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Advancing Sustainable Bioenergy: Evolving Stakeholder Interests and the Relevance of Research

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Abstract The sustainability of future bioenergy production rests on more than continual improvements in its environmental, economic, and social impacts. The emergence of new biomass feedstocks, an expanding array of conversion pathways, and expected increases in overall bioenergy production are connecting diverse technical, social, and policy communities. These stakeholder groups have different—and potentially conflicting—values and cultures, and therefore different goals and decision making processes. Our aim is to discuss the implications of this diversity for bioenergy researchers. The paper begins with a discussion of bioenergy stakeholder groups and their varied interests, and illustrates how this diversity complicates efforts to define and promote "sustainable" bioenergy production. We then discuss what this diversity means for research practice. Researchers, we note, should be aware of stakeholder values, information needs, and the factors affecting stakeholder decision making if the knowledge they generate is to reach its widest potential use. We point out how stakeholder participation in research can increase the relevance of its products, and argue that stakeholder values should inform research questions and the choice of analytical assumptions. Finally, we make the case that additional natural science and technical research alone will not advance sustainable bioenergy production, and that important research gaps relate to understanding stakeholder decision making and the need, from a broader social science perspective, to develop processes to identify and accommodate different value systems. While sustainability requires more than improved scientific and technical understanding, the need to understand stakeholder values and manage diversity presents important research opportunities.

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Introduction

The need to mitigate greenhouse gas emissions and increase domestic energy security, as well as the opportunity to support farm production and boost rural economic growth, have focused public attention on biofuel production. The relative prominence of each issue has shifted over time, tracking the interest of stakeholders that span agribusiness and farming communities, policy makers and scientific researchers, and environmental activists and regulators. The rapid increase in biofuel consumption over the last decade, in turn, has led many of these stakeholders to question the environmental, economic, and social benefits of using agricultural commodities as feedstocks for ethanol and biodiesel production. Policy makers in the U.S. have responded by passing legislation and modifying regulations governing renewable fuel production to encourage the use of alternative biomass feedstocks, and industry and the broader research community are working to develop supply chain pathways to convert this next generation of feedstocks into a wider range of vehicle fuels. As new biofuel production pathways emerge, additional and increasingly diverse stakeholder groups will become associated with biofuel production. These stakeholders will be involved in or affected by different parts of the biofuel supply chain, require different types of information to support their decision making, and have varying perspectives on what constitutes "sustainable" biomass use. This dynamic is expected to continue as we transition from using a limited number of agricultural commodities as biofuel feedstocks to thinking about multiple forms of biomass as primary energy resources that are available for conversion into a greater variety of energy carriers, including vehicle fuels, electricity, steam, and heat.

This paper investigates the implications of stakeholder diversity for bioenergy research. Our goal is to inform the scientific and technical research communities of the importance of social science issues related to their work, especially the need to understand the broader stakeholder decision making environment. By "stakeholder," we adopt Reed's (2008) definition and refer to "those who are affected by or can affect a decision," in this case public and private decisions involving bioenergy production. We also stress the need to look at stakeholder involvement across the entire bioenergy supply chain, from biomass feedstock production and processing, through its conversion to more useful energy carriers and the final distribution and end-use of this energy.

The challenge for researchers concerned that their work supports actual decision making is to recognize that the prominence of different issues will vary with the participation and influence of different stakeholders. One must understand how values and interests differ across stakeholder groups to identify significant research questions and even relevant analytical assumptions (National Research Council 1996). The nature of bioenergy production is evolving, however, and the emergence of new stakeholders with potentially unique concerns complicates researchers' efforts to identify their audience and pertinent issues. In addition to knowing who stakeholders are and anticipating who they might be, researchers also need to consider the decision making environment and factors driving receptivity to new information—whether stakeholders perceive it to be worth knowing—if the product of their work is to reach its widest potential use. We therefore make the case for both stakeholder analysis (Reed and others 2009) and the development of participatory research processes in which stakeholders help frame research questions (National Research Council 1996, 2008).

In turn, we also identify opportunities for social science researchers concerned with the development of sustainable bioenergy resources. "Sustainable" bioenergy production can be characterized as the use of biomass as an energy resource in a manner that: (a) contributes to some combination of climate change mitigation, energy security, and economic development goals; (b) results in no more than manageable environmental and social impacts; and (c) achieves economic self-sufficiency. Stated broadly, this definition is unlikely to be controversial, but diversity in stakeholder values will lead different groups to focus on more specific goals. While diversity in stakeholder interests is natural, we argue that a lack of processes to negotiate these differences poses a potential barrier to the long-term development of economically viable, environmentally positive, and socially beneficial bioenergy resources.

Competing stakeholder interests stem from different values and objectives, and can lead to different perceptions about the relevance and even existence of problems, as well as fragmented decision making, that may be detrimental to the larger bioenergy enterprise (Buchholz and others 2009). Policies such as the U.S. Renewable Fuel Standard revisions ("RFS2," USEPA 2010), which resulted from the U.S. Energy Independence and Security Act of 2007 ("EISA," see Title II of U.S. Public Law 110–140), provide an important start, but focus exclusively on biofuels, rather than bioenergy, and do not cover the full range of sustainability concerns voiced by different stakeholder groups (and certain provisions of these regulations have actually given rise to significant disagreements among stakeholder groups). We make the case that additional natural science and technical research alone will not resolve these issues, and that the important research gaps relate to decision making and the need, from a broader social science perspective, to develop processes to identify and accommodate different value systems (Glicken 2000; National Research Council 2008). While such processes do not guarantee that all stakeholder views will prevail, they do increase the acceptance of decisions impacting specific stakeholder groups (National Research Council 1996). We argue that this acceptance is essential to advancing the development of bioenergy systems, and therefore to the sustainability of bioenergy.

