The ontologies of industrial ecology?

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Abstract: Industrial ecology is one of a number of new fields of study, such as 'green chemistry' or 'ecological economics', that have deliberately reached across different disciplines in both name and substance. This raises a number of issues for the practitioner, including difficult questions of boundary and field content (when is something 'industrial ecology' and when is it a part of another dialogue?). Such issues are challenging enough. But industrial ecology raises even more complex questions, in particular the possibility that in some senses, industrial ecology is one of the first post-modern fields of study, in that, unlike most more traditional disciplines, it embodies not a single ontology, but a set of complex and, in some ways, mutually exclusive ontologies. How such multi-ontological fields can be conceptualised, and represented coherently through traditional institutional forms such as journals and societies, is not yet clear, but it is highly likely that the industrial ecology community as a whole will need to learn to do so.

Keywords: industrial ecology; ontology; transdisciplinary; multidisciplinary; earth systems engineering and management; Science and Technology Studies (STS); postmodernism.

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1 Introduction

For those who have been involved in industrial ecology for many years, it has been a unique intellectual experience. This is not only because of the new data, methodologies, and understanding which the field has produced regarding industrial systems, but because industrial ecologists, taken as a whole, are a reflective group, and thus they also tend to the reflexive study of themselves studying industrial ecology.[1] This is reflected in the history of industrial ecology. Thus, for example, the idea that industrial and ecological systems share certain traits, and thus the study of one might inform the other, has a long history that has itself become a growing focus of study in the industrial ecology literature (Ehrenfeld, 2004; Erkman, 2002; Allenby and Cooper, 1994; Korhonen, 2004a; Graedel and Allenby, 2003). In the spirit, then, of learning not just about industrial ecology, but the process by which a field arises and is defined, this paper discusses several questions that have drawn this reflexive attention, including that of the 'appropriate boundaries' of industrial ecology. Beyond that, however, this paper will suggest that industrial ecology, unlike traditional disciplines or fields of study, integrates multiple, mutually exclusive ontologies, and is thus conceptually complex in ways which are new and particularly challenging. (For our purposes, following the philosophic tradition, we can consider an 'ontology' as a set of particular assumptions about the nature of being and reality.) Among the many issues this raises for further research are whether a scientific field can, in fact, contain, as a permanent structure, multiple ontologies (if not, does that mean that industrial ecology can never be a 'scientific field'?), and how open, respectful and meaningful communication can be encouraged in a community with such a structure.

2 Relationship to other areas of study

The development of industrial ecology over the past decade and a half has not occurred in a vacuum. Indeed, there are a number of other academic initiatives with somewhat similar characteristics that have become institutionalised over the same time period, such as ecological economics, 'environmental security' studies, life cycle assessment methodologies, 'sustainable engineering' and other 'sustainability' initiatives within disciplines, 'sustainability science', and the like (Allenby *et al.*, 1996; Costanza, 1991; Allenby and Richards, 1994). Taken as a group, these activities tend to represent efforts to integrate environmental considerations into heretofore non-environmental academic discourses and communities; take a 'systems view' of the world in doing so; include industrial activities, products, and systems in their analyses; and overlap, sometimes substantially, in their research interests and foci. They also tend to be inherently multidisciplinary, in that they either explicitly bridge among existing academic disciplines ('ecological economics'), or implicitly combine areas of study or communities of interest that have previously not been linked. 'Environmental security', for example, conceptually represents the overlap between traditional environmental studies, and national security interests (Allenby *et al.*, 1996).

This leads to a number of difficulties in defining the boundaries of these fields. Thus, what subject matter or disciplinary approaches are 'in' the field of industrial ecology is not at all clear, a condition exacerbated by the fact that, unlike some disciplines such as engineering, the subject matter of study – industrial and economic systems and concomitant environmental impacts – does not itself imply any easy boundaries. Indeed, as will be discussed in greater detail below, it is the investigator, not the system, that in most cases creates the (necessarily contingent) boundaries. After all, industry is at least a physical phenomenon, an economic phenomenon, a social and cultural phenomenon, and a major source of interaction between human and natural systems. Thus, the subject matter does not clearly answer even simple questions such as the extent to which social sciences are a part of industrial ecology studies and whether they are core to the discipline, or ancillary.

There are clearly important implications to this inability to achieve an easily understood boundary between what is, and what is not, 'included' in the field of industrial ecology. The first involves the very practical necessity to continue institutionalising industrial ecology. Even as the International Society for Industrial Ecology continues to mature, there is continued ambiguity between intellectual content and institutional structures. Thus, for example, conceptually the industrial ecology community tends to include life cycle assessment and material flow accounting within industrial ecology, even while organisationally other institutions, such as SETAC, operate in much the same space (see, *e.g.*, Allenby and Cooper, 1994; Korhonen, 2004a; Graedel and Allenby, 2003; Allenby, 1999; Socolow *et al.*, 1994 and discussions therein; SETAC website – www.setac.org/), and a similar ambiguity applies to the Society's relationship to the ecological economics community (see the website for the International Society for Ecological Economics at www.ecoeco.org/). And how does industrial ecology relate to more traditional disciplines, which it clearly draws upon either methodologically or intellectually, such as business studies of various kinds, and engineering studies (Design for Environment, an integration of industrial ecology principles into a product realisation design process, being an early example of the implementation of industrial ecology (Allenby, 1992))?

