or human-centered. For example, McMichael et al. (2003: 1919) define sustainability as "transforming our ways of living to maximize the chances that environmental and social conditions will indefinitely support human security and well-being." At the core of sustainability is a concern that current human activities and their effects on the environment are undercutting the ability of that environment to support the well-being of both current and future generations. "Despite the awe in which we hold nature and the value we place on its conservation," argues Clark (2009: 82), "ours is ultimately a project that seeks to understand what is, can be, and ought to be the human use of the earth."

Thin sustainability serves as a general normative frame, or as Jan Rotmans noted in his interview, a "normative orientation," for sustainability scientists. For Pim Martens sustainability "has a value as a kind of a framing [or] framework."[11] Thin sustainability is both a source of motivation and a normative goal for research. Sustainability scientists are able to tap into the thinly moral underpinnings of sustainability to express concern for the impacts of human activity and justify research agendas (more on this latter point in the following section). Moral minimalism "is everyone's morality because it is no one's in particular; subjective interest and cultural expression have been avoided or cut away" (Walzer 1994: 7). So too is science perceived by many scientists and the public as universalist, objective and free of cultural context. A sustainability from which "subjective interest and cultural expression [has] been avoided or cut

[11] Pim Martens. Interview. 9 July 2009.

away" serves to reinforce this image of science and maintain its authoritative role in society (Collingridge and Reeve 1986; Jasanoff 1987).

"Thick morality" or "moral maximalism," on the other hand, is contextual and embedded in a certain place or unique to a certain people. Maximalism "is idiomatic, particularist, and circumstantial…[it] is the socially constructed idealism of *these* people" (Walzer 1994: 39). Norton (2005) picks up on this, arguing that sustainability has the potential for constructing an improved language for discussion of environmental problems because it is both descriptive and evaluative – i.e., it is a "thick" concept that can (1) encapsulate a great deal of information and (2) present that information in a way that makes explicit its importance to widely held social values. Scientists have embraced thin sustainability and its universalism and have limited the degree to which deeper discussions over a "thick sustainability" and the role of science take place. Furthermore, as Jamieson (1995, 1998) notes, attempts to provide scientific or technical definitions for highly normative concepts, such as sustainability or ecosystem health, often result in a circumvention of ethical and political issues or lead to a bedeviled debate in which ethical, political and scientific issues are confused.

Universalist sustainability is in some ways an implicit acknowledgment that more substantive or thick definitions of sustainability are to be worked out by society in a certain place. Parris and Kates (2003: 8068), for instance, believe that "defining sustainability is ultimately a social choice about what to develop, what to sustain, and for how long." Pam Matson separates the values of society from the values of the scientist:

> …the values are the values of the decision makers. And, of course, scientists all have their own value systems, too. And mine would say – …meeting the needs of people while protecting the life support systems of the planet. I'm including the ecosystems and the species within them, on land and in the oceans, because I think they provide all of the [ecosystem] services that we need.[12]

The values of sustainability motivate scientists, but, at the same time, scientists are careful to control the degree to which such values infiltrate science. Boundaries are drawn between the personal values and those that might influence the way society and decision-makers understand sustainability. The values and motivations of scientists and sustainability science are acknowledged but at a level that is universal. It is "everyone's morality because it is no one's in particular." These are the scientists' values and they are everyone's values. Both the definition of sustainability and the usefulness of science to sustainability efforts are universal.

"With thickness," notes Walzer (1994: 6), "comes qualification, compromise, complexity, and disagreement." The context and conflict that come with thickness are absent in thin sustainability. Parris again notes that there is a reason for choosing a thin definition of sustainability:

> It's the part that everyone can agree on… But then there's another circle where people add layers of definition to it…equal treatment of all species [for example]. The point is that there's a core…because people don't universally agree to the various additional layers that people add on to it… [W]e aren't valuing biodiversity for its own sake. We're valuing biodiversity because it promotes resilience and agricultural systems or

[12] Pam Matson. Interview. 26 September 2009.

> something like that. And then it becomes a testable hypothesis as to whether that's true or not.[13]

By embracing a universal sustainability, scientists are able to avoid opening up an arena in which the role of science and the knowledge produced by scientists may be contested along with other components of sustainability. To some degree, as Parris notes in the quote above, scientists can turn thin sustainability into a set of research questions. For example, what are the human impacts on the earth's life support systems? How do ecosystems contribute to human well-being?

Procedural Sustainability. Thin sustainability attempts to define the substance of sustainability – i.e., what is it and what it requires. A methodological approach, on the other hand, focuses on how sustainability comes to be defined and how pathways are developed to pursue it. The NRC (1999: 48) acknowledges this, arguing that sustainability is a "process of social learning and adaptive response amidst turbulence and surprise." This way of defining sustainability is referred to as *procedural sustainability*.

John Robinson provides perhaps the most succinct explanation of this view and the difference between the two approaches:

> I have two answers [to the question of how I define sustainability]: a substantive one and a procedural one**.** The *substantive* one is a version of the many-legged stool approach that's very common. So I like thinking of sustainability as the reconciliation of three imperatives: ecological imperative [to] stay within…physical carrying capacity, an economic imperative to provide adequate material standard of living for all, and a social imperative to provide systems of governance that propagate the values people want to live by… But my preferred definition is the *procedural* one because I think those substantive ones are fine, but they just sort of lay out domains. The procedural one is that sustainability is the emergent property of a discussion about desired futures that's informed by

[13] Thomas Parris. Interview. 8 July 2009.

> some understanding of the ecological, social, and economic consequences of different courses of action. (emphasis added)[14]

Rather than being defined in thin, universalist terms, sustainability is defined through a participatory or democratic process contingent on place and time.[15] As Norton (2005: 335) argues, "…the problem of how to measure sustainability… is logically subsequent to the prior question of what commitments the relevant community is willing to make to protect a natural and cultural legacy."

Derk Loorbach, Director of the Dutch Research Institute for Transitions (DRIFT), views sustainability as an "an open-ended process of constantly trying to improve how parts of society are organized in terms of energy, in terms of materials, but also in terms of values and in terms of cooperation."[16] Rotmans, the former Director of DRIFT, also makes a case for procedural sustainability:

> [Sustainability] is very context dependent…[I]n practical environments, my opinion is that what is sustainable is defined by the stakeholders that will be involved in this process… It means that it might be different in Rotterdam than in Amsterdam… [I]t's more the process itself where…you are continually making tradeoffs in time, and in space, and in domains, and if you do that systematically and continuously, then the outcome for me doesn't matter as much as the process itself.[17]

This is different from the participation of stakeholders in scientific research or the process of linking knowledge to action, which will be discussed below.

Procedural sustainability has to do with an understanding of sustainability

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[14] John Robinson. Interview. 5 October 2009.

[15] How this process is shaped, by whom and who is included are obviously important issues involving deliberative ideals and procedural justice that will influence how sustainability comes to be defined. These issues are, however, beyond the scope of this chapter.

[16] Derk Loorbach. Interview. 8 July 2009.

[17] Jan Rotmans. Interview. 24 November 2009.

as a process for identifying important societal values and pathways for a desirable future. It emphasizes difference and context rather than agreement on a broad definition. It is not that procedural sustainability is in opposition to thin sustainability; rather, a thin definition is only useful insofar as it aids in the process of developing a contextual understanding of sustainability in a certain place or community.

Ambiguous Sustainability. None of this is meant to suggest that researchers are not aware of the critiques of sustainability as meaningless (e.g., Worster 1994) or lacking intellectual rigor (Lélé 1991), or that they do not share in such criticisms themselves. Jan Rotmans, for example, notes that sustainability "is a really contested notion both socially and scientifically, so that means that there is no universal definition."[18] Masaru Yarime views sustainability as "a kind of property or a characteristic of many things."[19] I refer to this set of definitions as *ambiguous sustainability*.

Ambiguous sustainability can be either thin or procedural. Martens (2006: 37) argues that sustainability has been difficult to pin down – "…complex, normative, subjective and ambiguous, it has been criticized both from a social and from a scientific point of view." Elinor Ostrom contends that it is largely meaningless until the question "of what?" is addressed.[20] B.L. Turner contends "the fact that it has multiple meanings…is exactly why it has cache…[but] it can

[18] Jan Rotmans. Interview. 24 November 2009.

[19] Masaru Yarime. Interview. 22 July 2009.

[20] Elinor Ostrom. Interview. 30 September 2009.

mean…[that] the West can continue its lifestyle."[21] For Jinguo (Jingle) Wu sustainability is a very broad concept: "A concept like sustainability [is] like freedom, democracy. How can you define it in very specific terms?... Sustainability means different things in specific terms to different people, even the same people in different places."[22]

This is similar to the way the NRC (1999: 22) view of sustainable development as the "most recent conceptual focus linking the collective aspirations of the world's peoples for peace, freedom, improved living conditions and a healthy environment." These definitions are perhaps more expansive than thin sustainability; however, like thin sustainability, ambiguous definitions can take a universalist approach.

Many view the multiple meanings of sustainability as one of its chief assets, as a way to frame a process for defining sustainability more specifically. Raskin believes sustainability's value is in its "creative ambiguity" and that "it's [an] inherently…nebulous idea…[that is] best not to be pinned down too precisely, and is really a term that involves a lot of conversation and debate."[23] Robinson refers to its "constructive ambiguity":

> Everybody has their own [definition]. So we really need this kind of open discursive playground that is bounded in some way, but not so tightly that we can't reach any form of agreement. I'm not a big fan of very precise

[21] B.L. Turner III. Interview. 5 June 2009.

[22] Jinguo Wu. Interview. 4 June 2009.

[23] Paul Raskin. Interview. 17 December 2009.

> definitions. I do want to keep that ambiguity built in as part of the process.[24]

Jäger notes that "it doesn't bother me that there are lots of definitions…different interpretations will be necessary for different places, different factors…it's extremely valuable to have a broad interpretation…where different people can find themselves when you get into dialogue about the future and what needs to change."[25] Correspondingly, for Loorbach though sustainability may be an "empty concept…it creates a frame for…the process of change."[26]

This way of approaching the ambiguous nature of sustainability reinforces a more procedural sustainability. Jamieson (1998: 188) picks up on this notion of sustainability and argues that sustainability's very breadth and popular appeal "has the potential to structure discourse between people who have quite different values and epistemologies." Similarly, Norton (2005) views sustainability as a platform for constructing a new and improved language for discussion of environmental problems. In this way, ambiguous sustainability can also act as a sort of "clearinghouse" model of sustainability that allows for a more constructive combination of various definitions, goals and values.

Research Agendas

Regardless of the way scientists define sustainability, there is widespread agreement (Lubchenco 1998; Palmer et al. 2004; Levin and Clark 2010) that science should contribute to sustainability efforts – "promoting the goal of

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[24] John Robinson. Interview. 5 October 2009.

[25] Jill Jäger. Interview. 18 November 2009.

[26] Derk Loorbach. Interview. 8 July 2009.

sustainability requires the emergence and conduct of the new field of sustainability science" (Friiberg 2000: 1). As both Matson and Clark noted in their interviews, they adhere to a "big tent" theory for what is to be included in sustainability, particularly at this point in its development. Two major themes in the construction of research agendas for sustainability are the *coupled systems approach* and the *social change approach*.

Coupled systems approach. Sustainability science "seeks to understand the fundamental character of interactions between nature and society" (Kates et al. 2001: 641). As Carpenter et al. (2009: 1305) note, it is "motivated by fundamental questions about interactions of nature and society as well as compelling and urgent social needs." Likewise, Turner et al. (2003a: 8080) argue "sustainability science seeks understanding of the coupled human-environment system in ways that are useful to the different communities of stakeholders." I will refer to this set of research agendas as the *coupled systems* approach to sustainability science.

The coupled systems approach is focused on producing knowledge about "the complex dynamics that arise from interactions between human and environmental systems" (Clark 2007: 1737). In its broadest sense, as Turner says, "anything that fits under the rubric of how humankind is altering the basic structure and function of the earth's system…is a critical problem that ought to be studied."[27] The role of sustainability science, argues Parris, is in "understanding how it [the human-environment system] functions."[28] Similarly, Ostrom contends

[27] B.L. Turner III. Interview. 5 June 2009.

[28] Thomas Parris. Interview. 8 July 2009.

that sustainability science should be concerned with "developing rigorous methods for analyzing complex systems over time."[29] While this couple systems approach has characteristics in common with ecological and environmental science (Bocking 2004), including an emphasis on complexity, it diverges in part in its focus on *coupled* systems and understanding of the social concepts and variables, rather than just on the environment.

The coupled systems approach has several important implications for regarding boundary work both within science and with its relationship to sustainability in society. It positions research on coupled human-natural systems as critical to efforts to move towards sustainability. For example, Clark (2010: 82) states that "the *core* of sustainability science lies in seeking to understand how society's efforts to promote a transition toward sustainability are constrained or promoted by the interactions between human and environmental systems" (emphasis original). The problems of sustainability require scientific analysis. More specifically, they require fundamental knowledge about the dynamics of coupled human-natural systems[30], which sustainability science can provide. Carl Folke, for instance, believes "sustainability really requires an integrated view of people and environment as one system, not a separate entity... Sustainability science…focuses more on the role of science around those issues."[31]

[29] Elinor Ostrom. Interview. 30 September 2009.

[30] Coupled human-natural systems are also referred to as human-environment or social-ecological systems. Broadly, they can be defined as "integrated systems in which people interact with natural components" (Liu et al. 2007: 1513).

[31] Carl Folke. Interview. 30 September 2009.

A key component of this approach is that it is problem-oriented:

> Like the fields of medical science and agricultural science, the emerging field of sustainability science is not defined by disciplines but rather by problems to be addressed and solved. It encompasses and draws on elements of the biophysical and social sciences, engineering, and medicine, as well as the humanities, and is often multi- and interdisciplinary in effort. The substantive focus of sustainability science is on the complex dynamics of the coupled human/environment system. Matson (2009: 39)

"The commitment of sustainability science to problem-driven agenda setting," however, "does not mean that it has been confined to 'applied' research. Indeed, pursuit of practical solutions to the pressing challenges of sustainability has driven the field to tackle an array of fundamental questions" (Clark and Dickson 2003: 8060). Clark (2007: 1737) refers to this approach "as neither 'basic' nor 'applied' research. Rather, it is an enterprise centered on the 'use-inspired basic research'… it serves the quest for advancing both useful knowledge and informed action by creating a dynamic bridge between the two."

The coupled systems approach to sustainability science seeks to produce what Clark refers to as "reliable knowledge"[32] about interactions between human and environmental systems. Echoing Matson's comments above, Clark (2010: 82) views sustainability science as problem-oriented yet grounded by a search for fundamental understanding of human-environment systems:

> Like 'agricultural science' and 'health science' before it, sustainability science is a field defined by the problems it addresses rather than the disciplines or methods it employs. For us, those problems are defined as the challenges of promoting a transition toward sustainability—improving human well-being while conserving the earth's life support systems over appropriate time and space scales. Sustainability science then draws from—and seeks to advance—those aspects of our understanding of

[32] William C. Clark. Interview. 18 November 2009.

> human systems, environmental systems and their interactions that are useful for helping people achieve sustainability goals.

This knowledge is produced in conjunction with stakeholders so that it is not just reliable but also salient, legitimate and trustworthy and thus most likely to assist society in transitioning to sustainability (Cash et al. 2006; Clark and Dickson 2003; Kates et al. 2001; NRC 1999). This leads to a final key component of the knowledge-oriented approach research agendas – connecting scientific research to practice, or linking knowledge to action (Cash et al. 2003). Again, Matson (2009: 41):

> Another key aspect of academic programs around sustainability science is the purposeful intent to link knowledge to action. Much of sustainability science is hard-core fundamental research, but the field is essentially use-inspired and is oriented toward decisionmaking of all sorts. Just as in the agricultural and medical fields, public outreach and knowledge extension are crucial aspects of sustainability science.

However, as Matson noted in her interview, while "a lot of progress has been made [in understanding life support systems]…there is going to be a lot more [research] needed in decision science, in behavioral research."[33] Knowledge of the system and its use in decision-making is viewed as a limiting factor to action. Part of the mission of sustainability science is to determine what knowledge is needed. This is done based on a better understanding of decision-making and perceptions. How and why this knowledge is linked to societal action and the implications will be discussed in further detail in the following section and a chief component of the sustainability science agenda that differentiates it from environmental science.

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[33] Pam Matson. Interview. 26 September 2009.

Social change approach. Sustainability science, according to Jäger, "is very much about process and very much about dialogue…it's a process for social change, learning, and transitions."[34] It should "drive societal learning and change (SLC) processes" and focus "on the design and running of processes linking knowledge with action to deal with persistent problems of unsustainability and to foster transitions to sustainability" (Jäger 2009: 3). I refer to this as the *social change approach* to sustainability science.

The social change approach seeks to construct, inform and study processes for defining and pursuing sustainability. Rather than producing knowledge about underlying dynamics that are sustainable or unsustainable, it both participates in and produces knowledge about the processes of sustainability transitions. Raskin argues that we must focus on "the ultimate drivers" that cause unsustainability or that might result in positive action – "culture, power, politics and values."[35] Following the notion of procedural sustainability discussed earlier, Swart et al. (2004: 138) argue that sustainability science must "emphasize the need to develop approaches for evaluating future options, recognizing diverse epistemologies and problem definitions, and encompassing the deeply normative nature of the sustainability problem."

The social change approach is envisioned by some scientists as a mode of governance. The field of transitions management highlights this issue. Loorbach and Rotmans (2009: 3) define transitions management as "a deliberative process

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[34] Jill Jäger. Interview. 18 November 2009.

[35] Paul Raskin. Interview. 17 December 2009.

to influence governance activities in such a way that they lead to accelerated change directed towards sustainability ambitions.” Loorbach (2007: 18) defines a transition “as a continuous process of societal change whereby the structure of society (or a subsystem of society) changes fundamentally.” Transitions management is a form of meta-governance – “how do we influence, coordinate and bring together actors and their activities in such a way that they reinforce each other to such an extent that they can compete with dominant actors and practices?” (Loorbach and Rotmans 2009: 3).

This approach is concerned with how sectors of society or certain communities define sustainability in context, the process that facilitates a dialogue about this as well as the strategies that might be pursued to meet the goals that are set. While not always referred to as sustainability science by its adherents, it too is stakeholder-oriented, interdisciplinary and incorporates a systems perspective. The social change approach potentially creates a privileged role for science as a designer of and key participant in procedural sustainability. Epistemic authority emanates from knowledge shared and developed through the process of transitions management rather than knowledge about underlying system dynamics. It should, however, be noted that in focusing on the process it is recognized that there is a continual negotiation between actors about goals, knowledge and strategy for action. This approach creates a space for science as necessary to procedural sustainability as part of the process and as a source of knowledge on how to design an effective process.