The following sections expand on these points. We begin by placing our argument in the broader bioenergy sustainability literature, and then continue with a discussion of the diversity of stakeholder groups involved with bioenergy production. The next two sections illustrate how this increasing diversity complicates efforts to define "sustainable" bioenergy and gives rise to the need to negotiate stakeholder differences. A discussion of the implications for research practice follows, and we then use the stakeholder engagement literature to highlight additional social science research needs. Throughout, we recognize that differences in stakeholder values and decision making are natural, and even beneficial for sustainable bioenergy production. Efforts to understand these differences will improve the usefulness of research and help the research community point out where communication, dialogue, and negotiation might be needed. Such efforts will become increasingly important as society addresses larger sustainability-related challenges, such as climate change, which involve multiple competing stakeholder groups, driven by different value orientations and interests.

The Need for a Bioenergy Stakeholder Focus

The increase in use of biomass as an energy feedstock has led researchers and members of the environmental community to examine, and in some cases challenge, the environmental, social, and economic impacts of its use on a scale that would offset a significant fraction of our petroleum consumption. Concerns raised by these groups include issues related to: the net energy balance of biofuel production (Farrell and others 2006), its climate benefits (Keeney 2008; Williams and others 2009), related ecosystem service impacts (e.g., Robertson and others 2008; Dominguez-Faus and others 2009; and Karlen and others 2009), and the direct and indirect global impacts of biofuel feedstock cultivation on international land use change (Searchinger and others 2008; Fargione and others 2008; Melillo and others 2009), agricultural markets (Hayes and others 2009), and food security (Brown and others 2009).

This array of bioenergy concerns relates largely to the current large-scale use of a limited range of biomass feedstocks, especially agricultural commodities such as corn grain and soy. The development of so-called "second-generation" cellulosic feedstocks offers a means of mitigating many of the negative environmental and social impacts of bioenergy production, but this promise rests on uncertain technology development, infrastructure investment, and feedstock market creation. Industry and academic efforts to overcome these barriers to large-scale sustainable production have focused on specific scientific, technical, and economic issues, but have also led to calls for system-wide analyses that integrate these dimensions (e.g., Robertson and others 2008; U.S. Department of Energy and U.S. Department of Agriculture 2009).

Ensuring that bioenergy provides an environmentally, economically, and socially viable means of achieving larger sustainability ends (such as providing energy security, boosting the rural economy, and mitigating greenhouse gas emissions), however, is not simply a scientific or technical problem (Buchholz and others 2007). Several authors (e.g., Costello and Finnell 1998; Roos and others 1999; Rosch and Kaltschmitt 1999; Mayfield and others 2007; McCormick and Kaberger 2007; Altman and Johnson 2008) have looked at the non-technical dimensions of bioenergy market development. These factors include regulatory, financial, infrastructure, and public perception issues (Costello and Finnell 1998), degree of market organization (Altman and Johnson 2008), and knowledge diffusion (McCormick and Kaberger 2007). Beyond these factors, we argue in the following sections that sustainable bioenergy production ultimately rests on an understanding the wide array of current—and future—bioenergy stakeholders, and their differing interests, values, and decision-making environments. Before discussing the implications of this diversity, we provide an overview of bioenergy stakeholders.

The Diversity of Bioenergy Stakeholders and Their Interests

Behind the range of interests promoting bioenergy, as well as concerns about its long-term sustainability, is a heterogeneous and expanding set of stakeholders. These stakeholders are involved in or affected by different aspects of bioenergy production, and have varying perspectives on what constitutes "sustainable" biomass use. This diversity in interests and concerns is due in part to the relative complexity of bioenergy production (Elghali and others 2007). Unlike fossil energy resources, for instance, bioenergy can draw on a wide range of feedstocks, make use of a variety of conversion processes, and link both with different end uses along a diverse set of supply chain configurations. In addition, with the exception of sectors like forestry, pulp and paper, and food processing, the bioenergy industry is not vertically integrated (Altman and Johnson 2008). Finally, the entire bioenergy supply chain intersects with other economic, technical, and regulatory systems, and components operate at scales that do not coincide with established environmental management regimes.

Uncertainty in the direction bioenergy production may take also increases the diversity of potential stakeholder concerns. Given the relatively nascent state of the contemporary bioenergy industry, many feedstocks lack established markets, several potential conversion technologies exist only at pilot scales, and the funding to build out components of the supporting infrastructure for cellulosic and other advanced feedstocks awaits investor confidence. Moreover, this uncertainty extends beyond technical and economic issues to include the environmental impacts of bioenergy production along—and beyond—the supply chain, as well as related policy support and social acceptance. Consequently, there are groups that either may not be recognized as stakeholders today, or may not themselves realize that they will have an interest in bioenergy production in the future. It is impossible, in fact, to identify the full range of future stakeholders until supply chains, logistics, and markets become more established and mature.

Previous assessments of bioenergy stakeholder values and decision making include Peelle's survey of environmental groups, farmers, and the broader agricultural community (Peelle 2000), as well as the more recent surveys by Buchholz and his colleagues (Buchholz and others 2009) of individuals with expertise in different aspect of bioenergy production and by Dwivedi and Alavalapati (2009) of entities involved with forest resource use in the southern U.S. Related to these surveys are attempts to integrate stakeholder perspectives in the development of decision support frameworks and tools (e.g., Van Dommelen and De Snoo 2006; Ayoub and others 2007; Elghali and others 2007; von Geibler and others 2010). While quite useful for identifying stakeholder concerns and calling attention to stakeholder decision making, these studies do not directly address the implications of increasing stakeholder diversity.