Moreover, the current state of ambiguity causes some degree of concern among practitioners of industrial ecology, especially and understandably among students who are studying to become industrial ecologists. And indeed there are dangers, and not just in the pragmatic sense that, without some kind of relatively rigorous definition of industrial ecology, those who seek to practice it may face difficulties in the job market. An obvious one is that, in the presence of ambiguity, efforts to build a structured field of practice may be weakened and perhaps undermined completely by alternative approaches emphasising the romantic and subjective. And this leads to perhaps a more fundamental question: is industrial ecology an objective field of study, similar to the physical sciences and engineering, or is it a normative field of study?

3 Industrial ecology: objective or normative?

To an observer of industrial ecology as a case study in the evolution of a new field of study, one of the most interesting dialogues revolves around whether industrial ecology is an 'objective' or a 'normative' activity. This, of course, in part reflects trends in the larger society, particularly the 'culture war' issue of whether science is a privileged discourse (Hacking, 1999; Lyotard, 1979).[2] It also, however, reflects a tension between the objective and the normative that is particularly acute in areas of science dealing with environmental issues such as conservation biology, environmental science and industrial ecology, where the line between scientific observer and advocate seems more often to be blurred than in other areas of scientific endeavour.[3] Finally, it reflects an implicit assumption that industrial ecology, as a field, is a 'science' rather than, say 'literary criticism' or 'environmental activism'. This may be the position adopted by most industrial ecologists, and in many cases it appears to be a useful one – but that does not necessarily mean that it is always valid.

There are a number of developmental reasons why such definitional issues have been particularly vexed for some industrial ecologists. For example, industrial ecology has been accused by some of being a technological determinism run amok, as well as being at least naïve as regards the purported 'objectivity' of science and technology (Boons and Roome, 2001; Opoku, 2004).[4] This latter concern, which tends to be expressed more by those trained in social science and criticism, may reflect not just the usual tendency of the scientific and technological communities towards a frequently unconscious logical positivism, but also the birth of modern industrial ecology in an industrial and managerial context, which has coloured at least some of the initial formulations (see, *e.g.*, Erkman, 2002; Allenby and Richards, 1994). Moreover, it also probably reflects a desire of at least some of the early formulators of the industrial ecology project (at least the current author) to avoid having the concept of 'industrial ecology' become so broad and ambiguous that it lost all content, and thus value for public discourse as well as practitioners. But with the maturing of the field, a more nuanced approach can be taken.

As stated – 'is industrial ecology normative or objective?' – the proposition is virtually guaranteed to raise high levels of emotion while generating very little light, primarily because every research endeavour, and every stage of the scientific and technological enterprise, has both objective and normative elements. The question must be parsed more carefully. To begin with, it is important to note that industrial ecology is neither purely scientific, nor purely technological, but includes elements of both, and that science and technology are not necessarily the same activities. Conceptually, science is an activity that attempts to determine 'what is', and measures its success by its alignment with data and physical reality.[5] Technology, on the other hand, is more akin to art, in that it creates that which will be – although always in negotiation with its cultural context (Bijker *et al.*, 1997). The trick with industrial ecology, of course, is that it has characteristics of both science and technology.[6] When one generates data on material stock and flow components behind the automotive technology system, one is more on the scientific side; when one uses Design for Environment methodologies to determine how to best reduce the environmental impacts of products through good design, one is operating more on the technology side. Thus, industrial ecology begins with a more complex relationship between the normative and the objective than most fields of study – even without considering social science.

Even in 'purer' sciences, however, since Kuhn (1970) it has been reasonably accepted that science, as a human activity, necessarily reflects its time and place in many ways, and to that extent is not a 'purely objective' activity. Moreover, science and engineering are self-selective processes, in that those who choose to pursue such professions as opposed to, say, law or economics or crime, choose to do so for a number of reasons, many of which are not 'objective' in the usual sense (such as, for example, status, employment opportunities, desire to create a better world, and the like). The context within which science occurs, and individual scientists self-select, therefore, is heavily normative.