Science in Society

Regardless of the specific approach or research agenda, there is a shared belief that science should be responding to societal needs and the challenges of sustainability (Lubchenco 1998). Whether science is producing knowledge about complex coupled human-natural system dynamics or about sustainability transition management processes, in each case science is a knowledge provider. But the role of knowledge in society, how it is developed and deployed, and how scientific knowledge is viewed relative to other types of knowledge is complicated. If a primary goal of sustainability science is to help society transition to sustainability, it makes sense to ask: How might scientific knowledge help society solve problems and create solutions that will help a transition to sustainability?

Building on the previous discussions, this section analyzes how scientists envision the knowledge produced by sustainability science contributing to society. Two broad themes emerged in my analysis of subject interviews and the literature: the *knowledge-first* approach and the *process-oriented* approach.

Knowledge-first approach. Cash et al. (2003: 8089) argue that without drastically increasing the contribution of science and technology, "it seems unlikely that the transition to sustainability will be either fast or far enough to prevent significant degradation of human life or the earth system." Carpenter et al. (2009: 1305) contend that "compelling and urgent social needs" stress "the urgency and importance of accelerated effort to understand the dynamics of coupled human-natural systems." Sustainability science performs fundamental research on problems identified by society which, scientists argue, will help move towards solutions. I refer to this vision of the role of science in society as the *knowledge-first approach*; i.e., "science characterizes problems in terms of their causes and mechanisms as basis for subsequent action" (Sarewitz et al. 2010: 1).

As Matson (2009: 41) notes, "the purposeful intent [of sustainability is] to link knowledge to action. Much of sustainability science is hard-core fundamental research, but the field is essentially use-inspired and oriented toward decision-making of all kinds." Sustainability science, says Matson, can "help make better decisions" but there has to be a "pull" from decision-makers. "The biggest challenge," notes Matson, "is finding mechanisms to have that ongoing conversation, dialogue, interaction with decision-makers."[36] That is, decision-makers have to signal to scientists what kind of information is needed to make better decisions. Simon Levin, for example, notes that scientists have "no special expertise to deal with ethics, and certainly not with politics, so I see the role of scientists as not making decisions, but as informing decision-makers."[37] Part of this process then is finding out what decision-makers need. Again, Matson – "We are creating knowledge that can be useful in decision-making. And we're understanding enough about what's needed so that the knowledge we create…is useful in decision-making."[38]

[36] Pam Matson. Interview. 26 September 2009.

[37] Simon Levin. Interview. 16 December 2009.

[38] Pam Matson. Interview. 26 September 2009.

This knowledge, it is argued, must be co-produced with stakeholders and decision-makers. Co-production is *not* used in the same sense here as Jasanoff (2004a) and others use the term. Co-production of knowledge in the case of sustainability science refers to the act of producing information "through the collaboration with scientists and engineers and nonscientists, who incorporate values and criteria from both communities" (Cash et al. 2006: 467). Organizing and facilitating co-production of knowledge at the interface of science and society is referred to as boundary management (Cash et al. 2003). Boundary management is often performed by boundary organizations, "which help stabilize the boundary between science and politics" (Guston 1999: 88). These actions are meant to ensure the salience, credibility and legitimacy of the knowledge produced.

The knowledge-first approach views the problem of sustainability as a problem of not using available knowledge due to lack of credibility or legitimacy, having insufficient knowledge or not having knowledge about the necessary aspects of the system (salience). If science can provide the knowledge that is needed about coupled system dynamics, for example, then better and more informed decisions may be made (i.e., decisions that will move society towards sustainability). For knowledge-first sustainability science, working with stakeholders and decision-makers is necessary to determine what knowledge is needed given certain goals set by society.

Sustainability scientists, however, are still careful to keep such activity separate from the core of the scientific research agenda -- fundamental research into coupled human-natural systems. As both "basic" and "applied," knowledge-first sustainability science creates a boundary zone (see Figure 2.1) where it justifies its usefulness to society and decision-making for sustainability while maintaining epistemic authority by keeping its core research fundamental and free of values. As Kristjanson et al. (2009: 5049) conclude, “there is certainly a role in sustainability science for both traditional, curiosity-driven research and for context-specific problem solving— so long as both are conducted within a larger framework that ensures rigor and usefulness.”

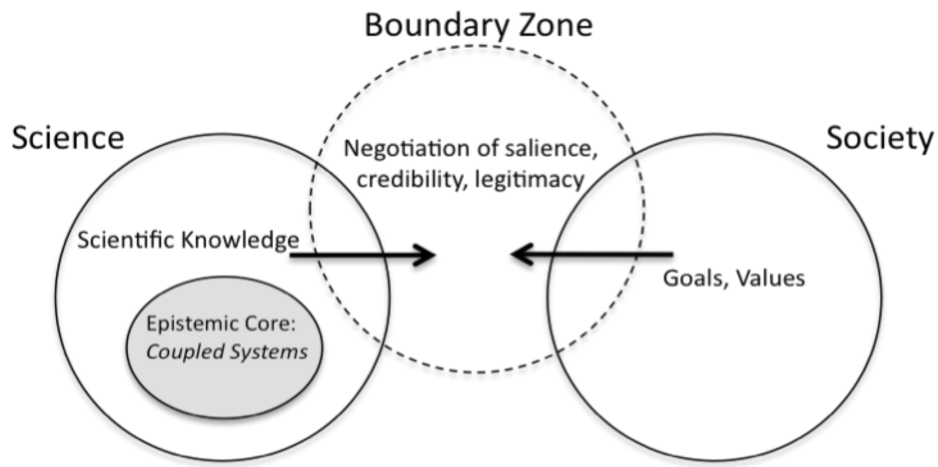

Figure 2.1. Relationship between knowledge-first sustainability science and society.

The knowledge-first approach is similar to the concept of “trans-science” (Weinberg 1972), which “preserved the authority of pure science as a course of credible policy advice while conceding that something more was needed…in order to provide useful answers to contemporary policy questions” (Jasanoff and Wynne 1998: 9). In the case of sustainability science, however, the boundaries between science and politics are less transgressive; that is, through boundary work (in Gieryn’s sense of the term) and boundary management, sustainability science is able to externalize the potential risk politics pose to its epistemic core while at the same time claiming to produce the knowledge that was heretofore limiting societal action. The knowledge-first approach attempts to be both free of and concerned with affecting politics:

> Despite the awe in which we hold nature and the value we place on its conservation, ours is ultimately a project that seeks to understand what is, can be, and ought to be the human use of the earth. We pursue this goal, however, in the conviction that what is possible and desirable for people can only be understood through an appreciation of the *interactions* between social and environmental systems. (Clark 2010: 82; emphasis in original)

Process-oriented approach. Richard Welford, who was skeptical about the promise of sustainability science throughout the interview, contends that "the only point of doing research is to create change."[39] Likewise, Olsson argues that sustainability science can be called "action research or…social intervention research…[where scientists] intervene and then that intervention becomes [a subject] of study… [R]ather than…simply understanding…how do you actually feed into [the intervention]?"[40] Here, the focus is on setting up, participating in and conducting research on social and technological processes attempting to define and move towards sustainability. I refer to this approach as the *process-oriented* approach.

In some instances, the process-oriented approach goes beyond collaborative or participatory research to facilitating or actively participating in what Rotmans calls "arenas for change or transition." Rotmans, reviewing the progress of the MATISSE project (Methods and Tools for Integrated

[39] Richard Welford. Interview. 6 July 2009.

[40] Lennart Olsson. Interview. 30 October 2009.

Sustainability Assessment) speaks of intervention, assessment and steering: "First of all, what we learned is the strength of the combination of theorizing and practicing it…secondly, what we do is guid[e] that process…We are analyzing the process and co-structuring it… We are facilitating the process...[and] co-steering the process because we are actively engaged in it all…"[41] There is an active role for science and scientists in establishing, facilitating and participating in mechanisms or dialogue for change as opposed to simply providing knowledge from a more removed position.

In transitions management, a "transition arena" is created where this work takes place. Loorbach and Rotmans (2009: 7) define a transition arena as an "informal network…within which a group process unfolds, often in an unplanned and unforeseen way." These arenas are sites for boundary management and joint knowledge production by scientists, decision-makers and other stakeholders (Kemp and Rotmans 2009). The aim of boundary management in this case is not necessarily to ensure that knowledge produced about coupled human-natural systems will be salient, credible and legitimate; rather, it is to facilitate a process for determining multiple trajectories for a transition and continual, mutual learning (Kemp and Rotmans 2009).

Like the knowledge-first approach, science still acts as a knowledge provider in the process-oriented approach. "Science is still playing a big role in that first of all it's a knowledge provider," says Jäger, "but not the only

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[41] Jan Rotmans. Interview. 24 November 2009.

knowledge provider."[42] Robinson makes a similar point -- "Science plays the crucial role of providing some of the information about consequences and tradeoffs associated with difference choices, but it doesn't tell us anything about where we want to be. That has to emerge from discussion…We [scientists] want to engage them as citizens of part of a collective."[43] The role of science is to help society or communities deliberate over what sustainability might look like and how communities might move towards it. Both the knowledge-first and the process-oriented approaches are concerned with assisting a sustainability transition by producing credible knowledge. Most sustainability scientists acknowledge the importance of working with stakeholders so that science can provide useful information. However, how they envision the type of knowledge needed and the role of that knowledge in assisting society is quite different.

David Kriebel, co-Director of the Lowell Center for Sustainable Production, cautions that "[scientists] have to be aware not to allow the need to fully characterize the system delay action." Kriebel believes that it's important to make a "distinction between the system in which the problem occurs and the system in which the solution occurs."[44] By focusing on where the solution may occur, he argues, the conversation shifts from a scientific characterization of the system to the social, political, economic and technological processes involved in

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[42] Jill Jäger. Interview. 18 November 2009.

[43] John Robinson. Interview. 5 October 2009.

[44] David Kriebel. Interview. 16 November 2009.

formulating a desirable outcome. In Jäger's words, "it's trying to find ways to get things done."[45]

In response to a question on the role of sustainability science in society, Robinson asks, "Who needs to know the science?" He sketches three potential ways in which scientists might seek to help society move towards sustainability. The first potential method would be to use guilt to pressure individuals into changing their behavior, which, he notes, has not been terribly successful thus far. A second would be "to do a brilliant analysis, and it's so compelling and convincing that when we give it to policy makers, they change everything." In his own experience, however, Robinson argues that the role of science "has to be [in] a conversation where various forms of certified knowledge are brought together with various ethical and normative views of citizens…in an exploration of where we want to be in the future."[46]

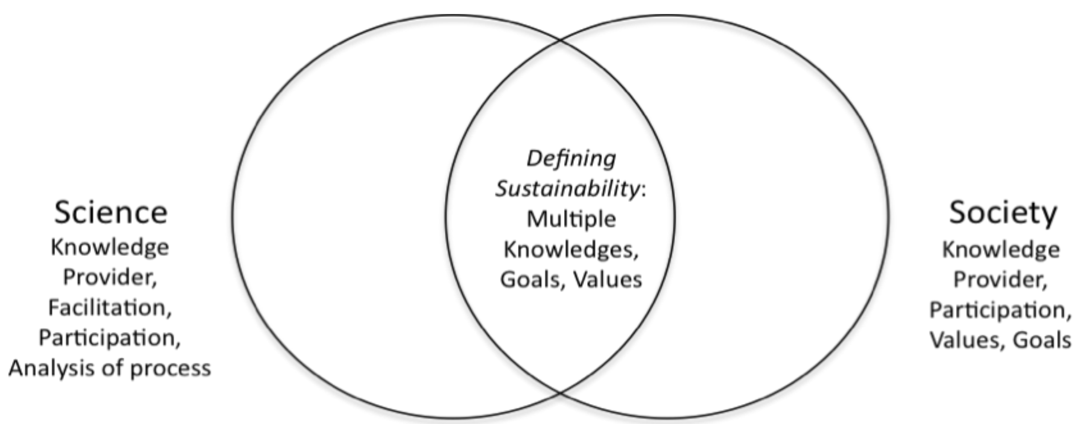

Figure 2.2. Relationship between process-oriented approach to sustainability science and society.

[45] Jill Jäger. Interview. 18 November 2009.

[46] John Robinson. Interview. 5 October 2009.

The process-oriented approach at once creates a space for science as a source of credible knowledge and limits its own epistemic authority by acknowledging that it is just one source of such knowledge among many. Scientific analysis is focused on transition arenas (e.g., Loorbach and Rotmans 2009), solution spaces (e.g., Sarewitz et al. 2010) or, more broadly, the process of envisioning and pursuing pathways to sustainability (e.g., Robinson and Tansey 2006). Regardless of any evaluation of the actual effectiveness of such efforts, they are focused on processes of change. Rather than knowledge acting as the limiting factor in the ability to make decisions, it is a matter of constructing a social process in which various forms of credible knowledge, perspectives and values can come together to define sustainability. This creates a more open discourse about what sustainability is and how a given community might move towards it (see Figure 2.2). The process-oriented approach is more concerned with exploring pathways to sustainability, or as Jäger said, "get things done" than with maintaining a core program of fundamental research.

Table 2.1. Summary of sustainability science approaches.

Defining Sustainability	***Universalist*** •Normative frame •Universal values •"Value-free" science	***Procedural*** •Defining as process •Values of community •Contextual	***Ambiguous*** •Clearinghouse •Criticisms •More constructive?
Research Agendas	***Coupled Systems*** •Fundamental research •Social needs •Co-production	***Social Change*** •Action research •Processes of transitions •Participant	
Science-Society	***Knowledge-first*** •Problem space •Salient, credible, legitimate knowledge •Knowledge provider	***Process-Oriented*** •Social intervention •Beyond understanding •Facilitate and participate in process	

Bounding Sustainability

In both the universalist and procedural definitions of sustainability scientists are carving out a role for science and shaping the way society might understand sustainability. For thin sustainability, a universal understanding of sustainability is complemented by the universal applicability of science. Thin sustainability allows science to continue to represent "the only universal discourse available in a multiply fragmented world" (Jasanoff 1996: 173). This limits debate not just over the appropriate or effective role of science but also important social, political and cultural debates over the nature of sustainability, especially in specific contexts. Sustainability is prevented from becoming "thick" because science cannot go there; science cannot become contextual, contested and qualified. While thin sustainability has a wide, almost universal, appeal, it may also inhibit efforts to develop thick sustainabilities in specific places that conflict with each other or with thin notions of sustainability.

As Jamieson (1998: 189) argues, at this universal level “there is too little by way of shared beliefs and values to provide enough content to ideas of sustainability to make them effective.” Procedural sustainability, on the other hand, attempts to identify social values that are important for sustainability that will result in action. According to Norton (2005: 405) the question that a more procedural sustainability can help address is -- “How can diverse, democratic communities develop procedures that encourage cooperative action to protect their environment?” Considered in light of procedural sustainability, the process-oriented approach to the relationship between science and society establishes a dual role of science as both participant and observer of the procedures Norton proposes.

In order to address the problems of sustainability, Cash et al (2003) urge that society “harness the power of science and technology.” Both the coupled systems and social change approaches to sustainability make “compelling arguments for why science is uniquely best as a provider of trustworthy knowledge, and compelling narratives for why [their] science is bona fide” (Gieryn 1999: 4). The coupled systems approach does this by maintaining a core of basic science while conceding that it must also be applied in order to link knowledge to action. Somewhat differently, the social change approach is more critical of the usefulness of science, yet it carefully maintains a space as part of societal processes that define sustainability *and* as uniquely positioned to analyze such processes.

Scientists, particularly in the coupled systems approach, seek to establish their epistemic authority over facts about the sustainability of system dynamics and its usefulness in decision-making. At the same time, they both site a thin sustainability as a normative goal or motivation *and* establish normative discussions as outside of the realm of hard-core science. An examination of two acts of boundary work on the part of the coupled systems approach serves to highlight these issues.

First, boundary work performed by sustainability scientists delineates the analysis of coupled human-natural systems as the scientific purview of sustainability science. The coupled systems approach is similar to what Thompson (2010) refers to as functional integrity. Functional integrity can be “understood in terms of threats to or failures in the integrity of functional systems on which they depend” (Thompson 2010: 221). This leads to a perspective that certain human activities are sustainable or unsustainable according to the ways in which they affect this functional integrity. Furthermore, as Thompson (2010) and others note (Jasanoff and Wynne 1998; Miller et al. 2008; Norton 2005), how the boundaries of such systems are drawn contain various assumptions. As Jasanoff and Wynne note, “The universalism of technical discourses is often maintained through scientists’ unstated naturalization of their own assumptions concerning social behavior; that is, scientists come to accept their own assumptions a natural and not open to question.”

Given the complexity of these systems, science is relied upon to reveal and translate for society. This leads to the second act of boundary work – sustainability scientists imagine the effective pursuit of sustainability as in need of fundamental knowledge about coupled systems that sustainability science provides. However, as Sagoff (2008) warns, there is a danger in relying too heavily on science in areas that he argues are primarily of ethical concern. For example, Sagoff (2008: 207) argues that environmental science "presents nature as a system for interdisciplinary scientists to model and administer for the collective good rather than as an object for moral instruction and aesthetic appreciation for every individual."

For sustainability, there is a potential tension between the scientific and technical complexity of coupled systems and the social or community values that define sustainability for a given community (Norton 2005). Often, the problem is not related to a need for more knowledge, as Matson alluded to in a quote given earlier. Instead, it may be that a myriad of other social, political, technological or ethical issues require resolution (Sarewitz and Nelson 2008). This is not to say that scientific knowledge will not help to make more informed decisions or even lead to convergence on a decision in certain situations. At the extreme, sustainability science potentially black boxes sustainability as a scientific and technical issue (Latour 1987; Winner 1986).

Conclusion

I have used the lens of co-production and boundary work to open up the various approaches to sustainability science and their implications for sustainability in society. In so doing, this analysis presents the opportunity to navigate these issues and potential tensions between science and sustainability. The question then is how is sustainability science to be positioned to assist society in a sustainability transition?