Here we define stakeholders as all groups that either participate in, or are at least affected by, public and private decision making as it relates to bioenergy production (Reed 2008, who uses Freeman's [1984] definition). Although individuals are stakeholders, we are concerned here with identifiable groups (either formal organizations or broader categories of related individuals or organizations) united by shared interests, and will use "stakeholder" and "stakeholder group" interchangeably (Glicken 2000). Following Reed (2008), we exclude the public at large, though it benefits from the larger environmental and economic goals various stakeholders rely on to promote biomass use.

Table 1 provides an overview of bioenergy stakeholders, which can be classified as being: (1) directly involved with the design, operation, and financing of the bioenergy supply chain; (2) affected by bioenergy operations, though indirectly involved with its production; (3) responsible for governance of supply chain operation and development through formulating or implementing policies, regulations, and standards; and (4) interested in advancing or shaping bioenergy development, though not directly impacted by bioenergy production on the ground. For each stakeholder group within these categories, Table 1 notes the nature of the group's involvement with bioenergy production, its conception of sustainability, and the primary resources it is likely to rely upon for information.

Table 1 is a product of our personal experience with the bioenergy industry, a review of the literature (including broad overviews such as Royal Society 2008 and EPA 2010), and involvement with other researchers at meetings such as the *Sustainability of Bioenergy Systems: Cradle to Grave* workshop (held Sept. 10–11, 2009 at Oak Ridge National Laboratory in Oak Ridge, TN). For a topic as broad as bioenergy production, contemporary stakeholder groups are self-evident. Researchers and policy makers typically rely on focus groups, interviews, and more elaborate social science methods of stakeholder analysis when working on narrow issues or specific projects, where the concern is with identifiable individuals and organizations rather than broad classes of players (Chess and Purcell 1999; Reed and others 2009). As we note later in the paper, a rigorous extension of these methods to characterize bioenergy stakeholders is a social science research need.

As Table 1 illustrates, the stakeholders to bioenergy production are no longer involved exclusively with commodity crop production, or even with agriculture (Keeney 2008). With increasing ethanol production volumes, for instance, a growing share of the U.S. corn crop now ends up as a vehicle fuel, rather than a source of feed or food. Consequently, livestock producers and international nongovernmental organizations have become stakeholders to bioenergy production, broadening the range of sustainability concerns from direct environmental and economic effects to include impacts on the availability of animal feed and stability of global food prices. Likewise, the prospect of higher ethanol-gasoline blend levels has raised the prominence of small engine and vehicle manufacturers as stakeholders, with both concerned about liability for the impacts of higher ethanol blends on engine performance. Other stakeholders with diverse interests and conceptions of bioenergy sustainability include: water authorities (wetland protection and maintenance of water supplies and quality), waste management companies (stability of renewable energy markets), and the transportation industry (predictable market growth for capacity expansion).

This shift from stakeholders rooted in agriculture will become even more pronounced as biomass continues to transition from an offshoot of food and feed production to an independent energy resource. With this shift will come additional stakeholder groups, with different industrial histories, cultures, and values, as well as information flows and decision processes. For example, wastewater treatment and power utilities could become bioenergy stakeholders if the development of novel feedstocks such as algae succeeds. Likewise, future expansion of international biomass feedstock markets could involve new players, such as palm oil producers, further heightening stakeholder differences.

The remainder of this paper discusses implications of this increasing stakeholder diversity for the bioenergy research community. We first describe the challenge for researchers seeking to understand their audience and its interests when both are changing. We then look at how the need to develop approaches to manage conflicting stakeholder values presents an opportunity for the bioenergy research community, and conclude with thoughts on what these issues imply for sustainability more generally.

Table 1 Characteristics of bioenergy stakeholder groups

Stakeholder group	Interest and involvement in bioenergy	Conception of bioenergy sustainability	Primary information sources	Location on supply chain				
				Produce biomass	Move biomass	Make energy	Move energy	Use energy
Direct actors								
Feedstock producers/suppliers	Feedstock planting and harvest/removal	Feedstock market stability, soil quality maintenance	Extension services, agricultural trade publications	X				
Lumber companies	Feedstock planting and harvest/removal	Feedstock market stability and growth	Industry (trade) publications	X				
Waste management companies (e.g. landfill gas)	Energy resource supply	Renewable energy market stability and growth	Industry (trade) publications	X		X		
Grain elevators/co-ops/preprocessing and storage	Capacity planning	Market stability and growth	Extension services, agricultural trade publications		X			
Transportation industry (truck, rail, water)	Capacity planning	Market stability and growth	Industry (trade) publications		X		X	
Petroleum and refining industry	Capacity planning	Market stability and growth	Industry (trade) publications			X	X	
Pipeline industry	Capacity planning	Market stability and growth	Industry (trade) publications				X	
Fuel blenders, distributors and retailers	Capacity planning	Market stability and growth; ability to match demand with supply	Industry (trade) publications				X	X
Investment community	Investment opportunities	Market stability and growth, return on investment	Market research	X	X	X	X	X
Engineering and construction firms	Business opportunities	Market stability and growth	Market research			X	X	
Indirect Actors								
Rural communities	Economic development	Employment growth, preservation of resource base	Planning literature, development consultants	X	X	X	X	
Livestock producers	Dependence on agriculture commodities for feed	Stable input (feed) prices, land prices	Extension services, ag trade publications	X		X		
Engine and vehicle manufacturers	Liability for impacts on existing engines (and vehicles); development of future powertrains	Reduction of impacts to existing engines, market stability and growth	Market research, industry and academic research					X
Oversight officials								
State environmental agencies	Maintain compliance with regulations	Maintenance of air and water quality	Statutory information reporting	X	X	X	X	X
Water authorities	Water use and protection of water quality	Wetland protection, maintenance of water supplies and water quality	Statutory information reporting	X		X	X	

Table 1 continued

Stakeholder group	Interest and involvement in bioenergy	Conception of bioenergy sustainability	Primary information sources	Location on supply chain				
				Produce biomass	Move biomass	Make energy	Move energy	Use energy
U.S. Environmental Protection Agency Program (regulatory) Offices	Promulgation of regulations	Lifecycle greenhouse gas emissions	Internal and sponsored research, academic literature, statutory information reporting	X	X	X	X	X
U.S. Environmental Protection Agency Regional Offices	Enforcement of current regulations	Environmental goals embodied in regulations	Internal and sponsored research, academic literature, statutory information reporting	X	X	X	X	X
U.S. Department of Agriculture (Farm Services Agency, National Resources Conservation Service)	Use of agriculture commodities and residues as feedstocks; competition between food and feed	Agricultural market growth	Internal research and sponsored research	X	X	X		
Interested parties								
Biofuel industry groups (e.g., Renewable Fuel Association	Biofuels promotion	Market growth and policy stability	Market research			X	X	X
Farm groups (e.g., Corn Growers' Association)	Biofuels (ethanol) promotion	Market growth and policy stability	Market research	X	X			
Conservation groups	Natural resource protection	Preservation of resource base (e.g. habitat and other ecosystem services)	Academic literature, internal and field research	X	X			
Non-governmental Organizations	Sustainable bioenergy supply chain development, impact on food prices and supply	Varies (e.g., environmental protection, economic development, social equity)	Academic literature, internal and field research	X	X	X	X	X
Academia	Research priorities (and funding), communication and use of research	Varies with discipline (e.g., environmental protection, economic development, social equity, industry viability)	Academic literature, internal and field research	X	X	X	X	X
Extension services	Educational and information needs	General environmental protection, farm community health	Academic literature, internal and field research	X	X			
U.S. Department of Energy	Sustainable bioenergy supply chain development, energy security	Energy security and supply growth	Internal and sponsored research, academic literature	X	X	X	X	X

These characterizations of information sources are consensus views of the authors and do not reflect official views of their respective agencies. They are offered as the starting point for discussion, and are not based on a survey or a thorough review of any particular publications

Bioenergy Research and the Evolving Bioenergy Issue Domain

The diversity of bioenergy stakeholders and their interests poses challenges to bioenergy researchers concerned with producing decision-relevant information. In this and the following sections, we argue that even those engaged in physical science, biological, and engineering research should be aware of what might be thought of as a purely social science issue: how differences in stakeholder groups, especially their decision making processes and values, affects both the questions researchers ask and the type of information they provide. The relevance of research results to stakeholders and the chances that research will lead to sustainable outcomes depend on this awareness.

Part of the difficulty in understanding stakeholder differences lies in identifying who is a stakeholder to bioenergy production. Bioenergy can be thought of as an "issue domain": the larger set of interests and concerns defined by "the beliefs of actor coalitions, their resources, the institutions that govern their interactions, and their collective decisions" (Clark and others 2002, p. 12). As an issue such as bioenergy becomes prominent, the number of interested and affected parties it attracts expands, and the nature of the issue domain changes. Furthermore, as individual issues and controversies within bioenergy wax and wane (e.g., the use of specific feedstocks, the availability of different conversion processes, net energy requirements, indirect land use change), not only does the composition of the stakeholders change, but their individual prominence and leverage does as well. The issue domain therefore becomes a moving target and, even in an ostensibly technical area like bioenergy, evolves independently of scientific research and technology development. As new stakeholders emerge, new issues become prominent; these new issues, in turn, attract new actors and reframe the debate. For the research community concerned with furthering the sustainability of bioenergy production and use, the evolving bioenergy issue domain—the continuing changes in both the audience for its outputs and the issues of concern—complicates efforts to identify relevant research questions, endpoints of concern, and approaches to moving research results into practice.

Researchers themselves can affect the issue domain (Cash and others 2003). Research can address debates and attempt to reconcile uncertainties, add depth of understanding to a particular topic, and subsequently increase or decrease the relevance of a particular topic. Each of these outcomes can have the effect of changing the mixture of issues within the domain, as well as the importance of those issues. With this changing mixture comes the concomitant potential to engage new stakeholder groups. As a consequence, research and research activity has the effect of evolving both the issue domain and those involved with it, even while it is being responsive to the changes set forth by other stakeholders.

The history of large-scale U.S. ethanol production illustrates the evolution of issues surrounding use of biomass as an energy resource. As recounted by Keeney (2008), widespread consumption of ethanol as a vehicle fuel had its origins in the development of high-fructose corn syrup (HFCS) which, by the mid-1970s, had supplemented refined sugar as a sweetener. Ethanol was originally seen as a byproduct of the wet mill HFCS production process, though food processing companies such as ADM wanted to capitalize on ethanol's value and promoted its use as a transportation fuel. This promotion coincided with the first OPEC oil embargo, and politicians passed what might be considered early energy security (and farm support) legislation, such as the 1978 Energy Tax Act, favoring ethanol via tax breaks for ethanol-gasoline blending and funds for research and development (Keeney 2008).

The 1990 Clean Air Act Amendments added a new motivation for ethanol production by requiring the use of oxygenates in gasoline sold in certain urban areas as a means of managing air pollution, and ethanol replaced methyl tertiary-butyl ether (MTBE) when subsequent concerns with ground water contamination forced discontinuation of the latter. Employment became yet another justification for ethanol promotion with the passage of the 2004 American Jobs Creation Act, which included new ethanol tax subsidies and added import tariffs (Keeney 2008). Energy security motivations then returned with the 2005 Energy Policy Act, which established ethanol production mandates under a Renewable Fuel Standard (RFS), and the 2007 Energy Independence and Security Act (EISA), which modified the first RFS by significantly increasing the 2005 production mandates and adding life-cycle greenhouse gas (GHG) reduction qualification thresholds for different biofuel categories (USEPA 2010). Industry and Congressional efforts to promote agricultural interests, in particular the development of new markets for corn grain, provided an additional motivation for this legislation. Finally, the prospect of GHG regulation is broadening public and private interest in the use of biomass as a primary energy resource for power and heat (steam), as well as vehicle fuels (Campbell and others 2009). The bioenergy research literature from the last decade reflects this more recent emphasis on GHG emissions (Ridley and others 2012).