This chapter is not meant to give a definitive answer to this query. It should also be noted that the evolution of sustainability science has been the result of coordinated efforts on the part of scientists and other stakeholders and should not be taken lightly. This analysis, however, while reviewing this development also offers an opportunity to continue this dialogue in new directions. Where, for example, is scientific knowledge a limiting factor in decision-making? Where will fundamental understanding of human-natural systems enhance our capacity to make decisions? What are other factors that are limiting decision-making and how will science affect that context? How is science to be engaged in the social, political, and ethical components of sustainability while maintaining its ability to provide credible knowledge where needed? What can the approaches outlined here offer each other? These questions must be addressed by scientists and society more broadly if sustainability science and related inquiry are to proceed effectively. Towards that end, the next chapter presents an in-depth analysis of some of the tensions between the goals and practice of sustainability science.

Chapter 3

TENSIONS IN SUSTAINABILITY SCIENCE: TOWARD A MORE REFLEXIVE RESEARCH AGENDA

Introduction

The greatest challenge facing humanity in the twenty-first century is the ability to reconcile continued improvement in human welfare around the globe with the capacity of natural systems to support such development. It is this grand challenge that the allied concepts of sustainable development and sustainability attempt to articulate. This challenge has gained significant traction in the scientific community over the last decade as scientists have attempted to formulate research agendas in response to what they view as the problems of sustainability (e.g., Holling 2001; Lubchenco 1998; Mihelcic et al. 2003; NRC 1999; Palmer et al. 2005; Schellnhuber et al. 2004).

Many scientists have argued that the problems of sustainability, from climate change and biodiversity loss to access to adequate safe water supplies and poverty alleviation, require renewed effort on the part of the scientific community to conduct research on the issues that matter most to society. Scientists stress the urgency of harnessing the contributions of science and technology as a means for developing solutions to many of the problems of sustainability (e.g., Cash et al. 2003; Clark et al. 2004; Kates et al. 2001; Hardin 1993; Leshner 2002; Reid et al. 2010). The National Research Council (1999: 7), for instance, concludes that "significant advances in basic knowledge, in social capacity and technological capabilities to use it, and political will to turn this…into action" are necessary for transitioning to sustainability.

One of the most prominent efforts of the scientific community to address these issues has been the emergence of sustainability science. Kates et al. (2001: 641) define sustainability science as an interdisciplinary field that aims to understand the "fundamental character of interactions between nature and society" and enhance "society's capacity to guide those interactions along more sustainable trajectories." Sustainability scientists seek to both advance fundamental research on coupled human-natural systems and link this knowledge to societal action. Cash et al. (2003: 8089) argue that without drastically increasing the contribution of science and technology to efforts to solve sustainability problems, "…it seems unlikely that the transition to sustainability will be either fast enough or far enough to prevent significant degradation of human life or the earth system." Sustainability science has been positioned by some of its advocates as a new paradigm that attempts to reconceptualize the relationship between humans and nature and construct scientific research agendas that address pressing social and environmental problems (Chapin et al. 2009; Ellis and Haff 2009; Fisher et al. 2007; Kates 2001; Weinstein 2010).

As sustainability science continues to develop with the establishment of academic programs and research centers, dedicated peer-reviewed journals and funding from the National Science Foundation, the American Association for the Advancement of Science and the National Academies of Science, it is worth taking a step back to examine the implications of current developments in the field. While the research goals of sustainability science—fundamental research on complex human-natural systems—and its stated mission—linking knowledge to action for sustainability—are often assumed to be synergistic by sustainability scientists (see Chapter 1), this chapter explores underlying tensions that, if navigated poorly, will devalue important normative debates about sustainability goals, elevating some norms (for instance, narrower technical and scientific values) over broader societal norms (responsibility to nature and future generations, for example), and make for an ineffective research agenda.

The first such tension is between science and the normative nature of sustainability—the potential consequences of transforming sustainability, a normative, contested and ambiguous concept, into the subject of scientific analysis. Sustainability can provide communities with a conceptual framework to articulate and pursue visions of social and natural well-being (Norton 2005). The role of science in fostering such efforts is, however, not straightforward. Science can provide descriptive foundations for normative statements in favor of sustaining ecosystem resilience or adaptive capacity, for example. Yet, science, through the perceived epistemic authority of its explanations, can also limit what is considered appropriate discourse (Appadurai 1996; Smith 2009). For instance, scientific explanations of climate change and atmospheric dynamics have served to underpin a global understanding of climate and the mitigation of greenhouse gases as a potential solution, rather than more local or regional explanations and approaches such as adaption (Pielke, Jr. et al. 2007). Science can both *enable and constrain discourse* about problems and their potential solutions.

The second tension revolves around the issue of what is known (or unknown) about the institutional and epistemological contexts that link knowledge to societal outcomes. The assumed relationship is that more knowledge will lead to better decisions. The role of scientific knowledge in decision-making is, however, much more complicated (Collingridge and Reeve 1986; Jasanoff 1990). There may be numerous factors at play in affecting decision-making capacity in any given context, the least of which is the level or certainty of scientific knowledge. This is the tension between *knowledge and action*.

Thomas Kuhn (1977, 1996) uses the notion of essential tensions to great effect to illustrate the conservative and innovative imperatives of science. Scientists, argues Kuhn, must be able to solve puzzles effectively within a given paradigm. The practice of normal science "is a highly convergent activity based firmly upon a settled consensus acquired from scientific education and reinforced by subsequent life in the profession" (Kuhn 1977: 227). Yet, divergent thinking is necessary when scientists must grapple with and seek to explain anomalies that do not fit their traditional paradigm.

In Kuhn's view, the tension between the necessity of convergent thinking for the practice of everyday science and divergent thinking for innovation in the pursuit of anomalies is essential to the advancement of scientific knowledge. Crucial to Kuhn's thinking on this point is that innovation and paradigm shifts will not occur without the convergent standards of normal science to support the ability of scientists to recognize novelty. Occasionally, as a crisis occurs due to the inability of the current paradigm to explain anomalies, "scientists must be able to live in a world out of joint" (Kuhn 1996: 79).

Social studies of science scholars have also used the idea of tensions to illustrate various aspects of scientific research in practice. Hackett (2005), for example, explores the systemic tensions that research groups must navigate, including those between autonomy and control in managing a research lab, and between novelty and accepted methods and problems in the pursuit of research pathways. The concerns of Kuhn and Hackett have focused primarily on the internal machinations of science—the array of social and institutional forces that pull at scientists as they perform research.

Here, the focus is not on the social forces internal to science; it is on the tensions that emerge as scientists attempt to perform research on issues of societal importance and link scientific knowledge to social outcomes. There is a pervasive model in both science and society, which holds that more scientific knowledge is necessary to achieve beneficial outcomes (Collingridge and Reeve 1986; Neff in press; Nelson 2003). This chapter explores the tensions between the knowledge produced by sustainability science and the use of that knowledge by society. It is hoped that in bringing these tensions to light they may be more effectively navigated by sustainability scientists and contribute to the construction of a more effective and reflexive research agenda for sustainability.

The chapter begins with a discussion of benign and wicked sustainability problems and why this is crucial in exploring the tensions that arise in the conduct of sustainability science. The remainder of the chapter is devoted to an analysis the tensions between sustainability science and social outcomes—the enabling and constraining power of science, and the tension between knowledge and action. The chapter concludes with a brief discussion of the ways in which sustainability discourses might be affected if these tensions are navigated poorly.

Benign and Wicked Sustainability

Sustainability issues are often *wicked*—that is, they are problems wherein solutions are not obvious, complexity is high, uncertainty is rampant, values are in dispute and trade-offs are the norm (Funtowicz and Ravetz 1993; Miller et al. 2011; Norton 2005; Rittel and Webber 1973). Many of the problems that fall under the rubric of sustainability—ensuring adequate access to clean water supplies, developing alternative energy systems, evaluating intergenerational trade-offs in natural resource use, and advancing solutions to widespread poverty—are not only difficult to define but rarely yield to simple, one-time solutions. As the coiners of the term, Rittel and Webber (1973: 161), note: "The formulation of a wicked problem *is* the problem! The process of formulating the problem and of conceiving a solution (or re-solution) are identical, since every specification of the problem is a specification of the direction in which a treatment is considered."[47] Tame or benign problems, on the other hand, are those

[47] Rittel and Weber (1973) identify ten distinguishing characteristics of wicked problems: (1) There is no definitive formulation of a wicked problem; (2) Wicked problems have no stopping rule; (3) Solutions to wicked problems are not true-or-false, but good-or-bad; (4) There is no immediate and no ultimate test of a solution to a wicked problem; (5) Every solution of a wicked problem is a "one-shot operation"; (6) Wicked problems do not have enumerable (or an exhaustively describable) set of potential solutions; (7) Every wicked problem is essentially unique; (8) Every wicked problem can be considered to be a sympton of another problem; (9) The existine of a discrepancy representing a wicked problem can be

in which the goal is clear and it is easy to determine if the problem has been solved (Norton 2005; Rittel and Webber 1973).

Wicked problems are not just empirically challenging, they are linked to normative criteria (Fischer 2000; Hoppe and Peterse 1993). A central characteristic of such problems is that they are defined by value pluralism and that these values are highly contested. Consensus over problem definitions or the identification of solutions is very difficult. In the case of tame or benign problems, convergence on policy and technical solutions is possible in part because the proposed solutions are able to satisfy multiple value positions (at least for a time). Richard Nelson's (1977) moon-ghetto metaphor may help to highlight why distinguishing between tame and wicked problems is critical. The moon-ghetto metaphor refers to the following question: "If we can land a man on the moon, why can't we solve the problems of the ghetto?" Though technologically complicated, landing on the moon is a relatively tame problem. The mission is straightforward and it is clear when it has been achieved. It is a matter of economic investment and technological capability. The problems of the ghetto, however, are difficult to define and rarely give way to scientific or technological applications. How can we provide decent and affordable health care? How can high school graduation rates be improved? Addressing issues such as these is infinitely more complex and wicked. Moreover, the solutions to such problems are often highly contextual.

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explained in numerous ways. The choice of explanation determines the nature of the problem's resolution; (10) The planner has no right to be wrong.

Many of the environmental problems that society has been successful in solving to some degree have been tame. Sewage treatment facilities and sanitation networks led to vast improvements in water quality and public health throughout Western Europe and North America in the mid-19th century (Melosi 2008). Likewise, the invention and eventual widespread use of the catalytic converter in the 1950s and 1960s substantially reduced the toxicity of automobile emissions, contributing to improvement in air quality in heavily congested cities. A key point is that these tame problems are amenable to technical applications that are relatively uncontroversial and help to settle potential value debates. This is possible because the goal is clear and does not involve significant trade-offs between various interests (Lindblom 1959). For wicked problems, this process is not possible. Potential technological or policy solutions to wicked problems such as climate change often divide as many interests as they bring together. Furthermore, due to their normative and empirical complexity, solutions to wicked problems often end up leading to the proliferation of additional unforeseen problems (Latour 1993; Scott 1998).

Yet, it is also the case that before modern sewage and sanitation systems, the problems of water borne disease, water quality and public health were wicked.[48] This is an example in which a wicked problem was tamed by technological developments, political will and institutional change. Such

[48] Of course, such problems are *still* wicked in many parts of the world. The contextual variability of problems as well as the differential presence of technology, know-how and institutions necessary to regulate or deal with such problems in large part can determine whether a problem is wicked or not. A wicked problem is not a wicked problem everywhere and a tame problem is not a tame problem everywhere.

developments can occur in the absence of necessary scientific understanding or even despite incorrect scientific understandings. For example, in the case of sanitation, the miasmatic theory, which associated disease with bad smells, dominated contemporary thinking as new methods for sanitation and disease prevention were first implemented (Melosi 2008). Additional scientific knowledge may not necessarily be the tool to help solve or settle a wicked problem. In fact, additional knowledge will likely be contested by differing scientific findings or political positions and reveal additional uncertainties, rather than eliminate them. If sustainability scientists are to facilitate social learning and link knowledge to action (Kates et al. 2001), they must be able to differentiate between these various types of problems and provide the knowledge or tools appropriate for a given context.

Tension I: The Enabling and Constraining Power of Science

"The tempting aspect of the distinction between facts and values lies in its seeming modesty, its innocence, even: scientists define facts, only facts: they leave to politicians and moralists the even more daunting task of defining values."
– Latour (2004: 95)

"The substantive focus of sustainability science," states Matson (2009: 39), "is on the complex dynamics of the coupled human/environment system." As Clark (2009: 82) states "[sustainability science] is ultimately a project that seeks to understand what is, can be, and ought to be the human use of the earth." Similarly, Jan Rotmans notes that sustainability serves as a "normative orientation" for sustainability scientists (interview, 24 November 2009). Yet, Parris and Kates (2003: 8068) believe that "defining sustainability is ultimately a social choice about what to develop, what to sustain, and for how long." It is important to consider how the fundamental research goals of sustainability science and its commitment to contributing to more sustainable outcomes might affect the understanding and pursuit of sustainability in society.[49] We must be aware of how the epistemic and normative commitments of sustainability scientists shape societal understandings of sustainability (and vice versa).

At the core of this issue lies a tension between the ability of science to both reveal what were previously unobservable phenomena and constrain the variety of alternative legitimate explanations for those phenomena. As science and technology studies scholars have shown, the ways in which we come to know the world also shape it, including the way we value it (Jasanoff 2004; Latour 1993; Shapin and Schaffer 1985). The following discussion seeks to illuminate the implications of subjecting a contingent, contextual, contested and value-laden concept—sustainability—to objective, empirical scientific analysis.

Communities focused on environmental and sustainability issues have traditionally relied on science to reveal problems and contribute to and defend solutions (Bocking 2004; Jasanoff 2004). Science, on the one hand, can help to illuminate new realms of ethical concern. Concern for sustainability and intergenerational equity, for instance, was driven in part by inquiries into climate change and other long-term environmental impacts (Sarewitz 1996). On the other hand, the role of science in such issues is much more complex. Science can reveal more uncertainty and support multiple value positions that may in fact exacerbate

[49] See Chapter 2 for detailed discussion of coupled human-natural systems research in sustainability science.

the difficulty of resolving problems (Collingridge and Reeve 1986; Jasanoff 1990; Sarewitz 2004).

Additionally, there is often a gap between how scientists think about a problem and how the public comes to know or understand it—what Jasanoff (2005) refers to as civic epistemologies. Civic epistemologies are "the social and institutional practices by which political communities construct, review, validate, and deliberate politically relevant knowledge" (Miller 2008: 1896). The process of knowledge making by political communities and how it is argued, reasoned, promoted and utilized in public deliberation over sustainability goals and indicators (Miller 2005) is different from the social and institutional arrangements and epistemic commitments of the scientific community.

Further, as Dupré (1993) notes, "science aims to detect order and to create order." The way in which science interrogates an issue can impact the way that an issue is framed by policy and the public (Bocking 2004; Miller 2008). There is reason to doubt that the ways scientists frame problems will necessarily make for the most effective or democratic social outcome. The goals (e.g., to advance knowledge, disciplinary expertise) and institutional context (e.g., to publish in an area of expertise, gain tenure) of science and scientists may actually serve as constraints on acting pragmatically, which can be defined in terms of social action by way of policy or politics that might advance visions of sustainability. As sustainability science continues to develop as a field, it makes choices about what aspects of coupled systems to examine and how. As it does this, sustainability scientists exclude other ways of knowing, often unwittingly.

At one level, this is the classic tension between the technical nature of environmental (and sustainability) problems and the need and desire for transparency and democratic deliberation (Bocking 2004; Brown 2009; Fisher 2000). My concern is slightly subtler, engaging the epistemic nature of this tension. Sustainability science, like all empirical work, requires developing ways to categorize the world (Bowker and Star 1999; Cartwright 1999; Porter 1995; Scott 1998). Scientific communities do not just seek knowledge about nature, they seek knowledge about nature under a specific description – e.g., teleological, mechanistic or as a complex adaptive system (Longino 1990). Before any knowledge is produced or any research performed, the system under inquiry must be characterized "in ways that make certain kinds of explanation appropriate and others inappropriate" (Longino 1990: 98).

In its quest for understanding, science disciplines problems, making them amenable to certain methodological approaches and theoretical frameworks. Yet, the difficulty of finding solutions for many sustainability problems is often not related to an inadequacy of scientific knowledge. A better understanding of a given issue may not succeed in taming a wicked problem or in making it any more amenable to social, political and technological solutions. Sustainability science has, however, made a promising move towards place-based research that attempts to address concerns as scales that are socially significant.

How sustainability science disciplines or frames the issues with which it is concerned will make those issues either more or less tractable and either more open or closed to debate. This is a problem for sustainability science if it intends to contribute to societal efforts to pursue sustainability transitions because other scientific ways of understanding and value-based perspectives are excluded. Robbins (2001), for example, tells the story of a satellite image of a small town in India. Robbins showed this image to several of the town's inhabitants, evoking myriad interpretations. Foresters pointed to evidence of reforestation; farmers noted the bare soils and denuded areas; a retired forester lamented the loss of tree cover; and, a worker at a local advocacy organization for pastoralists cited the amount of grassland that has been lost to increased tree cover.

This single satellite image highlights the plurality of interpretations of categories in the landscape. Seemingly simple concepts that many scientists take for granted such as 'forest,' 'degraded' and 'grassland' are contested. Satellite imagery is not an impartial, objective tool. Rather, imagery itself is both a political tool used to settle categories in the landscape and a force of transformation of the environment. In Robbins' account, the result is the reproduction of green canopy cover with little human or ecosystem value. These categories become normalized and objective as they get reproduced (Anderson 1991; Porter 1995). As Robbins argues, "The measurement of these resulting landscapes through the very tools of their transformation [i.e., satellite imagery] naturalizes the resulting ecologies and erases the history of intervention from which they arise" (Robbins 2001: 176). The erasure of this history transforms contested categories of land-use and land-cover change into black boxes (Latour 1987). They become accepted facts in landscape management rather than contested categories open to interpretation and embodying different practices and livelihoods.

Science has the power to constrain discussions over contested concepts and categories. It influences what counts as "real" in the world. Scientists, perhaps necessarily, take reductionist approaches as they search for causal mechanisms, analyze problems and advance knowledge. This constraining power of science has implications for the ability of communities to voice legitimate normative perspectives about their future and how we understand phenomena that may impact those perspectives (i.e., what is sustainable or not in a given context), especially when it comes to wicked problems.