The participation of the research community has also shifted the bioenergy issue domain. The early and continuing public debate about the sustainability of biofuel production, for instance, focused on national and global scale outcomes: the displacement of fossil fuels, net energy benefits, and the ultimate impact of biofuels on climate (Keeney 2008). To this end, a number of studies sought to refine the life-cycle accounting of the full biofuel supply chain, including both direct and indirect energy inputs, and the net energy and GHG emissions of biofuels (see Farrell and others [2006] for a comparative analysis). The debate over the environmental costs and benefits of biofuels production then shifted fundamentally when studies suggested that resulting changes in U.S. commodity crop exports could increase international agricultural production, which in turn would bring additional land into cultivation and result in a net increase in carbon emissions (Fargione and others 2008; Searchinger and others 2008). The issue thus changed from one of indirect inputs (e.g., the upstream energy used in producing fertilizer and pesticides), to one of indirect impacts via market mechanisms (e.g., indirect land-use change).

As public and private motivations for using ethanol, and now bioenergy more generally, have evolved from establishing new economic markets and supporting rural economies to expanding the nation's energy portfolio and providing climate change mitigation, the issue domain has grown and stakeholder groups have become more diverse. Table 1 identifies differences in scale of concern, for instance, and the ethanol example illustrates how newly attracted stakeholders operate and have influence.

There is thus no simple answer as to whether use of biomass as an energy resource is beneficial, or is a viable means of furthering larger sustainability goals, when the question itself is conditional on the perspectives and values of particular stakeholders. Additional scientific and technical research alone will not answer the question without a focus on this diversity. To inform the public debate over bioenergy sustainability and be relevant to actual decision making needs, research should begin with an understanding of the full range of stakeholder values, and frame research questions and choice of analytical assumptions accordingly (National Research Council 1996). Researchers, as we discuss in a later section, therefore should to attend to public deliberations and engage with stakeholders in participatory processes (National Research Council 1996, 2008)—both of which, it is worth noting, are distinct from advocacy. With the growing recognition that complex social issues, such as the promotion of alternative energy resources like bioenergy, require basic through applied research, the expectation is that researchers will ultimately produce information for stakeholders (National Research Council 2009). Understanding stakeholder motivations is central to this task, though the increasing diversity of bioenergy stakeholders, and uncertainty concerning the development of future bioenergy supply chains, complicate the challenge.

Bioenergy Sustainability and the Need to Negotiate Stakeholder Differences

Sustainable bioenergy production will depend on successful efforts to provide scientific and technical information aligned with stakeholder values, interests, and decision making processes. The diversity in stakeholders and stakeholder values that poses a challenge to researchers concerned with producing decision-relevant scientific and technical information may also impede sustainable bioenergy production by giving rise to fragmented decision making and conflicts between stakeholder groups. However, rather than the diversity in stakeholder interests and concerns being an obstacle, we argue that lack of processes to negotiate effectively among competing stakeholder values and decision making is a potential barrier to sustainable bioenergy production.

Stakeholders need to be engaged with each other to make the larger bioenergy system work, but without mutually agreed-upon processes to manage this interaction we risk myopic decision making and conflicts about issue relevance that can lead to unsustainable outcomes on a collective scale. Myopic decision making, for instance, becomes an issue when different stakeholder groups pursue actions that depend on each other but are uncoordinated, or that ignore costs posed on other stakeholders or society at large. Stakeholders naturally have a limited range of concerns based on the extent of their involvement with the bioenergy production supply chain and the resulting temporal and spatial reach of their activities and interests. System-wide viability, however, depends on more than narrowly-focused "optimization" of individual interests. For instance, creation of unique enzymes for biochemical conversion of specific cellulosic feedstocks may be rendered ineffectual if environmental considerations limit development of markets for those feedstocks. Perhaps more seriously, shared resources will be consumed at unsustainable rates when individual actors account only for the marginal costs of their own use, and ignore the larger marginal impacts of this use to society (Libecap 1995). Overuse of the environment as a sink for excess nitrogen, or depletion of land resources across generations, are examples of this effect.

In other situations, even when stakeholders take a broader perspective, they may still disagree about the fundamental relevance of certain issues as the basis for collective decision making aimed at increasing the common good. Environmental groups, for example, see greenhouse gas mitigation as an important objective, with biofuels one possible means to that end. Those stakeholders concerned with energy security focus on the ability of biofuels to displace imported petroleum. Corn growers and their associations, meanwhile, are primarily concerned with expanding markets—domestic and international—for their products. These value differences can lead to sharply divergent views of the importance, for instance, of considering international land use change impacts when evaluating the benefits of corn-grain ethanol. Conflict over issues such as the relevance of international land use change can impede development of the bioenergy industry by introducing uncertainty about which biomass resources will be eligible as feedstocks for renewable fuels.

Note that such conflict is not simply a matter of reducing scientific uncertainty. Even if the different groups agreed on the "facts," these fundamental differences in values would lead to dissimilar notions about what "sustainable" biofuel production entails—about the underlying problems and the questions that need to be addressed. More often, conflicting stakeholder groups will selectively use results of scientific research to buttress their positions, a phenomena Sarewitz refers to as "scientization" (Sarewitz 2004). Such use of ostensibly objective "facts" masks what are really more fundamental differences in values, and once again points to the need for processes to address conflicts at this level.