The categories scientists create are adopted by social actors in unpredictable and unintended ways (Porter 1995). James Scott (1998) details the rise of scientific forestry in late eighteenth-century Germany. State-managed forest science transformed a dynamic and diverse old-growth forest into a uniform, legible, mono-cropped grid of board feet of timber, an ecosystem and cultural domain into volume of lumber. As Scott (1998: 15) notes, "the German forest became the archetype for imposing on disorderly nature the neatly arranged constructs of science." Germany forestry science came to dominate the curriculum of American and European forestry schools, shaping both science and forest management on both continents for the next century.

While successful in the short run, this utopian vision of a regimented forest producing a sustained yield of lumber under the tutelage of scientific forestry eventually met with the more complex reality of the diverse ecological processes required to support a healthy forest. In the worst cases, the result was *Waldsterben*, or forest death. Scott's account (1998: 21) "illustrates the dangers of dismembering an exceptionally complex and poorly understood set of relations and processes in order to isolate a single element of instrumental value." As Thompson (2010: 239) notes, many scientists argue:

> …advanced systems modeling is a wholly value-free process that will, through pure science, generate the information we need to save the planet … but … the way we conceptualize a system is deeply value laden and reflects judgments about what is thought to be problematic, as well as likely guesses about where the solutions might lie.

Forest scientists simplified German forests to maximize yields; so too must sustainability science produce simplifications to make wicked problems amenable to empirical analysis.

Positioning the understanding of complex coupled human-natural systems as crucial to efforts to move towards sustainability, sustainability scientists also put themselves in an epistemically superior position. Sustainability scientists presumably hold the key to helping society move towards sustainability. Through their theories and methods, society is able to gain access into the workings of complex systems. The pursuit of the community-defined goals for sustainability is, however, not equivalent to the realization of scientifically objective goods. The danger lies not just with the simplifications that may be necessary to make dynamics of complex coupled human-natural systems the object of scientific analysis, but also in effects of sustainability science on value debates in society. Societal efforts to articulate and pursue sustainability require a certain discursive and conceptual "breathing room" that allows for an open deliberation of aims and value commitments.

Environmental philosopher Mark Sagoff (2008), for instance, highlights the issues that arise between science and value-laden pursuits such as sustainability, or, in Sagoff's case, between environmental science and environmentalism. Sagoff argues that environmentalists have relied too heavily on scientific theories and facts in what are essentially value-based arguments about aesthetics and environmental health. Environmentalism now,

> ….appeals to theories of the structure and function of ecosystems, the balance of nature, and other scientific principles…to prescribe values to society rather than to respond to values society already had… Environmentalism insofar as it relies on scientific theories or postulates has little to do with the places—particular forests or vistas—that people know, care about, or what to protect (Sagoff 2008: 205).

Similarly, Jamieson (1995) and others (Schrader-Frechette and McCoy 1994; Worster 1990) critique attempts to base environmental goals on science. For example, Jamieson (1995) argues that the concept of ecosystem health works to objectify our preferences related to ecosystem values. Such efforts are themselves unlikely to succeed in providing an objective basis for ecosystem management because our preferences and values related to ecosystems, like that of human health, are contextual and unstable (Nash 2001). Efforts to found value-based goals, whether they be environmental, sustainability or otherwise, on science are not only ontologically and epistemologically dubious—defining ecosystem health or sustainability scientifically is often, if not always, extremely difficult or impossible; they are also normatively and politically undesirable, limiting the ability to legitimately express conflicts about what is valued.

As the epigraph from Latour at the outset of this section indicates, scientists purport to focus on the facts—i.e., the dynamics of coupled systems—while society and decision-makers deal with the realm of values—i.e., what is to be sustained. Sustainability scientists attempt to address value-laden, wicked problems while maintaining a pristine epistemic core of fundamental research. For example Clark (2010: 82) states that "the *core* of sustainability science lies in seeking to understand how society's efforts to promote a transition toward sustainability are constrained or promoted by the interactions between human and environmental systems" (emphasis in original). By placing the understanding of coupled human-natural systems at the center of the research agenda, sustainability science is given access to understanding complex system dynamics. This framing has the effect of privileging sustainability science over alternative understandings of such dynamics in larger sustainability debates. It becomes less important to have discussions over potential future pathways for a community; instead, sustainability science is able to *know* what dynamics are (un)sustainable and deliver that information to society. Value debates are rendered impotent through the threat of incontestable nature (Latour 2004).

Scientists, policy-makers and the public are rarely aware of how the ways in which science categorizes the world also work to shape it (Jasanoff 2005). As Longino (2002: 189) notes, "After consensus, the constructive role of scientists disappears, and the result or theory is seen as inevitable, an expression of nature." It becomes black-boxed (Latour 1987). While necessary for the advancement of scientific knowledge, this eliminates the plurality of values within the sustainability discourse and constrains the number of legitimate voices and explanations for the sources of and solutions to various problems. Conceptualizing social problems in scientific and technological terms can confuse or eliminate cultural, political and normative discussions through the value-neutral, objective language of science (Fisher 2000; Jamieson 1995). Elucidating these tensions is a step towards enhancing the reflexivity of sustainability science and societal efforts to move towards sustainability goals.

Tension II: Knowledge and Action

A key characteristic of sustainability science is the effort to link scientific knowledge to societal action (Cash et al. 2003; Clark 2007; Kates et al. 2001; Matson 2009). Sustainability scientists are driven not just by fundamental research questions but also by performing research on pressing social and environmental problems (Clark and Dickson 2003; Levin and Clark 2010). As Carpenter et al. (2009: 1305) state, "sustainability science is motivated by fundamental questions about interactions of nature and society as well as compelling and urgent social needs." They continue, arguing that the challenges of sustainability highlight "the urgency and importance of accelerated effort to understand the dynamics of coupled human-natural systems." Similarly, Matson (2009: 41) views the "purposeful intent to link knowledge to action" as a core component of sustainability science. While "much of sustainability is hard-core fundamental research," notes Matson (2009: 41), "it is essentially use-inspired and is oriented towards decisionmaking of all sorts." Sustainability scientists assume that science will support the pursuit of sustainability values and knowledge about coupled human-natural systems will lead to better, more sustainable decisions.

Sustainability science is of course not unique among research efforts that aim to contribute directly to positive social and environmental outcomes by improving decisionmaking. For example, while serving as President of the American Association for the Advancement of Science (AAAS), Jane Lubchenco (1998) called for a new social contract for science. Lubchenco argues that science has led to incalculable benefits for society while seeking knowledge that is largely divorced from considerations of societal benefit. However, society now faces a set of challenges that require scientists to shift their research priorities and translate knowledge to policy-makers and the public more effectively. Scientists must address the most urgent needs of society, communicate the knowledge they produce to inform policy and management decisions and exercise good judgment in doing so (Lubchenco 1998). Similarly, Palmer et al. (2004, 2005) lay the foundations for a new pathway for ecological science—an "ecology for a crowded planet." They argue that for too long ecological research has focused on pristine ecosystems in which humans are viewed as a disturbance. They see a key role for ecology in informing decisions that support environmental sustainability and argue that a new research agenda must be built that focuses on ecosystem services and ecological design and restoration.

Underlying these efforts are two interrelated assumptions about the relationship between scientific knowledge and decision-making for sustainability: (1) Scientific knowledge is necessary and may even compel action relative to sustainability goals; and, (2) Sustainability science and its focus on fundamental questions in coupled human-natural systems dynamics can provide that knowledge. The first has to do with the diagnosis of the factors limiting the ability of society to take action relative to sustainability goals—i.e., a lack of scientific knowledge. As Cash et al. (2003: 8086) argue, "A capacity for mobilizing and using science and technology is increasingly recognized as an essential component of strategies for promoting sustainable development." Similarly, in a study of research priorities in ecology, Neff (in press: 5) finds that many ecologists believe that "amassing a preponderance of evidence about anthropogenic impacts…can compel leaders to make 'better' policies and decisions." Additional knowledge is required to make decisions that will be more sustainable. The second assumption is that science, and in this case, sustainability science, can provide the necessary knowledge about coupled system dynamics that will contribute to decision-making and improve decisions.

A brief examination of what Nelson (1977) refers to as the "science and technology policy perspective" will serve to further illuminate these assumptions and the potential tension between knowledge and decision-making. The key intellectual commitment of this perspective is that many problems can be solved with the proper application of scientific knowledge and technological capabilities. It is only a matter of directing research towards the appropriate goals. However, as Nelson (1977: 62) notes,

> While formally trained scientists and engineers, engaged in organized research and development, have been remarkably effective in advancing knowledge and creating powerful new capabilities in certain selected arenas, there is a strong element of faith attached to the proposition that

> these kinds of talents and activities can be applied powerfully to the solution of most any problem.

Nelson uses the example of crime and education. While the ability to address each of these problems may be limited by knowledge in some way, it is doubtful that the application of natural science or engineering could wholly address such issues. As Nelson (2003) notes, this is not a comment on researchers in the field of education (or in sustainability science for that matter). Instead, it has to do with limitations of the ability of research to contribute to areas where progress is largely tacit (i.e., relies on experience and practice) and social.

In this simplified model of the relationship between science and action, scientific knowledge provides the understanding on which decisions can be made (Komiyama and Takeuchi 2006; Levin and Clark 2010; Sumi 2007; Palmer et al. 2004; Parris and Kates 2003). Mooney and Sala (1993: 566), for instance, contend that better science will lead to more sustainable use of natural resources—"We conclude that sustainable use of resources is feasible, but the only way to achieve this goal is by improving our understanding of ecological systems." Many sustainability scientists, however, have recognized the limitations of this model. A central component of sustainability science is that research ought to be place-based (Kates et al. 2001; Turner et al. 2003). This is in part because sustainable development efforts take place locally (Kates and Parris 2003). Place-based research allows scientists to work with potential users of knowledge to ensure that it is credible, salient and legitimate (Cash et al. 2003, 2006; Clark and Dickson 2003). As Clark et al. (2002: 24) note,

> …for knowledge to be effective in advancing sustainable development goals, it must be widely viewed not only as reasonably likely to be true (i.e., "credible"), but also as relevant to decision makers needs (i.e., "salient") and as respectful and fair in its choice of issues to address, expertise to consider, and participants to engage (i.e., "legitimate").

These characteristics are necessary to "certify knowledge" (Clark et al. 2002). Sustainability scientists have proposed the concepts of boundary management and boundary organizations as crucial to negotiating the credibility, salience and legitimacy of knowledge between scientists and other stakeholders in order to ensure that scientific knowledge is used in decision-making (Cash et al. 2003, 2006; Guston 1999, 2001; Kristjanson et al. 2009).

While these efforts offer a more nuanced interpretation of the relationship between knowledge and action, a tension remains as the assumptions of sustainability scientists are only slightly modified from those presented above: (1) Science has not been producing the "right" kind of knowledge; and, (2) Decision-makers and, more broadly, society have not been utilizing the knowledge that science has produced. According to this perspective, problems in the production and use of knowledge must be fixed before science can aid decision-making. Science, up to this point, has not been addressing the appropriate questions to which society and decision-makers need answers. "Promoting the goal of sustainability requires the emergence and conduct of the new field of sustainability science" (Friiberg 2000: 1), which must be more applied and interdisciplinary in order to produce the knowledge that is required for decision-making (Clark 2002; Kates et al. 2001; Levin and Clark 2010). Decision-makers and society, according to this assumption, have not been using the knowledge that science has produced because it is not perceived as credible, salient or legitimate. For example, as Pamela Matson explains “there has to be a pull” from decision-makers or other stakeholders; they have to demand knowledge about certain issues (interview, 26 September 2009).

In this model, the role of science as knowledge provider has been ineffective because it has not been responding to demand or it is not being incorporated into decision-making. In each of these cases, advancing societal action towards sustainability outcomes is seen as requiring the production of more knowledge. This approach falls into what Sarewitz et al. (2010: 3) refer to as the knowledge-first trap “where rational action is viewed as deriving from factually correct assessments of the causes of a problem.” The knowledge-first trap can lead to a spiral of endless research and technical debates (Collingridge and Reeve 1986; Nelson 2003; Sarewitz et al. 2010). Collingridge and Reeve (1986: 5) argue that there is a fundamental mismatch “between the needs of policy and the requirements for efficient research within science which forbids science any real influence on decision-making.”

For example, in 1980, when transboundary acid rain policy was controversial in the United States. Congress created the National Acid Precipitation Assessment Program (NAPAP) to reduce the uncertainties of acid deposition causes and effects before the nation committed itself to an acid reduction policy that was potentially costly (Herrick 2000). Although NAPAP created a wealth of scientific understanding about acid rain, many retrospective evaluations have criticized its failure to create an integrated and consistent policy recommendation for Congress. NAPAP failed to generate scientific knowledge that was useful for policy makers in that the causes and effects of acid rain are extremely complex. Studying them requires multiple scientific disciplines to synthesize incongruent methods, systems of knowledge and perspectives. Furthermore, NAPAP became preoccupied with fundamental research questions and moved away from its original use-inspired orientation, thus eroding its potential value as an aide to policymaking.

As discussed earlier, sustainability scientists are both motivated by pressing societal problems and aim to conduct research on fundamental questions about coupled system dynamics (Carpenter et al. 2009; Levin and Clark 2010; Matson 2009). Given the complexity and uncertainty inherent in sustainability issues, there is an understandable temptation to produce scientific knowledge in order to reduce uncertainty. In seeking to apply scientific knowledge to sustainability problems (Clark and Dickson 2003; Cash et al. 2003), sustainability scientists are treating wicked problems as if they were tame problems amenable to scientific analysis. A crucial step in navigating this tension is for sustainability scientists to begin to develop frameworks to differentiate between problems that may very well be tame and thereby amenable to technological fixes or the application of scientific knowledge from those that are more wicked and for which narrow scientific and technical discourse will subvert the need for further ethical and political discussion.

While it may be the case that additional scientific knowledge is required to act on sustainability goals and advance sustainable practices, it may also be that there are number of other more proximate issues preventing action, such as technological capabilities and political debates. Without subjecting the link between scientific knowledge and beneficial societal outcomes to the same analytical rigor called for in addressing the challenges identified, the research that results may be either irrelevant to decision-making or will make such decisions even more difficult.

Scientizing Sustainability

When dealing with wicked problems, the response is often to call for more research to reduce uncertainty and lay the foundation for policy action and decision-making (Bocking 2004; Collingridge and Reeve 1986; Nelson 2003). Scientists have been trained to produce new knowledge. As scientists move to focus on real world problems, they do so with their weapon of choice—scientific knowledge. As Clark (2010: 82) states,

> Like 'agricultural science' and 'health science' before it, sustainability science is a field defined by the problems it addresses rather than the disciplines or methods it employs. Sustainability science then draws from—and seeks to advance—those aspects of our understanding of human systems, environmental systems and their interactions that are useful for helping people achieve sustainability goals.

A brief examination of this analogy serves to highlight some of the tensions discussed in this chapter. Medical scientists perform research that aims to increase human health and decrease morbidity. Agricultural scientists seek to increase yields per acre and decrease input of resources per unit of output. However, how these goals are defined and problems solved in practice is far more complicated and contested.

For example, medical science has come under criticism for pursuing increases in life expectancy at the expense of quality of life (Fuchs 2010). There are many issues in the doctor-patient relationships in terms of defining health problems, treatment and positive outcomes (Teutsch 2003). These involve questions of values and how one wants to live one's life. Even the very notion of what is healthy can differ in various cultural contexts (Jamieson 1995). Furthermore, much of medical science, as measured by research funding, is far more concerned with end-of-life diseases such as heart disease and cancer, which are health problems in the developed world, rather than chronic or acute ailments that develop earlier in life. This leaves diseases, such as malaria and tuberculosis, with the largest impact of global human health, particularly in the developing world, with a paucity of funding and research. There is a misalignment between the diseases that contribute to the global burden of death and the dominant directions in medical research (Flory and Kitcher 2004). As Sarewitz (1996) reminds us, most research and development occurs in the developed world and is designed to address its specific problems (e.g., health of aging populations, space exploration, national security, consumption) and not those of the developing world (e.g., infant mortality, malaria, poverty, malnutrition).

As for agricultural science, there is little doubt that research and development has led to enormous increases in human well-being throughout the world. New technologies (e.g., high yielding crop varietals), however, are not developed and deployed in context-free environments. Many efforts to increase crop yields, the Green Revolution in particular, have led to a mixed blessing at best as a result of a failure to adequately consider the social, economic and ecological context in which new crop varieties and information were being deployed. These artifacts of techno-science (Winner 1986) have shaped and been shaped by social and economic systems throughout the world as market and land tenure reforms were undertaken in an attempt to increase production and competitiveness (Moseley et al. 2010). Additionally, it is not clear that the lessons from such troubles have been gleaned as criticisms of renewed efforts for a second green revolution (this time focused on Africa) supported by the Rockefeller Foundation and Bill and Melina Gates Foundation illustrate (e.g., Holt-Gimenez et al. 2006).

While these sciences may be shaped by the problems they address, the disciplines they employ also shape the definition of problems, how they are pursued and potential solutions that they offer. A sustainability science modeled on these examples may fail to account for the difference between the context in which knowledge was initially developed and where and how it might be used. In addition, both medical science and agricultural science are arenas in which the voices and knowledge of non-experts are largely unwelcome, but for those instances where lay citizens have been able to adopt and change the language and concepts of the experts (e.g., Epstein 1996). Techno-scientific changes in medicine have led to the "medicalization" of society as scientific and technological interventions come to dominate not only efforts to improve human health but also produce visions of what it means to be healthy (Clark et al. 2003; Conrad and Leiter 2004). Likewise, agricultural science has scientized agricultural practices and devalued traditional knowledge and practice (Howard 1994).

If the tensions discussed above are navigated poorly, sustainability science may (a) be limited in its ability to contribute to sustainability efforts, or (b) *scientize sustainability* via the epistemic authority of the analysis of coupled systems and thereby positioned to settle cultural and political disputes over sustainability. Appeals to scientific arguments and the expertise of sustainability scientists may mask or push aside important political and value debates about sustainability (Jasanoff 1996; Nowotny 1982; Sarewitz 1996). Scientific and technical debates act as proxies for what are in fact debates about values and the good life (Miller et al. 2011; Sarewitz 2004). Scientists at once acknowledge the importance and necessity of the normative dimensions of sustainability while establishing it as outside of their expertise. It is thereby divorced from their science, enhancing its perceived credibility as value-free. There is a short-circuiting of any and all questions as to the nature of the bond between the sciences and society through the invocation of science (Latour 2004). Either outcome can be characterized as the result of "faulty" boundary work; i.e., boundary work that preserves the epistemic authority and autonomy of science *at the expense of* beneficial societal outcomes. As Herbert Simon (1983: 97) notes, "When an issue becomes highly controversial—when it is surrounded by uncertainties and conflicting values—then expertness is very hard to come by, and it is no longer so easy to legitimate the experts. In these circumstances we find that there are experts for affirmative and experts for the negative. We cannot settle such issues by turning them over to particular groups of experts."