A consideration of contrasting expectations about the availability of corn stover as a bioenergy feedstock illustrates these larger issues. Stover—the portion of a corn stalk remaining after corn grain harvest—will likely serve as a feedstock for many early commercial-scale cellulosic ethanol refineries (USEPA 2010). Currently seen as a byproduct of commodity corn production (i.e., as an agricultural residue), and therefore without its own production costs, stover is plentiful and could provide a biomass resource to support expansion of the existing U.S. ethanol infrastructure. Stover, however, also serves as an important source of nutrients, minimizes nutrient runoff, enhances soil carbon, and limits erosion when left on the field (Cruse and Herndl 2009; Kurkalova, Secchi and Gassman 2010).

Estimates of stover availability depend on many assumptions, and the consideration of specific assumptions varies with stakeholder perspective. At the most macro level, for instance, national estimates of aggregate stover quantities have relied on a combination of simple metrics: current and future corn production, typical yield and expected yield increases, and some assumption about "sustainable" residue removal rates—which may vary by tillage and other production practices, but do not account for field-specific environmental considerations (see, e.g., USEPA 2010). Such first-order estimates provide the necessary bounding value on stover availability for national bioenergy policy and regulatory analysis.

The complexity of determining stover availability becomes apparent in the contrast between this macro perspective and that at the field level. Farmers, for instance, will focus on net returns to their production activities, and weigh the revenue from stover sales against the additional equipment and labor costs of stover harvesting, as well as the price of nutrient replacements (fertilizer), in deciding whether to enter a stover market. Just because stover is there, does not mean that farmers will find it profitable to supply. Should a strong stover market develop, the returns to corn production will increase, leading to changes in crop rotations and other field-level management practices—including, at the extreme, shifts to continuous corn cultivation (Kurkalova and others 2010). While such changes will increase stover supply in the near-term, corn cultivation depletes soil nutrients, and intensified production will eventually lead to yield decreases. Additional fertilizer application, if economically justified, may stabilize yields, but at the cost of additional nutrient run-off. Environmental groups and related researchers, concerned with the impact of both stover removal and intensified corn production, will therefore factor nutrient loss, erosion, and water quality considerations (to both local watersheds and more distant water bodies, as is the case with Gulf of Mexico hypoxia) into their determination of sustainable stover removal rates. How a farmer responds to these concerns will depend in part on whether they own the land, and therefore consider long-term stewardship, or rent access to fields, and are more focused on short-term gains. In the aggregate, decision making at this level will determine the actual amount of stover available for biofuel production.

Making decisions between these geographic scales are the stakeholder groups that will use stover: investors in biorefineries and plant operators, who will be primarily concerned with ensuring a continuing supply of cheap biomass within an economical transportation distance. Simple calculations based on average regional corn production and an assumed stover removal rate will suffice for a siting feasibility determination, but the need to secure investment financing may require firm commitments from individual producers to deliver stover. These commitments will vary with heterogeneous motives and decision making, as well as shifts in commodity prices—and therefore planting decisions—driven by the diversion of crops (and land) to bioenergy production. Furthermore, supply uncertainty is compounded by the need to agree on delivered stover prices, since the opportunity costs to the farmer of removing stover may be greater than refinery operators, faced with the need to minimize their variable costs of production, are willing to pay for feedstock. A final layer of supply uncertainty reaches further into the future. Biorefineries will have an operating life that extends over multiple decades. Supply potential over this lifetime may be increased if the promises made by agribusiness of dramatic yield increases are realized, or may be limited by potential regulatory and voluntary actions designed to minimize the negative consequences of residue removal.

How much stover might be available for biofuel production therefore depends in part on whom one asks. Stakeholder perspectives, however, lead to different expectations about supply and costs. These expectations are based in part on technical considerations, including crop yield improvements and limits on stover removal rates due to equipment design, as well as on value considerations, including how much removal is acceptable in light of the economic and environmental trade-offs of increasing removal rates. Such expectations, in turn, lead to actions among stakeholder groups which may produce conflict. Development of economically viable, yet environmentally benign, stover markets will depend on how such conflicts are resolved.

One could argue that the policy making and regulatory processes could avoid or resolve potential conflicts like that illustrated here. Even though regulatory development processes offer multiple opportunities for stakeholder input and challenge, however, reality is dynamic and the resulting regulations generally do not have the flexibility to accommodate changing circumstances. In the context of bioenergy, new markets are developing, with new stakeholders and issues emerging. In the U.S., EISA and RFS2 establish a process under which new biomass feedstocks may be qualified to receive credit toward the renewable fuel production mandates, but this qualification concerns lifecycle greenhouse gas emissions and prevention of degradation in certain environmental conditions ("backsliding"), and not other environmental, social, or economic concerns (USEPA 2010). Moreover, once finalized, regulatory evaluation processes need to remain consistent over time, and therefore lack the flexibility to respond to a dynamic issue domain. Other social processes are needed to coordinate stakeholder interactions and manage conflict, and it is here that we see a role for the research community. We pick up with an overview of our research recommendations after a discussion of how stakeholder diversity affects research practice.

Biomass Research and Stakeholder Information Needs

Stakeholder diversity affects not only the questions researchers need to ask, but also the type of information they provide. With different stakeholder groups come different decision making processes and orientations to the use of information. In a broader discussion of scientific assessments, Mitchell and others (2006) describe three attributes that increase the influence of research: saliency, credibility, and legitimacy. The first of these attributes, saliency, captures the requirement that information be timely and relevant to stakeholder decision making. Credibility, the second attribute, refers to the need for scientific rigor and technical quality, while legitimacy, the third, concerns freedom from perceived bias.