Science can explore trade-offs between important social values and the possibilities of pursuing outcomes. Knowledge about coupled system dynamics is surely necessary to manage them well over the long-term. However, science does not present a certain, holistic picture of the world (Cartwright 1999; Dupre 1993). Nor is it value-free (Douglas 2009; Longino 1991, 2002). Just as sustainability science focuses on the coupled human-natural system in context, so too must the role of science be treated as contextual. Sustainability concerns the ability of communities to articulate and carry forward the social and natural values that are important to them and help to define their place (Norton 2005; O'Neill et al. 2008). Sustainability science may help inform and shape this process, but it should not dictate or define it. While sustainability scientists may not intend to do anything of the sort, as discussed through this chapter, the ways in which science can constrain debate and affect action can often be hidden and complex.

Rather than assuming a lack of scientific knowledge is limiting decision-making capabilities, sustainability scientists might examine when the level of scientific knowledge is regarded as a constraint on decision-making. Sustainability science must begin to explore what solutions are possible and how they might be fostered and from there determine what (if any) scientific knowledge would be helpful. While scientific knowledge may indeed be necessary to take action on particular sustainability problems, others can likely be ameliorated without any major advance in scientific knowledge. There are social, cultural, political, normative and technological constraints that may be far more proximate to society's ability to pursue more sustainable outcomes.

Conclusion

As Simon (1983: 105) aptly observes in relation to decision-making and social problems, "scientific knowledge is not the Philosopher's Stone that is going to solve all these problems." In fact, at least in the context of sustainability, scientific knowledge may inhibit the ability to solve certain problems by constraining debates, and lead to the assumption that more knowledge will generate better societal outcomes.

The point, however, is not to disparage current sustainability science efforts or argue that there is no hope for science to contribute to more sustainable social and environmental outcomes. There are several promising efforts in sustainability science and elsewhere that appear to be successfully navigating these tensions in their own ways. Fikret Berkes (2008, 2009), for example, is collaborating with indigenous groups in the Canadian Arctic to integrate traditional ecological knowledge (TEK) with scientific ecology in community-based natural resource management. Researchers at the Dutch Research Institute for Transitions (DRIFT) work to develop transition arenas for a variety of sectors including health care, waste management, climate mitigation and urban development where stakeholders can articulate goals and visions for more desirable outcomes and establish plans and policies to achieve them (Loorbach 2007; Rotmans and Loorbach 2009). Instead, the purpose is to maintain the ability of sustainability to act as a platform to articulate and pursue democratic visions of natural and social well-being.

The tensions discussed in this chapter present significant challenges to the practice of science, its usefulness to decision-making and its institutional structure. Future efforts in sustainability science must be more reflexive in examining how these tensions arise and play out in their own research. This will help to ensure the usefulness and relevance of knowledge in a given context. How they are navigated will in part determine the ability of sustainability science to encapsulate information in ways that are important to widely social values and will truly help society pursue more sustainable outcomes. In the next chapter, I develop a proposal for a new set of objectives and design imperatives that will enable sustainable science to successfully negotiate the issues raised here.

Chapter 4

RECONSTRUCTING SUSTAINABILITY SCIENCE:

A SCIENCE OF DESIGN

"The man who wears the shoe knows best that it pinches and where it pinches, even if the expert shoemaker is the best judge of how the trouble is to be remedied. A class of experts is inevitably so removed from common interests as to become a class with private interests and private knowledge, which in social matters is not knowledge at all."
—John Dewey (1927: 207)

Introduction

How can science and technology inform and foster social action for sustainability? This question has spawned a variety of efforts by members of the scientific community to contribute to the resolution of pressing social and environmental problems (Lubchenco 1998; NRC 1999; Palmer et al. 2005; Reid et al. 2010). Perhaps the most prominent and wide-ranging of these efforts has been sustainability science—an interdisciplinary, problem-driven field that addresses fundamental questions on human-environment interactions (Clark 2007; Clark and Dickson 2003; Kates et al. 2001; Levin and Clark 2010). Kates et al. (2001) laid the foundation for sustainability science, defining three core objectives for the field: (1) understanding the fundamental interactions between nature and society; (2) guiding these interactions along sustainable trajectories; and (3) promoting social learning necessary to navigate the transition to sustainability. Over the past decade, the field has gained significant institutional momentum with the formation of new research and education programs and centers, dedicated academic journals, and funding from the American Association for the Advancement of Science, the National Academies of Science, and the National Science Foundation, among others.

Much of the research in sustainability science, however, has focused on fundamental questions related to coupled human-natural systems and has relied on the assumption that this kind of research will compel social action related to sustainability goals (Cash et al. 2003; Carpenter et al. 2009; Clark and Dickson 2003). The sustainability science community has paid insufficient attention to the goals of guiding interactions along sustainable trajectories and promoting social learning. If sustainability science is to contribute to societal efforts to address pressing social and environmental problems, the objectives, structure and agenda of sustainability science must be reconsidered.

This chapter repositions sustainability science as a "science of design"—that is, a science of what *ought* to be in order to achieve certain goals, rather than a science of what *is*. This follows Nobel Laureate Herbert Simon's (1996) notion of the artificial sciences as sciences of design. Artificial sciences are concerned with how things "ought to be in order to *attain goals* and to *function*" (Simon 1996: 4-5). Here, I also utilize John Dewey's (1920, 1936) pragmatism which serves to ground sustainability science in lived experience and advances in inquiry are measured by progress in achieving goals. That is, the knowledge produced by sustainability should be helpful in bringing desired outcomes to fruition. Following Simon and Dewey, this chapter develops the idea of a more pragmatic sustainability science that evaluated on its ability to frame sustainability problems and solutions in ways that make them amenable to democratic social action.

It is not enough for sustainability science to focus on the analysis of system dynamics underlying certain problems; it must move toward research that is focused on the design of solutions. Following Sarewitz et al.'s (2010) sustainable solutions agenda, sustainability science must not be limited to research on the "problem-space," but most also be concerned with the space in which solutions are formulated and implemented, the "solution-space." Sustainability is a forward-looking, future-oriented concept that provides a conceptual platform for communities to articulate visions of social and natural well-being. Ironically, it is also partially backward-looking in that what is being sustained is a set of goods and values that have come to define a community over time. The mission of sustainability science should be to help bring such visions to fruition. Accordingly, I develop two core objectives for this reconstructed field: (1) To understand and contribute to the design of sustainable solutions; and, (2) To promote reasoning and deliberation over the meanings, goals and pursuit of sustainability.

Sustainability science is, however, ill-equipped to meet these objectives. This is not a result of an obvious flaw in how sustainability scientists have constructed their research agendas. On the contrary, part of the reason that the field has attracted attention is its ability to speak to a major gap in scientific research—interdisciplinary approaches to human-environment interactions and the claim that the knowledge gained from such research will support decision-making. This approach, however, falls short on fostering sustainable outcomes as a result of certain epistemic and normative limitations as well as a research agenda limited to addressing fundamental questions about coupled human-natural systems. To address these limitations, the research agenda for sustainability must be expanded and re-focused to meet a new set of objectives based on sustainable solutions and the fostering of public reasoning and deliberation over the goals of sustainability. I propose five design imperatives for the sustainability science research agenda. Sustainability science must be: (1) *contextual*, in its approach to sustainability problems and the design of potential solutions; (2) *plural*, taking multiple values and epistemologies into account; (3) *robust* in the formulation of its research agenda in order to remain responsive to a diverse set of sustainability issues; and, (4) *reflexive*, meaning that sustainability scientists must be aware of their role in shaping the societal discourse around sustainability. These imperatives and objectives act as a significant first step in repositioning sustainability science as a solution-oriented science of design.

The chapter begins with a discussion of the limits of sustainability science given certain characteristics of sustainability problems as complex, uncertain and contested. I then move to situate sustainability science as a science of design focused on a new set of core objectives. This is followed by a discussion of the proposed design imperatives for sustainability science and the implications of this new approach for the field.

The Limits of (Sustainability) Science

As discussed in Chapters 1 and 2, sustainability science has largely focused on two objectives: producing knowledge about human-environment interactions and linking that knowledge to action (Kates et al. 2001; Cash et al. 2003; Clark 2007; Friiberg 2001; Levin and Clark 2010). Sustainability science has been preoccupied with what can be referred to as the *knowledge-first approach*, the idea that more knowledge about underlying system dynamics will inform decisions and perhaps even compel action (Sarewitz et al. 2010). There are, however, severe limitations to this approach and to the ability of science to be of use in the contested, uncertain and value-laden context of sustainability.

While a lack of scientific knowledge can limit societal action in some cases, there are a myriad of social, political and technological issues and processes that are more proximate to the ability of society to act more sustainably, even if additional scientific information is available (Collingridge and Reeve 1986; Miller et al. 2009; Nelson 1977, 2003). In fact, in an early critique of the role of science in sustainability, Ludwig et al. (1993) argue that the scientific community has helped to perpetuate the illusion that progress in science can lead to sustainability. This section examines the epistemic and normative limitations of sustainability science in order to gain insight into how they can be recognized and dealt with more effectively.

Epistemic Limitations

Many sustainability problems present deep challenges to traditional scientific analyses and the role of science in society. Sustainability problems can often be classified as wicked problems—defined by high complexity, uncertainty, and contested social values (Funtowicz and Ravetz 1993; Ludwig 2001; Norton 2005; Rittel and Weber 1973). Traditional modes of inquiry are unable to produce knowledge that is robust enough to withstand contested values and high complexity. In fact, such problems are often characterized by multiple conflicting and equally valid scientific and social interpretations (Collingridge and Reeve 1986; Sarewitz 2004).

This limitation, then, is not just epistemic, but socio-political. Epistemologically, the very idea that science can produce authoritative or reliable knowledge about complex and contested phenomena has been challenged (Funtowicz and Ravetz 1993; Nowotny et al. 2001). At the same time, the reliability and usefulness of scientific knowledge in society and in decision-making contexts has been called into question. The scientific norms (Merton 1973) and epistemic values (Douglas 2009) governing scientific practice have not evolved to deal with wicked problems and arenas in which the validity of scientific knowledge is challenged outside of the laboratory (Crow 2007; Funtowicz and Ravetz 1993; Gibbons 1999; Jasanoff 2010; Nowotny et al. 2001).

Science, in such cases, is unlikely to reduce uncertainty or provide a common foundation for social action. Stakeholders often demand predictive information about policy outcomes from scientists. Many scholars have criticized the reliance on predictive modeling to eliminate knowledge shortcomings when complex systems (such as the climate) are under scrutiny. Oreskes et al. (1994) have argued that verifying scientific models of complex systems is impossible due to intractable epistemological limitations in understanding how a complex system's variables interact. Likewise, Nancy Cartwright (1999) has argued that science tends not to produce grand, hierarchical systems of natural laws consistent between disciplines. Rather, the relationship between laws is tenuous and we should avoid thinking of science as creating a coherent and consistent picture of our world.

At best, science may be able to inform decisions but never completely eliminate uncertainty in such complex systems; at worst, it may increase certain disputes and stall action. Such difficulties in the ability of science to inform decision-making often get attributed to social and political factors such as the public understanding of science or the politicization of science (Sarewitz 2010a; Wynne 1996). However, as Ludwig et al. (1993) argue it is likely that science will never reach consensus regarding causal mechanisms and dynamics of complex coupled human-natural systems.[50] More importantly, even if one were to grant that consensus in the scientific community is possible, meaningful social or political consensus on an understanding of an issue or a course of action is

[50] The perceived scientific consensus on climate change may seem to counter this claim. However, the consensus on the basic mechanisms behind climate change has not translated into concerted social action. Furthermore, as research in science studies has shown, this supposed consensus is fragile and hides significant and legitimate differences. The ability to achieve consensus is driven by social norms and processes, as well as institutional configurations (Jasanoff and Wynne 1998; Miller 2004; Schackley 2001; van der Sluijs 1998). In addition, as recent events such as "Climate Gate" have shown, such consensus is liable to be re-opened and challenged, providing a glimpse into the social, political and normative dimensions of scientific knowledge-making. This has as much if not more to do with social norms of scientific communities and institutions and political consensus (or lackthereof) as it does with the strength of scientific findings (Hulme 2010; Jasanoff 2010).

unlikely (Schwarz and Thompson 1990). This has as much, if not more, to do with the epistemic practices of science and the wicked nature of sustainability problems than it does with any perceived problems in the ability of decision-makers to incorporate scientific knowledge into their decisions.

Scientists, decision-makers and the broader public often perceive science as having privileged access to fact-based claims about the world (Jasanoff 2005; Latour 2004; Miller 2004). As a result, scientific knowledge and its perceived epistemic power can come to dominate alternative ways of knowing (Latour 2004; Scott 1998). Stephen Lansing's (1991) study of the disastrous (though well-intentioned) efforts by scientists and planners to reorganize farming practices in Bali, Indonesia highlights these issues.

During the Green Revolution, Balinese farmers were encouraged by planners, scientists and bureaucrats at the Bali Irrigation Project to abandon traditional cropping patterns and plant new, higher yield, hybrid rice varieties as often as conditions permitted. Planners at the Bali Irrigation Project also sought to improve the performance of the traditional irrigation systems through new construction and bureaucratic and scientific management. Before these changes brought about by the Green Revolution, Balinese farmers traditionally planned planting and harvesting through a complex social and technical process centered on a network of local water temples. Ultimately, these changes led to pest outbreaks and water shortages, particularly in the dry season, as scientists and planners attempted to plant a new round of resistant crops and develop new pesticides to stay ahead of the next potential rice pest. To the extent that social systems and the water temples entered into the analysis of the scientists and planners, it was largely in terms of the resistance of communities to the new technologies of the Green Revolution. Calls for return of the control over irrigation to water temples were perceived by the Bali Irrigation Project as religious conservatism and resistance to change. As one irrigation engineer responded, the farmers "don't need a high priest, they need a hydrologist!" (Lansing 1991: 115).

Lansing (1991) poses what he views as a fundamental question—Why wasn't the functional role of water temples a matter of common knowledge? He argues that the success of the water temples and traditional management practices made them invisible to scientists and planners studying them. Agriculture was viewed as a purely technical process. The invisibility of the water temples was also the result of the epistemic and disciplinary practices of the planners and scientists. The traditional management practices based on rituals performed at the water temples fell outside the boundaries of analysis for hydrologists, agricultural scientists and the like. These rites and rituals were not considered credible or legitimate by the planners, scientists and bureaucrats of the Bali Irrigation Project as they produced and utilized knowledge in different ways (Hacking 2002; Martello 2004; Miller 2008).

Scientific knowledge about coupled systems, their risks and vulnerabilities can shape discussion by highlighting certain aspects of the system and legitimizing some knowledge claims over others. As Norton (2002: 22) notes, in such contexts where interests vie to affect policy and management outcomes, "the relevant language cannot be the specialized languages of either a narrow, disciplinary science or of a narrow theory about what is meant by a small subset of the society." While the efforts of sustainability scientists may not be as heavy-handed as the Balinese Irrigation Project, they still must be aware of the ways in which their epistemic viewpoint can be both limited, resulting in the invisibility of certain factors, and, through its perceived power as value-free, constrain discourse and alternative understandings of sustainability.

Interdisciplinary research has emerged as a core characteristic of sustainability science and similar applied efforts in an attempt to overcome the fragmented and partial picture of problems presented by isolated disciplines. Many adherents of an interdisciplinary approach argue that it will provide a more complete and holistic account of the system or problem under investigation. For example, if, in addition to engineers, hydrologists, and agricultural sciences, social scientists and humanists had been included in the Bali Irrigation Project, the importance of the water temple institution might have been realized and taken into account. While interdisciplinarity can provide insights that may not have been possible from a strict disciplinary perspective, the quest for a more holistic picture of reality does not overcome the epistemic limitations of sustainability science (Sarewitz 2010b). There still may be a variety of valid interpretations (Miller et al. 2008).

To the extent that sustainability problems become settled, it will be a social and political effort of which science is but a part. Sustainability and its problems cut across disciplinary boundaries and defy both problem definition and easy solutions; they challenge not just the analytical tools and approaches of scientists but the use of scientific knowledge in society. As Nelson (2003) notes, this is not a comment on the quality of research in fields such as sustainability science. Instead, it is related to limitations of the ability of scientific research to advance action in areas that are highly social and contextual.

Normative Limitations

As discussed in Chapter 2, science can at once reveal issues that are of normative concern *and* constrain what is considered appropriate dialogue on the very same issues (Bocking 2004; Latour 2004; Longino 2002). How sustainability science navigates this tension can either empower or limit the ability of communities to articulate visions and goals for sustainability.

Most sustainability scientists acknowledge that they are indeed motivated by the problems and concerns of sustainability (Chapin et al. 2009). As F. (Terry) Stuart Chapin III noted in an interview, "It [sustainability] may be more of a calling on ethics and a sense of responsibility to the planet, a sense of responsibility to future generations" (interview with Chapin, 30 September 2009). However, the core of the sustainability science agenda is fundamental research into the dynamics of coupled human-natural systems (Carpenter et al. 2009; Levin and Clark 2010; Matson 2009). Values, many scientists argue, are better dealt with by decision-makers and other stakeholders. Citing the Brundtland Report (1987) or the National Research Council (1999) definition of sustainability, sustainability scientists embrace the values of sustainability, while at the same time maintaining a distance from such values by focusing on fundamental research. The role of the sustainability scientists is to supply knowledge that is perceived as credible, salient and legitimate that will inform decision-making in a value-free manner (Cash et al. 2003; Clark et al. 2002). In so doing, sustainability science is able to maintain an epistemic core of fundamental research that is value-free (Douglas 2009; Gieryn 1983, 1995).

Yet, key concepts in sustainability science such as risk and vulnerability (Turner et al. 2003a,b), tipping points (Scheffer et al. 2009; Schellnhuber 2009), planetary boundaries (Rockström et al. 2010), and even defining the boundaries and interactions between human and natural systems are suffused with values. The act of defining aspects of a wicked problem for scientific inquiry is inherently value-laden, with implications for democratic problem-solving and the pursuit of potential solutions (Fischer 2000; Jasanoff 2007; Latour 2004).

For example, the climate science community has predicted that a doubling of atmospheric carbon dioxide concentrations from pre-industrialization levels will result in a 1.5 to 4.5 degree Celsius increase in the global average atmospheric temperature (Rayner 2000; van der Sluijs et al. 1998). Beyond this temperature threshold, catastrophic climatic events await. Yet, the estimation of the temperature increase as a result of a CO_2 doubling has barely changed since Arrhenius' work on the greenhouse effect in the late 19th century (van der Sluijs et al. 1998). This is despite significant advances and investments in global circulation models (GCMs) and climate science more generally. Research has focused on classifying the uncertainties around this prediction and attempting to specify potential consequences (Rayner 2000). This has come at the expense of an expanded discussion that includes *local* (rather than just global) risks and vulnerabilities, adaption and technological solutions (Hulme et al. 2009; Pielke, Jr. et al. 2007; Rayner and Malone 1997). The scientific framing of climate change as a *global* problem that science can appropriately manage is also a social and political framing that has made it more difficult for alternative understandings and normative concerns[51] to enter into the discussion (Sarewitz and Pielke, Jr. 2007; Jasanoff 2001; Miller 2004).

The epistemic power of science, especially when presented or perceived as value-free, can come to dominate normative and political concerns (Douglas 2009; Latour 2004). The normative limitation of sustainability science is in its potential inability to recognize the degree to which supposedly value-free science is in fact value-laden and how scientific analyses can influence necessary and important political debates in society in complex ways. The challenge is to construct a science that is able to convey important information in a way that allows a plurality of values and understandings to emerge.

Each of the limitations discussed above is maintained and reinforced by the institutional structure of science. Scientists are incentivized through their training and evaluation to advance knowledge in their home discipline. Many of the activities that might be necessary to contribute to such outcomes, including interdisciplinary or participatory research are challenging, time consuming and rarely rewarded within the academy (Miller et al. 2008, 2011; Roux et al. 2006;

[51] Normative and ethical analyses of climate change normative analyses have focused primarily on issues related to the responsibility for greenhouse gas emissions and a fair and just allocation of future emissions (Jamieson 1992; Brown 2002; Gardiner 2004). Largely missing from this discussion is an intra-generationally more important question of how to fairly and justly help those currently vulnerability to climate and weather variability adapt.

Rowe 2007). Any change in the research agenda for sustainability science must be pursued in conjunction with institutional change.

Situating Sustainability Science: Objectives for a Science of Design

Sustainability presents a unique set of epistemic, normative and institutional challenges to science and its ability to contribute to positive, more sustainable social and environmental outcomes. The core question now facing sustainability science is: How can sustainability science shift from identifying problems in the biophysical realm to contributing to the pursuit of solutions in the social and political realm? It also requires scientists to face a question that is deeper yet: To what extent and in what ways is science necessary to advance sustainable outcomes? In order for sustainability science to address these questions, changes are necessary in the way sustainability is conceptualized, how sustainability science investigates problems and their potential solutions, and in the way we act to address them (Mitchell 2009).

In this section, I utilize Herbert Simon's (1996) notion of a science of design supported by John Dewey's (1920, 1938) pragmatic philosophy to (re)construct sustainability science as a more pragmatic mode of inquiry focused on problem-solving and the design of solutions. Following Dewey's (1920) own reconstructive project, I consider how science can best contribute to sustainability and propose two core objectives for the field that have heretofore been either underdeveloped or entirely absent in sustainability science: 1) To understand and contribute to the design of sustainable solutions; and, 2) To promote reasoning and deliberation over the meanings, goals and pursuit of sustainability. This follows Dewey (1938) method of inquiry, which as Minteer (2002: 43) notes, acts as "the social process for transforming problematic situations into ones that are more settled and secure." This method maintains a "critical link between reflective practice—thought—and the world of lived experience" (Minteer 2002: 43) and remains open to revision and refinement as new problems arise or existing problems come to be viewed in new ways.

The vision for a new sustainability science of design presented here is empirical, normative and, most importantly, pragmatic. It is empirical in that it seeks to advance the state of knowledge about how sustainable solutions can be created and how deliberation can be enriched and facilitated. It is normative in that I argue sustainability science *ought* to meet these objectives. Finally, it is pragmatic in that the test of its effectiveness in meeting its objectives ultimately lies in changes that result in more sustainable outcomes as defined through a deliberative process *in society*.

(1) Understanding and contributing to the design of sustainable solutions.

By design, I do not necessarily mean the creation and manufacture of a technological artifact such as a greener building or cleaner burning fuel (though these would still qualify). Rather, following Simon (1996: 111), the process of design is the choosing of a "course of action aimed at changing existing situations into preferred ones." A science of design attempts to understand what the preferred or sustainable situations are and contribute to the identification and navigation of a course(s) of action that might achieve them. It is concerned with how things ought to be, rather than with how things are.

As Simon argues, it is this latter question that has been the preoccupation of the natural and social sciences. As previously noted, sustainability science has also been stuck in this latter mode of inquiry. Research in sustainability science has focused on the "problem space"—the understanding of current conditions and dynamics. This often comes at the expense of inquiry into preferred (i.e., more sustainable) situations and how we might get there—the "solution-space." A design science for sustainability must move beyond analyzing how things are and engage with the question of how things ought to be. Even with a perfectly accurate and uncontested representation of the current state of affairs (which is likely to be ontologically, epistemologically and normatively impossible), the degree to which such information would lead to consensus in pursuing a common vision of the future is questionable. A design science for sustainability aims to support what Simon would call a "satisficing" solution. In the face of real-world complexity, real-world optimization is impossible. Therefore, we should aim for and accept "good enough" alternatives that satisfice (Simon 1983, 1996). Such satisficing design solutions avoid getting stuck in in the "knowledge-first trap" wherein more knowledge is required to reduce uncertainty before action is appropriate (Sarewitz et al. 2010). They are robust to a range of possible conditions and further experience allows for learning and changes in design and action (Hickman 2001; Lee 1993; Norton 2005; Simon 1996).

Design science, argues Simon (1996), devises artifacts to attain goals. Artifacts do not necessarily have to be material objects. Following both Simon (1996) and Hickman (2001), artifacts are defined as technological objects, assemblages, institutions, knowledge and conceptual frameworks that can be used to attain desired ends. Similarly, Dewey (1920: 60) argues that theories, systems and hypotheses are but tools whose "value resides not in themselves but in their capacity to work shown in the consequences of their use." Dewey (1920: 21), for instance, defines knowledge as "purposeful, experimental action acting to reshape beliefs and institutions." Even our futures are artifacts, which we construct and continually build and re-build (Hickman 2001). However, as both Simon (1983, 1996) and Dewey (1920) argue, advances in inquiry into the way things are have not been matched by similar advances in inquiry into how things ought to be. It is this imbalance that sustainability science must begin to rectify.

The brief case study presented of the Lowell Center for Sustainable Production at University of Massachusetts Lowell presents an example of how a design science for sustainability can contribute to the analysis and design of solutions through the production of artifacts (in the form of knowledge not just about the problem, but of the social system and through a demonstration of alternative solutions).

The Lowell Center for Sustainability Production: Sustainable solutions

The Lowell Center for Sustainable Production (www.sustainableproduction.org) focuses on the redesign of production and consumption systems. Sustainable production is defined as the creation of goods and services using processes and systems that are:

- Non-polluting;
- Conserving of energy and natural resources;
- Economically viable;
- Safe and healthful for workers, communities and consumers; and,

- Socially and creatively rewarding for all working people (Sustainable Production Project 2009).

The Lowell Center works with government, industry, community groups and others to develop practical solutions to environmental problems, particularly those related to occupational health and safety.

There are two core characteristics of the Lowell Center's approach that are especially relevant for a design science for sustainability. First, systems of production and consumption are viewed as both social and technological. Second, as co-Director David Kriebel notes, it is important to make the distinction "between the system in which the problem occurs and the system in which the solution occurs," or, in other words, to distinguish between the problem-space and the solution-space (Interview with Kriebel, 16 November 2009). Two brief examples serve to illustrate these points.

The Lowell Center's Sustainable Hospital Program works to reduce or eliminate worker and patient exposure to environmental hazards while maintaining patient care and costs (see www.sustainablehospitals.org). Formaldehyde, a carcinogen regulated by several national, state and local government agencies, is used in many hospital laboratories for tissue preservation and fixation. A Massachusetts hospital had been served several violations formaldehyde in its wastewater, the source of which was the histopathology laboratory. Despite the installation of expensive engineering controls, violations continued. Hospital managers sought to replace formaldehyde with the use of another chemical and a microwave oven; however, the laboratory's chief pathologist disagreed on their interpretation of the problem and argued that the managers' alternative would not allow the lab to produce the same quality of work. An alternative, glyoxal, was identified after learning of its use by a prestigious hospital nearby and a pilot study concluded that its use would maintain the quality of the laboratory practices while reducing the harmful side effects of formaldehyde (Quinn et al. 2006).

The second example illustrating the benefits of focusing on solutions is the conversion of dry cleaning facilities using the solvent perchloroethyene (Perc) to a water-based or "wet cleaning" process (http://www.turi.org/community/wet_cleaning). The water-based process substantially reduces adverse human and environmental health consequences but involves significant capital investments including a full equipment replacement. Working with the Toxic Use Reduction Institute (TURI) at the Lowell Center for Sustainable Production, researchers realized that the cost of new equipment (for which the state provided financial assistance) was not the only barrier to moving away from perc use in dry cleaning. In addition to cost barriers, retraining of personnel would be required to make the switch to wet-cleaning and Lowell Center and TURI researchers needed to demonstrate that the new systems would enable cleaners to grow their businesses. TURI worked with community leaders to set up demonstration sites of the wet cleaning processes in order to show the public (i.e., the consumers of cleaning services) the health and economic benefits of switching away from perc and dry cleaning (Silver Hanger Case Study Brochure 2010).

In both of these cases, the nature of the problem was clear—the use of formaldehyde and dry cleaning processes are harmful—and alternatives were known to exist and were easily accessible. Yet, the harmful practices and processes persisted. In each case, the barriers to more sustainable practices were in the solution-space not in the problem-space (Sarewitz et al. 2010). Lab workers knew that formaldehyde was harmful, but did not believe that there was a viable solution that would allow them to continue their work effectively. New wet cleaning practices required demonstration of effectiveness and training. Lowell Center researchers and their partners viewed each of these issues as much more than a simple technological fix—i.e., substitute perc for formaldehyde and wet cleaning practices for dry cleaning. Such “drop-in” attempts rarely work as they fail to systemically examine alternative strategies that minimize adverse consequences while achieving the desired outcome (Sustainable Products Project 2009). The critical barriers and opportunities to more sustainable outcomes were also social. It was not enough for researchers to analyze the problem and point out the harmful products and practices. Researchers, working with partners and stakeholders, demonstrated the viability of solutions (Rossi et al. 2006).

The Lowell Center case demonstrates that understanding of the problem is not sufficient to overcome barriers to change towards sustainability. Systems of production and consumption are not just part of the problems, but crucial contributors to sustainable solutions. By focusing on the social and technological barriers to change, the Lowell Center is able to work with partners to identify products and practices that result in positive, more sustainable outcomes.

(2) Promotion of reasoning and deliberation over the meanings, goals and pursuit of sustainability.

The objective of a sustainability science of design is not to develop more complete knowledge of underlying system dynamics that will lead to the identification of an optimal solution. Instead, it seeks to create artifacts, including knowledge and conceptual frameworks, that "permit functional reasoning" (Simon 1996: 146). That is, it should promote and enrich purposeful deliberation over preferred or desirable outcomes—what is sustainability, what should be sustained and for whom—and how to pursue them. To some extent, existing efforts in sustainability science may serve this role. However, this proposal seeks to broaden current research in sustainability to move beyond coupled systems research and engage with the social, political and normative aspects of not just the creation of sustainability problems, but the formulation of potential solutions. Particular research pathways and fields involved in a new science of design are discussed further in Chapter 4.

As Norton (2005: 335) argues, "…the problem of how to measure sustainability…is logically subsequent to the prior question of what commitments the relevant community is willing to make to protect a natural and cultural legacy." Part of the role of sustainability science is to support deliberation over such commitments and, from there, help communities monitor and navigate progress. This role for sustainability science stems from a democratic understanding of sustainability as a platform for the articulation and pursuit of community goals. This also follows Dewey's own notion of democracy, which, as Minteer (2002: 41) notes, "is not just one form of social life among other workable forms of social life; it is the precondition for the full application of intelligence to the solution of social problems."

A design science for sustainability explores how to achieve the goals of sustainability (i.e., the "ought") that communities and society articulate. Following Dewey and Norton (2005), design science is pragmatic in nature. It does not seek to fully characterize underlying system dynamics or define the "right" sustainability; rather, it serves to clarify and formulate questions of practical importance that will help communities act in the world. Sustainability science must focus on constructing the necessary artifacts (e.g., deliberative space, conceptual frameworks) for discussion and dialogue over the values that ought to be sustained in a given community. Sustainability science should help to clarify and formulate questions that have practical import in the pursuit of sustainability (Norton 2005).

As Dewey (1920) notes, "the isolation of thinking encourages the kind of observation which merely accumulates brute facts…but never inquiries into their meaning and consequences." Thinking, for Dewey, is not just confronting facts but also involves moral, aesthetic and political reflection on the process of inquiry and into the found reality. Dewey also argues that our advances in inquiry, invention and control on the part of biophysical sciences have not been matched by a similar command over our social and moral welfare. It is for this reason that we so often appeal to the biophysical sciences to help us solve difficult environmental problems. There is an embedded assumption on the part of sustainability scientists that a confrontation with the facts of human-environment dynamics isolated from moral and political reflection will help to change beliefs and institutions.

For pragmatists, as Norton (2005) notes, a shared focus on real-world problems and experience unites inquiry. Inquiry here is not limited to the purely scientific kind. Rather, it inquiry used more broadly—as Dewey (1920) employs it—as a confrontation with facts on the part of a community of inquirers and as a way to make sense of experience. In this sense, a sustainability science of design follows both Dewey and Norton in attempting to bind inquiry to experience and to ensure that it includes not only fact-finding but also moral and political reflection.

Reasoning and deliberation are necessary not simply for political means—to practically achieve some predetermined end. Sustainability necessarily (and normatively) must be defined through democratic processes as communities engage in both fact-finding and reflection about what is important. Furthermore, deliberative processes have been shown to be epistemologically and pragmatically valuable (Brown 2009; Newig et al. 2010; Norton 2005; Thompson et al. 2007). Such deliberation attempts to avoid an appeal to transcendent principles, whether they are scientific, ethical or otherwise. As Longino (1990: 141) argues, "The point is that there is nothing further, that appeal to standards or methodological norms beyond those ratified by the discursive interactions of an inquiring community is an appeal to transcendent principles that inevitably turn out to be local." Sustainability science, instead, should promote what Miller (2008) and Jasanoff (1998) refer to as *reasoning together*—"a mutual learning and accommodation among people with highly divergent approaches" and knowledges (Miller 2008: 390). Deliberation is also potentially transformative, changing beliefs and values via learning and discussion (Habermas 1984; Griffith 2010).

In this way, the epistemological (how we know what we know) and the normative (what ought to be) questions of sustainability can be brought together to foster social learning (Latour 2004; Norton 2005). This approach rejects the boundary that sustainability science has drawn around a detached epistemic core, bringing together questions of epistemic and normative significance. It promotes research that is relevant to widely held social values and allows communities to evaluate the impact of their experience and values on the environment or desired futures (Norton 2005; Redman 1999). As Norton (2005: 118) argues, this "social learning is expected to improve understanding of the environment through an iterative and ongoing process that will require not just unlimited inquiry but also the encouragement of variation in viewpoints and the continual revisiting of both scientific knowledge and articulated goals of the community."

This objective also endorses what Verweij et al. (2006) call "the case for clumsiness." As mentioned previously, many sustainability problems—from climate change to water management—involve endemic conflict and may involve multiple understandings of the problems and potential responses. Problem-solving strategies that limit ways of knowing and social values are likely to fail in contexts where there are a diversity of definitions of the problem, needs and stakeholders (Lach et al. 2005). Instead, so-called "clumsy solutions" (which is similar to what Simon would refer to as satisficing solutions) are preferable. They require deliberation and communication in order to develop "creative, flexible mixes of four ways of organizing,[52] perceiving and justifying that satisfy the adherents to some ways of life more than other courses of actions, while leaving no actor worse off. As such, they alleviate social ills better than other courses of actions do" (Verweij et al. 2006: 840).

Processes of reasoning and deliberation are necessary to address many sustainability problems faced by society. As such, sustainability science must explore ways to contribute to these deliberative processes and enrich the debate over the meaning, goals and pursuit of sustainability. There is a wide literature on various modes of deliberation, including consensus conferences (Einsiedel and Eastlick 2000; Guston 1999) and citizen juries (Smith and Wales 1999; Ward et al. 2003). The concern here is not with the exact mode of deliberation. Instead, following Dewey's (1927) concern in *The Public and Its Problems*, that there be an "improvement in the methods and conditions of debate, discussion and persuasion" (Fischer 2000: 7).

[52]Proponents of cultural theory refer to four ways of organizing, or plural rationalities (Douglas and Wildavsky 1982; Schwarz and Thompson 1990). These rationalities are based on myths of nature (benign; ephemeral; perverse/tolerant; capricious) and typologies of social relationships (individualist; hierarchist; egalitarian; fatalist) which map onto each other. This pluralism allows groups to hold contradictory certainties based on conflicting perceptions of the natural environment and social organization. In environmental controversies and other political spaces, it is not a question of determining "the real risks versus a whole lot of misperceptions…but the clash of plural rationalities, each using impeccable logic to derive different conclusions (solution definitions) from different premises (problem definitions)" (Schwarz and Thompson 1990: 57).

The case study of the Dutch Research Institute for Transitions (DRIFT) at Erasmus University in the Netherlands illustrates how sustainability science might be able to foster deliberation and social learning.

DRIFT: Transition arenas as deliberation spaces

DRIFT (http://www.drift.eur.nl/) aims to identify and facilitate transitions—changes in social (sub)systems resulting from cultural, economic, technological, behavioral, ecological and institutional developments at various scales (Rotmans and Loorbach 2008; Rotmans et al. 2001). Theoretically, DRIFT examines how transitions come into being and how to identify them. Practically, they work with stakeholders on how to envision, manage and monitor transitions.