All stakeholder groups will evaluate (explicitly or implicitly) information against these attributes, but the weights they place on the attributes will vary across groups. Different information sources will rank higher on some attributes than others, and as Mitchell and his co-authors (2006) point out, the attributes themselves often conflict. Increasing legitimacy by broadening the range of perspectives represented in an information resource, for instance, can lower credibility by including less trustworthy sources (Mitchell and others 2006). Researchers are therefore challenged by the need to understand the particular requirements of their audience, and often by the need to frame their work so as to appeal to the needs of as many different groups as possible. With the evolving bioenergy sustainability issue domain, these needs will be dynamic.

The notion that information must be salient, legitimate, and credible for it to have influence applies not only to bioenergy researchers addressing specific points in the bioenergy supply chain, but also to the flow of information between stakeholders and its applicability and acceptance along the supply chain (Mitchell and others 2006). The standards by which each stakeholder judges the attributes and threshold levels of acceptability when evaluating information vary by stakeholder and topic, as well as by the leverage and prominence each exerts. Researchers will be more effective when they are cognizant not only of how the information they produce will affect particular stakeholders directly, but also of how that information may or may not propagate as it is passed along from stakeholder to stakeholder throughout the bioenergy supply chain, with each stakeholder applying its own filters to the information of which it becomes aware.

We draw three implications from this discussion. First, researchers concerned with the application of their work should try to understand how the evolving bioenergy issue domain affects salience, legitimacy, and credibility, and structure their research accordingly. The ability to provide timely general information (saliency), for instance, may be more important at a given moment than complete scientific rigor (credibility). This does not mean that credibility is unimportant, but rather than continuing to refine research results can be counterproductive. Researchers therefore need to understand which dimensions are most important for particular stakeholders and decision-making situations. Direct stakeholder engagement and co-production of knowledge through participatory research, which we discuss further in the next section, provide a means of meeting this need (Mitchell and others 2006).

Second, those concerned with promoting sustainable bioenergy should understand the unique decision making needs of their particular audience(s), and the specific entry points for communicating with different stakeholder groups. Jones and others (1999) provide a complementary analysis to that of Mitchell and others (2006) and stress that research should be: relevant to stakeholder decision needs, compatible with actual decision making processes, accessible to stakeholders, and in such a form that stakeholders will be receptive to the results. Researchers should therefore recognize the institutional information flows, thought styles, and analytical models of specific stakeholders. Research will be less likely to influence decision making if it is not compatible with these stakeholder characteristics.

Finally, given that one source of information cannot simultaneously maximize all three attributes, a wide range of information resources will always be needed. Table 2 applies this conceptual framework to the stakeholder characterization in Table 1 and represents an illustrative attempt to classify how our four stakeholder groups might perceive different information resources. Direct actors, for instance, are likely to see the information provided by an extension service to be highly salient, and moderately legitimate and credible. As a key provider of information to biomass producers and similar on-the-ground decision makers, extension services are an immediate source of advice and technical assistance, even if they are not always on the cutting edge of research or free from the influence of institutional perspectives. Table 2 also illustrates how the weight of each attribute might vary by stakeholder group. For instance, direct and indirect actors, whose decision making concerns the operation of the bioenergy supply chain and whose information needs are more immediate, are likely to be more concerned with saliency. Oversight officials and interested parties, in contrast, both take a broader, longer-term view of supply chain operation and development, and are therefore more likely to stress credibility over saliency.

Our aim has been to make the case for research designed around stakeholder interests and information needs. A thorough elicitation of stakeholder views, coupled with a more complete survey of information resources, would benefit bioenergy researchers concerned that their work leads to sustainable outcomes. The next section discusses this and related social science research needs in greater detail.

Recommendations for the Bioenergy Research Community

The National Research Council has pointed to the need for both analysis and deliberation in environmental risk characterization and decision making (National Research Council 1996, 2008). Efforts to manage complex environmental risks inevitably confront both value and perceptual differences among affected stakeholder groups. Scientific and technical analyses should reflect these values and perceptual issues in their assumptions and the questions they ask if they are to provide useful information to decision makers (National Research Council 1996). Deliberation, "any formal or informal process for communication and for raising and collectively considering issues" (National Research Council 1996, p. 73), is therefore needed to frame analysis, which in turn informs deliberative processes. We generalize from the need for such iterative processes to make recommendations related to the issues we have raised in this paper. While these recommendations call for an expanded social science emphasis, interdisciplinary collaboration with the natural science and technical research communities will be required to ensure its success.

Our first recommendation concerns the value of participatory research. The earlier discussion of the implications of stakeholder diversity on bioenergy research practice pointed to the need for participatory processes that include stakeholders as active participants in research activities (Glicken 2000; Cash and others 2003; Hadorn and others 2006; Feldman and others 2008; National Research Council 2008). Participatory approaches and "transdisciplinary research" can improve research design (Grimble 1998), enhance decision support (Feldman and others 2008), and increase the salience, legitimacy, and credibility of research outputs (Mitchell and others 2006). Direct involvement with stakeholders represents a culture shift, and also raises concerns about the objectivity of scientific research, but is in keeping with what many see as being required to address issues of sustainability (Kates and others 2001).

Participatory research, however, does not imply advocacy, or favoring one group of stakeholders over another. Rather, the aim is interaction with affected stakeholder groups from research design through delivery (Bammer 2005). Boundary organizations, such as extension services or even federal and academic research institutions, can institutionalize this interaction (Guston 2001; Feldman and others 2008). Such organizations facilitate communication between experts and decision makers, support co-production of assessments, reports, and models, and ideally remain accountable to all participants (Guston 2001; Cash and others 2003). Successful interaction must be ongoing as the bioenergy issues domain continues to evolve, and stakeholder involvement—and therefore stakeholder information and decision making needs—will vary by issue, time, and place (Glicken 2000; Mitchell and others 2006).