Of particular interest to design science for sustainability are the concepts of transition management and arenas. Loorbach and Rotmans (2009: 3) define transitions management as "a deliberative process to influence governance activities in such a way that they lead to accelerated change directed towards sustainability ambitions." Transition arenas are experimental spaces "in which the actors involved use social learning processes to acquire new knowledge and understanding that leads to a new perspective on a transition issue" (Rotmans and Loorbach 2008: 9). It allows a network of actors to then envision what a transition might look like (i.e., the desired sustainable goals) and establish an agenda to achieve it.

One particularly interesting example is a health-care transition program initiated in 2007 by the Dutch Ministry of Health, Welfare and Sports that included community groups, Dutch health care sector organizations, DRIFT and others. Several transition experiments were set up to test alternative approaches that might act as possible solutions to persistent problems in health care in the Netherlands. Transition experiments included a youth-based mental health program, in-house care for the elderly, and the development of social support systems for patients. A transition arena was set up to run parallel to the transition experiments. The experiments allowed participants in the transition arena to better understand how the current health care system operates and what strategies for change might be successful. They also identified a basic gap between the "system" and the "human" (Loorbach and Rotmans 2009). According to Jan Rotmans, former Director of DRIFT, the transition arena resulted in a vision for the future of health care in the Netherlands that is "human-oriented, economically viable and socially embedded" (interview with Rotmans, 24 November 2009).

Critical to the transitions management process is the dialogue and deliberation enabled by the transition arena. This allows for information flow, articulation of values and goals, and the development and acquisition of new knowledge. Appropriate methods, tools and policies are then pursued relative to the vision for a transition. While understanding of the existing system is important, the focus is on how to shift to a more desirable system as articulated in the transition arena (Loorbach 2007). DRIFT contributes to the process by producing artifacts (including the transition arena itself) that enrich deliberation (e.g., knowledge about the current system, potential pathways) and courses of action (e.g., concrete actions and management to move towards articulated goals).

Design Imperatives for Sustainability Science

There are several key characteristics, or what I call design imperatives, for sustainability science that are necessary to position the field as a science for the design of sustainable solutions. This is *not* a proposal for a specific research agenda (see Chapter 4). Instead, these design imperatives act as guidelines for an effective sustainability science that can meet the objectives set out above (see Figure 4.1). Table 4.1, below, presents a breakdown of sustainability science as it has developed thus far and a sustainability science of design. Sustainability science should be designed to: (1) be *contextual* in its approach to problems and their potential solutions; (2) embrace both value and epistemological *pluralism*; (3) formulate a research agenda that is *robust* to the diversity of sustainability issues; and, (4) *reflexive* in terms of the influence of sustainability science on the ways in which sustainability is framed and understood by societal groups.

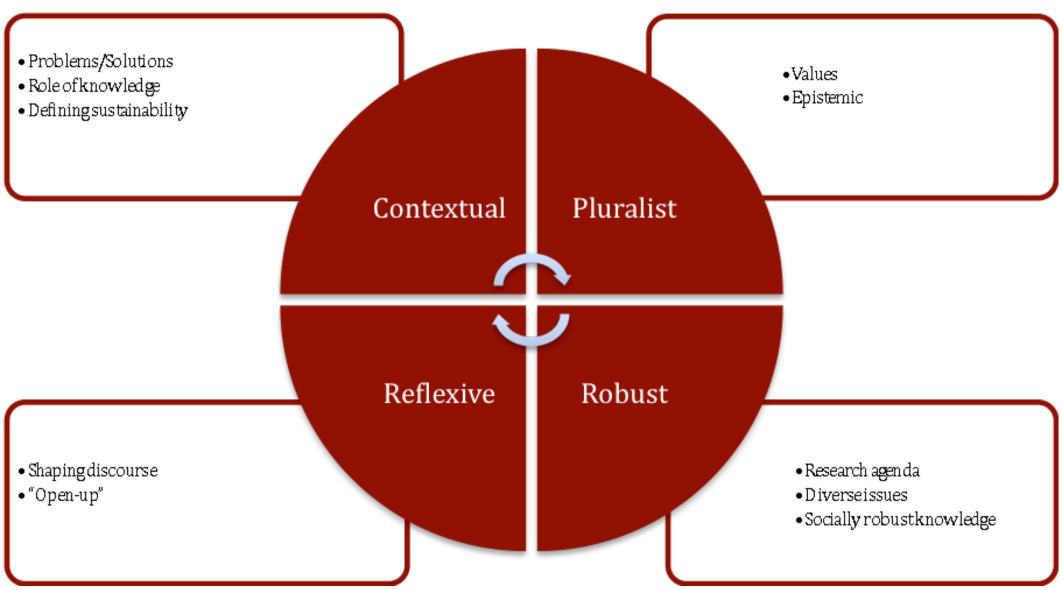

Figure 4.1 Design imperatives.

Table 4.1. Analytical focus, characteristics and objectives for potential sustainability science pathways.

	Sustainability Science	*Sustainability Science of Design*
Analytical Focus	Problem-space: Coupled Human-Natural Systems	Solution-space
Key Characteristics	• Interdisciplinary • Place-based • Problem-driven	• Contextual • Plural (value and epistemic) • Robust • Reflexive
Core Objectives	• Fundamental knowledge • Link knowledge to action	• Design and understanding of solutions • Foster societal deliberation

1. Contextual. Sustainability science must be contextual its approach to sustainability problems and in efforts to contribute to societal action. Sustainability itself is contextual – the meaning and goals of sustainability are dependent on who is involved in a given issue in a given place and what values are to be sustained (Norton 2005). Sustainability scientists have already recognized this by emphasizing place-based research (Kates et al. 2001; Turner et al. 2003a). Though it may be place-based, much of current sustainability science is not fully contextual in its approach as it is focused on producing a single-type of artifact (i.e., more knowledge about the problem-space) in each context.

The artifacts sustainability science devises must be contextual. First, they are dependent on specific circumstances and social practices. Artifacts (including knowledge) are contextual in the ways in which they are generated and in terms of the reality they attempt to reflect or manipulate. Second, their role in action, policy and decision-making are contextual. The artifacts required to facilitate deliberation and the development of solutions will differ depending on needs specific to a given situation. As Dewey (1920: 71) argues, "Action is always specific, concrete, individualized, unique. And consequently judgment as to acts to be performed must be similarly specific…. How to live healthily or justly is a matter which differs with every person." An effective design science must be contextual in its approach to the given problem (and solution) and the ways in which it seeks to foster deliberation.

This design imperative follows the concept of socially robust and contextualized knowledge developed by Nowotny et al. (2001). Nowotny et al (2001: 168) argue that "…the more highly contextualized the knowledge, the more reliable it is likely to be…because it remains valid outside the 'sterile spaces' created by experimental and theoretical science, a condition we have described as 'socially robust.'" This echoes Dewey's (1938) assertion that, as Brown (2009: 159) puts it, "the 'complete test' of scientific theories requires assessing their consequences in the world outside the laboratory." Rather than being rooted in disciplinary structures, socially robust knowledge is more responsive to the values and concerns of society and is produced in conjunction with public knowledge, or civic epistemologies (Jasanoff 2005). It is therefore more likely to be useful to society across a wider range of circumstances. In this case, it provides the means to enhance the ability of society to design more sustainable solutions.

2. Pluralist. Sustainability science must embrace both *value and epistemological pluralism*. This pluralism is necessary instrumentally and, more importantly, pragmatically (in its deeper philosophical sense). Instrumentally, pluralism must be recognized and dealt with as a means that is politically necessary to achieve desired ends.

Pragmatically, this pluralism will enhance the ability of sustainability science to meet the objectives presented earlier by enabling a richer deliberation over meanings of and potential pathways to sustainability (i.e., value pluralism) and a more robust account of current problems and the consequences of future actions (i.e., epistemological pluralism). While sustainability scientists have attempted to involve stakeholders in their research, pluralism is utilized as a means to enrich the goal of enhanced understanding of coupled human-natural system dynamics (Clark and Dickson 2003; Matson 2009). Instead, argue Thompson et al. (1998), plurality is located in discourse, not in the multiplicity of rationally similar actors. Pluralism emerges "in a dynamically patterned arrangement of social constructions, and in the divergent perceptions of risk and of fairness that those constructions give rise to" (Thompson et al. 1998: 352).

As a result of the diversity of ways in which humans interact with each other and the environment, sustainability is laden with a plurality of irreducible values (Minteer 2006; Norton 1991; O'Neill et al. 2008). To some, the idea of value pluralism within science is at odds with the perception of the value-free ideal of science (Douglas 2009). Yet, as science studies scholars have shown, "there are multiple possible ends that science can serve, multiple ways in which we might want to shape our world. Not only are values part of science, but science is very much tied to society and our decisions about its future" (Douglas 2009: 53; Frank 1953). Science does not simply provide facts, but shapes our world in particular and complex ways (Douglas 2009; Jasanoff 2004, 2005; Sarewitz 2010b). Deliberation requires value pluralism to ensure that appropriate values shape sustainability science, the artifacts it designs, and the pathways to sustainability that might be pursued. Incorporating multiple values in an explicit and transparent manner enhances democratic accountability and ensures that science addresses issues of social importance (Douglas 2009; Jasanoff 2003; Norton 2005). Value pluralism is especially important for supporting several of the additional design imperatives discussed below, especially reflexivity and robustness.[53]

This pluralism is also epistemic. That is, there are multiple ways of knowing the world as well as different notions of what constitutes knowledge,

[53] There is much debate within environmental ethics as to whether value pluralism can accommodate the intrinsic value of nature (Minteer 1998; Norton 2009; Rolston 1994). Following Minteer (2001), I would argue that the truth claims related to intrinsic value, while perhaps philosophically important, miss the point. The pluralism I endorse accommodates social actors that promote the intrinsic value of nature as part of a larger discourse regarding the value of and our responsibilities to nature. That is, intrinsic value exists insofar as it influences and motivates elements of social discourse and action.

how it is produced and how it is applied (Miller and Erickson 2006; Miller et al. 2008; Rescher 2003; Healy 2003). Sustainability science must find ways to incorporate and negotiate multiple ways of knowing, particularly civic epistemologies (Jasanoff 2005; Miller 2005), in order to develop a more robust view of current conditions and desirable futures. Furthermore, diversity significantly enhances group problem-solving abilities and improves the epistemic quality of deliberative practices (Brown 2009; Page 2007). These epistemological communities must be willing to learn from experience and are an essential aspect of sustainability because outcomes are not definable in advance but must emerge from a program of deliberation, active experimentation and learning (Miller et al. 2008; Norton 2005).

3. Robust. As Simon (1996) notes, real worlds are not additive. Actions have unforeseen consequences, giving rise to new problems. We can rarely be certain that a particular sequence of actions will provide the solution that satisfies all conditions and attains all goals. Instead, in some cases, it may be necessary to pursue multiple tentative paths. Robust strategies are insensitive to uncertainty about the future (Lempert and Schlesinger 2000). A robust framework asks: "what actions should we take, given that we cannot predict the future? The answer…is that society should seek strategies that are robust against a wide range of plausible…futures" (Lempert and Schlesinger 2000: 391).

As problems emerge, change, or come to be viewed in new ways, sustainability science must be adaptive in its approach. As the context changes, visions and strategies may have to be adjusted. This follows the concept of adaptive management (Lee 1993; Norton 2005), which recognizes that knowledge will rarely be certain, but that action is still necessary and so it is best to proceed on a course that might be effective over a range of possible conditions.

For sustainability science, this requires the pursuit of multiple research agendas and the exploration of alternative pathways to sustainability. The existing research agenda for sustainability science has been narrowed to focus on problem-spaces. While a robust research strategy would continue research on coupled system dynamics, it would also be part of a broader research agenda focused on sustainable outcomes.

4. Reflexive. The artifacts (including knowledge) produced by sustainability influence how sustainability challenges come to be understood by society, future research agendas, and problem framings in complex ways (Porter 1995; Sarewitz 2010c; Smith 2009). Therefore, it is especially important that sustainability science is fully reflexive in considering the ways it frames social understandings of sustainability—an ambiguous, contested and value-laden concept (Davison 2000; Norton 2005). Sustainability scientists must re-examine and re-evaluate their assumptions and "open-up" to alternative representations and the pluralism discussed above (Miller 2008; Miller et al. 2011; Stirling 2004).

Reflexivity involves attention to the representation of sustainability, its problems and proposed solutions, and the ways in which such representations end up conditioning how we view sustainability (Stirling 2006). More broadly, Grunwald (2004: 158) argues that reflexivity "implies…a far-reaching obligation for transparency of sustainability research with regard to the normative premises which are employed in the production of knowledge." These premises influence the way sustainability is represented and will influence subsequent action and condition appropriate behaviors.

Reflexivity requires openness to alternative approaches that may be more effective in advancing positive social and environmental outcomes. As Voß and Kemp (2006: 6) note, the consequence is that "problem solving becomes paradoxical in that it is oriented towards constriction and selection to reduce complexity but is forced into expansion and amalgamation to contend with the problems it generates." Reflexivity requires a careful balance between opening up to alternative explanations, values and representations in the design and deliberation process and closing down in order to reduce complexity and take action (Voß et al. 2006). A more reflexive sustainability science must respond to changing conditions and reexamine and reevaluate fundamental assumptions regarding the way sustainability, its problems and potential solutions are conceptualized and investigated.

The Way Forward: Implications and Concluding Thoughts

As John Dewey (1920: 10) noted, eventually "the environment does enforce a certain minimum correctness under penalty of extinction." To date, sustainability science has focusing on advancing our understanding of coupled human-natural systems. Sustainability scientists have attempted to discover the places where society might be in danger of operating beyond its limits. Such research, however, faces significant epistemic, normative and institutional challenges that limit its ability to provide useful artifacts, including knowledge, to society and is divorced from the more critical question of how to act. If sustainability science is to contribute to societal efforts to act more sustainably, a new and expanded pathway for sustainability science as a science of design is necessary.

I have proposed a new set of objectives for the field that re-position sustainability science to focus on *solutions* rather than on *problems* through the active design of sustainable outcomes and an enrichment of deliberation. These new objectives will also advance knowledge and understanding of the social, political, natural and technological processes necessary to foster the creation of sustainable solutions. The design imperatives proposed above move sustainability science to engage the role of knowledge, both scientific and public, in social action. Each of the imperatives addresses the normative and epistemic limitations of science in the context of sustainability problems.

A design science must be contextual in terms of both the production and use of artifacts that contribute to solutions *in context*. Value and epistemological pluralism require a diversity of perspectives and ways of knowing beyond the mere inclusion of stakeholders. Pluralism not only shapes the understanding of problems, but is critical in contributing to the design of solutions. Sustainability science must also take a more robust approach in terms of its research agenda. It must be broad enough to be useful in a wide-range of contexts and substantive enough to add to our understanding of the social, political and technical processes that present either barriers or opportunities to the design of sustainable solutions. Finally, sustainability science must be reflexive in its approach to the design of solutions. As sustainability scientists move to become more engaged with sustainability and social action, they will shape the way society understands sustainability. Sustainability scientists must be careful to reflect on how they are influencing discourse and deliberation.

One looming issue is whether or not academia is capable of meeting the objectives set here, and training the next generation of sustainability scientists. Perhaps the objectives and design imperatives discussed for a new science of design are better placed in non-governmental organizations, government or business and industry. As Simon (1996) notes, the design sciences are more often professional than academic. A science of design requires a different and expanded skill set from those typically gained in the natural and social sciences. Miller et al. (2011), for example, propose that for this new breed of sustainability scientists it is not enough to just acquire substantive knowledge in a set of disciplines or problem-areas; they suggest that future sustainability scientists must have a skill set that enables them to work between science and society, be aware of the normative and value dimensions of various issues, and understand and work amongst multiple of ways of knowing, or practice what Wiek (2007) refers to as "epistemediation."

A sustainability science of design requires thinking beyond the current state of affairs to explore how preferred, more sustainable, futures might be developed and pursued. Institutional changes in terms of the incentives of researchers, partnerships with other sectors and groups, and education must be pursued in parallel with the objectives and imperatives proposed here (Crow

2010; Miller et al. 2011). Just as Dewey encouraged experimentation in democracy, experimentation in the design of academic institutions that are performing sustainability science research and training the next generation of sustainability scientists should also be fostered.

From here, the next step must be to ground the objectives and imperatives that I have proposed in experience. In order to further develop the framework proposed here, exemplary case studies must be identified that have been able to successfully generate sustainable outcomes. This will help identify certain best practices that might act as guidelines for implementing the design imperatives.

Chapter 5

THE FUTURE OF SUSTAINABILITY SCIENCE:

BUILDING A TRANSFORMATIVE RESEARCH AGENDA

This chapter has been co-authored with Arnim Wiek.

Science and the Sustainability Challenge

The greatest challenge facing humanity in the twenty-first century is to transition socio-technical systems towards sustainability—advancing human well-being while maintaining the life support systems on which it depends (NRC 1999). The scientific community has addressed this challenge in several high profile attempts to bring the power of scientific knowledge to bear on the pressing problems of sustainability (Lubchenco 1998; Palmer et al. 2004; Reid et al. 2010; Schellnhuber et al. 2004). Perhaps the most wide-ranging of these efforts is sustainability science (Clark 2007; Levin and Clark 2010; Matson 2009). Ten years ago, Kates et al. (2001) laid the foundation for sustainability science, defining three core objectives: (1) understanding the fundamental interactions between nature and society; (2) guiding these interactions along sustainable trajectories; and (3) promoting social learning necessary to navigate the transition to sustainability. Over the last decade, sustainability science has developed rapidly with the establishment of peer-reviewed journals, the publication of major articles in leading scientific journals, national and international research initiatives, and the creation of academic departments and research centers.

Despite such progress, we contend that much of the research undertaken in sustainability science so far is incongruous with the second and third of the aforementioned objectives. We propose a shift in research trajectories to reinvigorate those objectives and move sustainability science on a transformative pathway—one that both advances knowledge of and contributes to societal efforts to move towards sustainability.

An Overly Optimistic Assumption: Knowledge to Action

The overwhelming focus of sustainability science research to date has been on pursuing knowledge about the interactions of coupled human-natural systems (Clark and Dickson 2003; Kates et al. 2001; Turner et al. 2003a; Ostrom 2009). This research is based on the assumption that more knowledge about these interactions is necessary for decision-making and action on sustainability. When problems are complex, uncertain, and contested, this "deficit model"—i.e., more must be known in order to act—often reverberates in endless scientific and technical debates (Collingridge and Reeve 1986; Sarewitz et al. 2010; Stirling 2010). As these are in fact the key features of many sustainability problems, this knowledge-first approach often leads to a "paralysis by analysis" (Brown 2009: 609; Sarewitz et al. 2010). Critically, knowledge about human-environment interactions rarely provides information on the barriers to or opportunities for action towards sustainable outcomes.