Second, in addition to participatory analytical collaborations, the bioenergy research community should focus on improving deliberative processes—the interactions among

Table 2 Stakeholder perceptions of information sources

Information source	Direct actors			Indirect actors			Oversight officials			Interested parties		
	Salience	Legitimacy	Credibility	Salience	Legitimacy	Credibility	Salience	Legitimacy	Credibility	Salience	Legitimacy	Credibility
Extension services	High	Mod	Mod	High	Mod	Mod						
Industry (trade) publications	High	Low	Mod	High	Low	Mod						
Market research	High	Low	Mod/Low	High	Low	Mod/Low				High	Low	Mod/Low
Planning literature				Mod	Mod	High						
Statutory information reporting							Mod	High	High			
Internal government research							Mod	Mod	High	Mod	Mod	High
Academic literature										Mod/Low	Mod	High
Internal and field research										High	Low	High

Each source used by a stakeholder group is rated (High, Moderate (Mod), Low), based on the information attributes in Mitchell and others (2006). A blank cell indicates that the information source is not widely used by a stakeholder group. These characterizations of information sources are consensus views of the authors and do not reflect official views of their respective agencies or a review of any particular publication

stakeholder groups. Researchers can serve as conveners, coordinating stakeholder-to-stakeholder engagements and developing processes and ground rules for identifying and negotiating differences and managing conflict (Walker and others 2006; Pohl 2008). In addition, researchers can support attributes of successful interaction processes, which "include transparency of process, inclusiveness, availability of decision-relevant information, explicitness about assumptions and uncertainties, independent review, and iteration" (National Research Council 2008, p. 181). The focus of such processes is less on attaining consensus than it is on facilitating social learning: "bring[ing] into consideration knowledge and judgments coming from various perspectives so that participants develop understandings that are informed by other views" (National Research Council 1996, p. 73).

In certain cases, heterogeneity in stakeholder interests and values, rather than being a source of conflict, may provide the research community with an opportunity for creative problem solving. To give an example, issue linkage—which occurs "when one stakeholder offers to do something for another on an issue that is not the focus of the [negotiating] group's work" (Susskind and others 1999, p. 341)—offers a means of attaining stakeholder cooperation (Martin 1995). Different stakeholders may be willing to compromise on other issues if they are able to achieve their own higher priority goals. Issue linkage may also bring to the table stakeholders who would not otherwise consider sustainability concerns in their decision making. As a hypothetical example, if a conservation group was concerned with what it viewed as unsustainable corn stover removal rates in a given region, and local farmers were unable to meet their own economic goals with the lower rates proposed by the conservation group, issue linkage could be used to compensate the farmers. The farmers could offer other options that would compensate the conservation group on somewhat tangential issues of concern, such as the management of riparian zones, or could propose changes in management practices (besides stover removal rates) such as reductions in chemical inputs or harvest delays based on bird breeding (Fletcher and others 2011). Once again, an understanding of stakeholder groups, interests, and values, combined with a neutral facilitator, is needed to take advantage of this possibility.

Finally, we link these recommendations with a call for rigorous and on-going bioenergy stakeholder analysis (Reed 2008; Reed and others 2009). Our earlier attempts in Tables 1 and 2 to identify bioenergy stakeholders, their motivating concerns, and their information requirements were intended to alert bioenergy researchers to the need for further consideration of these issues. Additional research is required to identify bioenergy stakeholders (both current and potential); understand their values, interests, and decision making processes; assess their technical capabilities and readiness for engagement; and map their interactions (Grimble 1998; Glicken 2000; Reed 2008). Efforts to understand influence networks and the ability of particular stakeholder groups to shape public decision making are also needed (Reed and others 2009).

Conclusions

Bioenergy is a complex, evolving issue domain. While sustainable bioenergy depends on the resolution of important scientific and technical problems, we have argued that the relevance of this work to actual stakeholder decision making requires a grounding in social science issues. Sustainable bioenergy development requires consideration of institutional and social factors as much as it involves the design of environmentally-friendly technologies and processes and the resolution of scientific uncertainties. With a focus on the bioenergy research community, we have stressed the value of understanding how diversity in stakeholder interests, values, and decision processes affects research practice, and have drawn on the decision making and stakeholder engagement literature to point out where participatory processes and additional social science research would be valuable. Researchers, in short, should understand the decision environment, values, and interests of the evolving bioenergy stakeholder community, and that more data will not, by itself, lead to better decisions. The complexities inherent in sustainable bioenergy production are as much social as they are technical, and interdisciplinary research is needed to grasp this multifaceted reality.

In conclusion, it is worth noting that the complexities and uncertainties arising from bioenergy production are similar in nature to those facing other efforts to move toward practices that are sustainable over time. As sustainable practices are applied to increasingly broader systems (such as bioenergy production), as opposed to systems of narrower scope (such as biomass feedstock production), it is inevitable that differences in perspective will arise due to the ever-increasing number of affected stakeholders. Yet, a process of airing and negotiating among these varied and possibly contradictory perspectives and drivers is needed if any complex system is to be viable—that is, sustainable—in the long-term.

Sustainability therefore involves more than maintaining environmental, economic, or social conditions. The goals driving these sustainability efforts must be determined and, as these are value-driven, they will vary across affected parties and be contested. Negotiations that include diverse perspectives will be more likely to identify social values and issues that are perceived to be important, and being part of a decision process often leads to greater acceptance even if particular views do not prevail. Although sustainability does not mean that every perspective will “win,” it does mean that environmental, economic, and social goals are recognized as critical to the system as a whole. The absence of different perspectives and values in decision making is an indication that the process may not be moving toward sustainable outcomes. Thus, understanding these differences and gaining insight into how decisions are made in complex systems is crucial to our efforts to build a sustainable bioenergy system, and potentially, any other complex system. Bioenergy, which brings together very different social, policy, and technical communities, epitomizes the needs of diverse decision making processes.

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