For example, while scientists can be credited with discovering climate change and getting it onto the global agenda (Weart 2003), additional research intended to resolve uncertainties has not translated into substantive coordinated action. A lack of knowledge about the global climate system is *not* the factor that is limiting society's ability to take effective climate action. It is a combination of economic and institutional structures, social values, political agendas, and technological innovation that is preventing effective social and political action (Davis et al. 2010; Pielke, Jr. 2010).

We do not argue that research on coupled human-natural systems is an unworthy research objective; rather, if the purpose of sustainability science is to contribute to society's ability to operate along sustainable trajectories and foster social learning, *then* more descriptive-analytical knowledge about coupled systems does not suffice. Sustainability science must redirect its attention and link research on problem structures with a more transformative and solutions-oriented approach. It must aim to understand and explore how more sustainable outcomes actually come into being—and define from there the appropriate research priorities.

The Next Decade of Sustainability Science

We offer four research priorities for the future of sustainability science research that are designed to move beyond the understanding of coupled system dynamics and towards transformative research on the social, political, cultural and technological processes necessary to advance sustainability transitions (see Figure 4.1): (1) creating and pursuing desirable futures; (2) mapping and deliberating sustainability values; (3) exploring and fostering socio-technical change; and, across the former ones, (4) enabling social learning for sustainable development.

(1) Creating and Pursuing Desirable Futures

A core component of sustainability science is its ability to support societal efforts to articulate and pursue visions of desirable, more sustainable futures. How the future might play out (scenarios) as well as what future states conducive to human development and well-being might look like (visions) are focal points of sustainability science concerned with the long-term vitality and integrity of coupled human-natural systems (Brewer 2007). Scenarios and visions enable scientists to work with communities to explore, design and implement sustainable development trajectories.

In an early response to the initial sustainability science research agenda, Swart et al. (2002) criticized the lack of consideration of uncertainty and future-oriented research. They proposed an extended sustainability science agenda that would complement descriptive-analytical research with anticipatory, normative, and participatory research; yet, it received little attention in the scientific community. Despite an increased recognition of uncertainty in predictions and the importance of scenario development in sustainability research (Carpenter et al. 2005; IPCC 2007), the actual relevance for developing strategies and taking action towards sustainability has been limited due to a lack of concreteness (how those scenarios play out where it matters to people) and embedding into actual decision-making processes.

Over the last few years, however, new methodologies have been developed for making future-oriented research more meaningful and relevant for solution-oriented sustainability science. Scenario studies have employed and further developed downscaling, visualization, and narrative approaches that make future pathways tangible to decision-makers (Shaw et al. 2009; Bryan et al. 2011). Following a few early movers (Swart et al. 2004; Carpenter and Folke 2006), new research on sustainability visions is underway adopting systems modeling for research on critical boundaries beyond which social-ecological systems might tip into undesirable states (Rockström et al. 2009; Reid et al. 2010). Advancing knowledge of how to construct plausible futures and linking these scenarios to decision-making would result in both transformative research and substantive outcomes.

(2) Mapping and Deliberating Sustainability Values

At its core, sustainability raises questions regarding the value of nature, responsibilities to future generations, and social justice (NRC 1999). Values underlie key concepts in sustainability including the ways in which problems are framed and defined (Ness et al. 2010; Rittel and Webber 1973; Voß et al. 2005), risk and vulnerability (Turner et al. 2003a,b), and tipping points that indicate shifts to states less desirable for human development (Rockström et al. 2009; Scheffer et al. 2009; Schellnhuber 2009). Yet, value-laden issues are often ignored or inadequately handled in sustainability science due to disciplinary divides and efforts to maintain scientific objectivity.

The values underlying sustainability goals and indicators and the ability of certain policies and programs to promote a convergence of values need to be elicited, explicated and mapped (Miller 2005; Norton 2005; Robinson et al. 2006). This will enable sustainability science to more effectively support societal deliberation over what values should guide sustainability transitions and the socio-technical changes that should be pursued (Fischer et al. 2007; Norton 2005). Understanding of the role of values in sustainability is necessary to evaluate the complex trade-offs between sustainability goals. Research in conservation and ecosystem management, for example, has increasingly shown that what were assumed to be win-win or mutually reinforcing goals of conservation and economic development are rarely aligned as such (McShane et al. 2011; Raudsepp-Hearne et al. 2010). Instead, a complex set of trade-offs is often the norm. How trade-offs between goals are evaluated and navigated will be informed by science and social values (Gibson 2006; Miller et al. 2011).

Sustainability science must pursue questions that are important to society and relevant to decision-making. Research into and awareness of the role of values in sustainability science and societal action must be moved upstream in the research process rather than treated as an important externality (Fischer 2000; Jasanoff 2007). An increased focus on the role of values will enable sustainability science to provide information that speaks to widely held social values and advance knowledge on how certain policies or programs can promote the convergence of values on more sustainable pathways.

(3) Exploring and Fostering Socio-technical Change

A critical component of a transition to sustainability will be society's ability to facilitate socio-technical change—shifts in the configuration of institutions, techniques and artifacts as well as the rules, practices and norms that guide the development and use of technologies (Smith et al. 2005). While socio-technical change has been the subject of research in a number of fields (Bijker et al. 1987; Hughes 1979; Loorbach and Rotmans 2009; Smith et al. 2005), it has been underappreciated in sustainability science as research has focused on the dynamics of coupled human-natural systems.

There are two overarching questions regarding socio-technical change and sustainability: How can socio-technical change be induced to meet sustainability goals?; and, How has socio-technical change actually happened historically? The first approach involves moving from one (undesirable or unsustainable) socio-technical regime to another (desirable or more sustainable). It explores the processes, policies and procedures necessary for desired change to a more socially and environmentally sustainable socio-technical regime. One prominent example of this approach is transitions research. Transitions management facilitates deliberative processes at multiple scales to influence the governance of socio-technical regimes to lead to change towards sustainability goals (Loorbach and Rotmans 2009; Schensul 2009).

The second approach is retrospective, examining how technology shapes and is shaped by social processes (Bijker et al. 1987). Examples of such studies include the analysis of the shift from gaslight to electric light (Schot 1998), the development of fossil fuel infrastructure (Jones 2010), and larger scale economic and industrial change (Rosenberg and Birdzell 1986).

Sustainability scientists must work to explore the social, political, institutional and technological leverage points that will help advance socio-technical change to more sustainable outcomes (Beddoe et al. 2009; Casillas and Kammen 2010; Walker et al. 2009). This research priority is essential to identifying the obstacles and opportunities to shift to more sustainable socio-technical pathways and advance knowledge on socio-technical change.

(4) Enabling Social Learning for Sustainable Development

Society's ability to successfully navigate along more sustainable trajectories will depend on its aptitude to learn from experience and adapt accordingly (Lee 1993; Norton 2005). Therefore, a critical research priority for sustainability science must be to foster such social learning and advance knowledge on how it actually occurs in order to build society's capacity for sustainable development.

The problems of sustainability are not bounded by either disciplines or expertise. They are often contingent, complex and contextual and require the engagement of knowledge that lies outside the walls of academia (Fischer 2000; Miller et al. 2008). Transdisciplinary research is essential for sustainability science to transcend disciplinary boundaries *and* move beyond expert knowledge to embrace non-expert, public knowledge and enable social learning (Hadorn et al. 2006; Klein 2004; Wiek 2007). While such research is gaining increasing momentum in the sustainability science community (Lebel et al. 2009; Reid et al. 2009), it must become a central component of the sustainability science research agenda if it is to foster social learning and respond to the pressing problems identified by society. Transdisciplinary research can both enable social learning critical for pursuing sustainability goals and lead to transformative advances in knowledge that would not have been possible in disciplinary research.

Table 5.1. Core Questions for the Future of Sustainability Science

Creating and Pursuing Desirable Futures

- What kind of participatory processes are required to craft visions of the future that are credible and legitimate?
- What are the most effective methods for creating visions of desirable futures?
- How, if at all, does envisioning potential futures translate into action? How can this be done more effectively?

Mapping and Deliberating Sustainability Values

- How and why do diverse values converge on certain policies or outcomes?
- What is the relationship between values and socio-technical change?
- How do certain values support more sustainable outcomes?

Exploring and Fostering Socio-Technical Change

- How are goals for socio-technical change determined?
- How can socio-technical systems be guided along more sustainable trajectories?
- How have socio-technical changes resulted in more sustainable outcomes in the past? What can we learn from these cases?

Enabling Social Learning for Sustainable Development

- What is the role of social learning in advancing more sustainable outcomes?
- What are the barriers (methodological, institutional, etc.) to transdisciplinary research?
- How can higher education institutions facilitate transdisciplinary research and education and enable social learning?

Moving Forward

Sustainability transitions will be a social, political and cultural process enabled in part by technology. While sustainability science has made substantial inroads into our understanding of complex problems in coupled human-natural systems, progress on how this knowledge will foster decisions that lead to more desirable outcomes and analyses of the processes necessary to transition to sustainability are lacking.

In each of the four domains discussed in this chapter, sustainability science should be viewed as a tool to help foster sustainability transitions. In order to ensure that science is focused on facilitating sustainability outcomes we must ask: What is the appropriate role of science in contributing to action and decision-making for sustainability? What knowledge, if any, is needed to make better decisions? How can we work *towards* outcomes that will foster sustainability across multiple scales? We should also note that the research proposed here require changes in the structure of education for sustainability scientists and practitioners (Fischer et al. 2007; Miller et al. 2011; Rowe 2007; Wiek et al. 2011).

We understand that each sustainability science research project will not result in the creation of more sustainable outcomes in itself. However, in order for sustainability science to contribute to solutions, it must embark on the transformative agenda we have set forth. We hope this is the beginning of an earnest and challenging discussion on new approaches and research pathways that are urgently needed to ensure a more relevant future for sustainability science and advance the state of knowledge on how social-technological change towards sustainability can be initiated.

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APPENDIX I

INTERVIEW SUBJECTS

Subject	*Position*	*Date*	*Location*
James Buizer	Science Policy Advisor to the President, Arizona State University	1.29.10	Via phone
F. Stuart (Terry) Chapin III	Professor of Ecology, University of Alaska Fairbanks	9.30.09	Gabriola Island, Canada
William C. Clark	Harvey Brooks Professor of International Science, Public Policy and Human Development, Harvard University	11.18.09	Via phone
Nancy Dickson	Co-Director, Center for International Development, Harvard University	11.13.09	Cambridge, MA
Carl Folke	Professor, Science Director, Stockholm Resilience Centre, Stockholm University	9.30.09	Gabriola Island, Canada
Mike Hulme	Professor of Climate Change, University of East Anglia	7.13.09	East Anglia, UK
Jill Jäger	Senior Researcher, Sustainable Europe Research Institute	11.18.09	Via phone
René Kemp	Professor of Innovation and Sustainable Development, Maastricht University	7.9.09	Maastricht, NL
David Kriebel	Co-Director, Lowell Center for Sustainable Production, University of Massachusetts Lowell	11.16.09	Lowell, MA

Simon Levin	Moffett Professor of Biology, Princeton University	12.16.09	Via phone
Derk Loorbach	Senior Researcher, Dutch Research Institute for Transitions, Erasmus University	7.8.09	Rotterdam, NL
Donald Ludwig	Emeritus Professor, University of British Columbia	10.5.09	Vancouver, Canada
Pim Martens	Scientific Director, International Centre for Integrated Assessment and Sustainable Development, Maastricht University	7.9.09	Maastricht, NL
Pamela Matson	Dean of the School of Earth Sciences, Professor of Environmental Studies, Stanford University	9.26.09	Palo Alto, CA
Takashi Mino	Professor, Department of Environmental Studies, Graduate Program in Sustainability Science, University of Tokyo	7.22.09	Tokyo, Japan
Lennart Olsson	Director, Lund University Centre for Sustainability Studies	10.30.09	Washington, DC
Elinor Ostrom	Distinguished Professor, Indiana University	9.30.09	Gabriola Island, Canada
Thomas Parris	Vice President, ISciences	7.8.09	Utrecht, NL
Paul Raskin	President, Tellus Institute	12.17.09	Via phone

John Robinson	Executive Director, UBC Vancouver Sustainability Inititative, Professor, University of British Columbia	10.5.09	Vancouver, Canada
Jan Rotmans	Director, Dutch Research Institute for Transitions, Erasmus University	11.24.09	Via phone
Kazuhiko Takeuchi	Vice-Rector, United Nations University, Deputy Executive Director, Integrated Research System for Sustainability Science	7.17.09	Tokyo, Japan
B.L. Turner II	Gilbert F. White Professor of Environment and Society, School of Geographical Sciences and Urban Planning, Arizona State University	6.5.09	Tempe, AZ
Richard Welford	Deputy Director, Corporate Environmental Governance Program, Hong Kong University	7.6.09	Utrecht, NL
Jinguo (Jingle) Wu	Professor of Ecology, Evolution and Environmental Science, School of Life Sciences, Arizona State University	6.4.09	Tempe, AZ
Masaru Yarime	Associate Professor, Graduate Program in Sustainability Science, University of Tokyo	7.22.09	Tokyo, Japan

APPENDIX II

INTERVIEW PROTOCOL

I. What is sustainability?

1. To start, please describe or define what sustainability means to you.

2. Do you think that sustainability is a meaningful concept?
    i. *Prompt*: In terms of science or societal action.
    ii. Can there be multiple definitions? (Positive? Liability?)
    iii. Is it something that is achievable?

3. What are some potential barriers or obstacles to sustainability?

4. What are some of the ways you see S&T contributing to sustainability?

II. Sustainability Science

1. Now I would like to turn to the role of S&T in sustainability. Sustainability has come to mean many things to many people. Please list what you consider to be the most important goals S&T should be pursuing to contribute to sustainability. (i.e., what to solve)

2. What are the key research questions and priorities for S&T for sustainability that you are researchers pursuing?
    i. What are the issues and concerns that are driving the agenda?
        1. *Prompt:* Why is this an important issue?
        2. To what extent is the S&T for sustainability research agenda defined by the problems it addresses?
            a. What problems? How are they defined?
    ii. What are the big problems/obstacles/challenges to addressing these issues?
    iii. What do you think the gaps in the research agenda are?
        1. Why do you think these gaps exist?
        2. How might they be addressed?

3. Does S&T for sustainability have distinct normative characteristics? (e.g., what to sustain, for who, how long)
    i. What are they?
        1. What should they be?
    ii. What does this mean for science?
    iii. How is S&T for sustainability distinct from other approaches such as those more traditionally based in ecology or environmental science, for instance?

4. Much of the literature on S&T for sustainability stresses the importance of involving stakeholders in research and in linking knowledge to action.
    i. In your view, who is driving the S&T for sustainability research agenda?

1. Who is missing from this?
2. What is the public's role? What should it be?
3. Do stakeholders need to be involved in S&T for sustainability?
4. What role do scientists play in shaping research agendas for sustainability? What role should they be playing?

ii. Has S&T been successful in linking knowledge to action?

1. How so? Why not?
2. What might this entail?
3. How might S&T for influence policy more effectively?
4. What kind of policy/action to you envision S&T affecting?

5. Do scientists involved in sustainability research have different responsibilities than those in traditional disciplines?

i. *Prompt:* Do they have different responsibilities to science/society?

ii. What does this entail?

6. Are there different subcommunities within the S&T for sustainability community?

i. What are the differences between them? Similarities?

ii. What wouldn't you consider S&T for sustainability?

III. Personal Research and Motivation

1. Please briefly describe your own research.

i. Has sustainability shaped your own research agenda? How?

1. How do you see sustainability making your research different?
2. *Prompt:* How is it shaping the questions you are asking? The problems you are addressing?

ii. Do you see your research contributing to sustainability? How?

1. Do you consider your own work to be sustainability science?

2. How is it different than other types of interdisciplinary research (or research performed in your home discipline?)

i. How would you identify yourself as a researcher? (What field?)

3. What has motivated you to perform research to address sustainability concerns?
4. Where would you like to see S&T for sustainability go in the next 10 years?

APPENDIX III

EXPLANATION OF CO-AUTHORSHIP OF CHAPTER 4

IGERT Fellows in Urban Ecology at Arizona State University are required to co-author one chapter of their dissertation in order to promote interdisciplinary research. I have co-authored Chapter 4 with Arnim Wiek (Assistant Professor, School of Sustainability). Dr. Wiek has granted permission for this chapter to be used as part of this dissertation.

APPENDIX IV

IRB APPROVAL FORM

ARIZONA STATE UNIVERSITY
RESEARCH AND ECONOMIC AFFAIRS

Office of Research Integrity and Assurance

To:	Ben Minteer LSA
From:	Mark Roosa, Chair Soc Beh IRB
Date:	12/11/2008
Committee Action:	**Exemption Granted**
IRB Action Date:	12/11/2008
IRB Protocol #:	0812003531
Study Title:	Evaluating the Emerging Ethical Frameworks of Science and Technology for Sustainability

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(2) .

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.

BIOGRAPHICAL SKETCH

Thad Miller was born on August 29, 1981 on Long Island, New York. He was raised in Malverne, New York where he received his elementary education at Our Lady of Lourdes Elementary School. After graduating from Chaminade High School in 1999, he attended Bucknell University, Lewisburg, Pennsylvania, majoring in Environmental Studies and Economics. Upon graduating in 2003, he entered the Environmental Science and Policy Masters Program at Columbia University School of International and Public Affairs at in New York City. After receiving his Masters in Public Administration in 2004, he worked for the Columbia Center for Children's Environmental Health as a Policy Coordinator. He then moved to Oregon where he worked for the Student Conservation Association and the National Forest Service at Mount Hood National Forest before joining The Climate Trust as a Research Associate. In August 2006, Thad entered the School of Life Sciences at Arizona State University and then transferred to the School of Sustainability in January 2007 where he was part of the first class to pursue a doctorate in Sustainability. He received a National Science Foundation Integrative Graduate Education and Research Training (IGERT) Fellowship in Urban Ecology. Thad was active in both the School of Sustainability, where he was elected as the first Student Representative, and the IGERT Program, where he served as Senior Fellow.167

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