Looking more closely at the scientific process itself, it is apparent that normative and historically contingent factors tend also to be important in the identification and formulation of hypotheses to be tested. Thus, a conservation biologist would be more likely to study ecosystems at risk, and an industrial ecologist would tend to study material flows that were for some reason problematic – chlorine, for example, rather than construction aggregate. Nonetheless, there are important 'objective' components in hypothesis creation – a hypothesis that is not falsifiable ('God created the world in seven days, and all evidence to the contrary was put there by the Devil to confuse you') is not considered a valid scientific hypothesis. And certainly, when it comes to the research component of the scientific process, there are clear objective standards, including the unacceptability of simply making up data, leaving out contrary data, and the need to have the data and analysis reflect external reality.[7] Even here, of course, absolute objectivity is impossible, but, through the testing of hypothesis and data against external reality and existing scientific findings, it can be approached. As Russell (1972, p.836) comments:

> "In the welter of conflicting fanaticisms, one of the few unifying forces is scientific truthfulness, by which I mean the habit of basing our beliefs upon observations and inferences as impersonal, and as much divested of local and temperamental bias, as is possible for human beings."

The final step which, especially with environmental sciences generally and industrial ecology specifically, is both immediate and powerful, is the feedback of the data and analysis into the policy process. Here, the traditional view is along the lines of science "as a disinterested force that could guide political decision-making by providing appropriate facts" (Sarewitz, 2004, p.388) – certainly, this is how the activists, whether industrialists or environmentalists, position the results that support their position. But there are reasons to suspect that this view may be somewhat naïve, for the line between established scientific results being injected into the policy process, and the scientific discourse as a whole being subsumed in the policy process, is not as clear as might be at first supposed.

Industrial ecology fits this general pattern. For one thing, it is fairly clear that the underlying context for the development of the field is a favourable cultural background in that environmental issues are taken as serious, industrial systems are seen as both part of the problem and part of the solution, and the ideas of 'sustainable development' have created a favourable framework within which the field can be understood. Indeed, it seems at least to this author that the reason that industrial ecology did not grow from pre-1989 efforts, but blossomed in the 1990s, is to a significant degree the more favourable cultural context which did not exist until then (Erkman, 2002). More subtly, industrial ecology as a metaphor gains strength in a historical period where the dominant explanatory metaphor is evolving from Newtonian mechanism to ecology (Allenby, 2005; Gandy, 2002). It is also evident that most in the industrial ecology community are committed in one way or another to ideas of sustainability and environmental protection. And, not unexpectedly given the above, the bulk of industrial ecology research is in areas that imply a belief that environmental systems are threatened by continued emissions and artefacts from industrial systems. At the level of the actual research itself, however, there is little evidence of fraud or suppression of data.

From this perspective, then, question is not so much whether industrial ecology is objective or normative. It is more one of individual tactics and the highly politicised context within which industrial ecology research, as with much environmentally oriented work, is done. To the extent the field of industrial ecology is perceived as a technocratic effort to stifle environmental concerns, or, conversely, as another mechanism by which activists can achieve environmental goals and income redistribution, it runs the risk of losing scientific credibility – put another way, those who, for whatever reason, are inclined to reject the results of industrial ecology research as well as the ideological conclusions drawn from it, will find it much easier to do so. The questions, then, are to a large extent ones of individual tactics – to what extent should I integrate my industrial ecology work into my activism, and at what eventual cost? How the individual approaches sum up to interact with the ongoing project of defining industrial ecology as a field, and affect institutional positioning (to what extent, for example, should the International Society for Industrial Ecology become an environmental advocacy group?), is yet unclear.

4 Industrial ecology as mutually exclusive ontologies

But the matter runs much more deeply than that. Industrial ecology is often touted as a systems-based, multidisciplinary discourse that seeks to understand emergent behaviour of complex integrated human/natural systems (*e.g.*, Graedel and Allenby, 2003; Allenby, 1999; Socolow *et al.*, 1994). Accordingly, while individual industrial ecologists will no doubt continue to do their research based on their particular inclinations and backgrounds, the field itself cannot avoid the serious challenges of learning to deal with the inherent complexity of these systems – a complexity that is simultaneously static, dynamic, and ontological.

To begin with, the idea of a single and understandable statement of foundational objective reality may, as Sarewitz and others argue, be too naïve when it comes to highly politicised areas of science such as the environment generally, or specific issues such as climate change (Sarewitz, 2004, p.388). On such contested terrain, where there are often too many rather than too few data (Sarewitz, 2004, p.389):

> "This condition may be termed an 'excess of objectivity', because the obstacle to achieving any type of shared scientific understanding of what climate change (or any other complex environmental problem) 'means', and thus what it may imply for human action, is not a lack of scientific knowledge so much as the contrary – a huge body of knowledge whose components can be legitimately assembled and interpreted in different ways to yield competing views of the 'problem' and of how society should respond. Put simply, for a given value-based position in an environmental controversy, it is often possible to compile a supporting set of scientifically legitimated facts."

Writing in the adaptive management literature, Michael (1995, pp.473–474) makes a similar point:

> "Persons and organizations view information from their personal and peer-shared myths and boundaries. More information provides an ever-larger pool out of which interested parties can fish differing positions on the history of what has led to current circumstances, on what is now happening, on what needs to be done, and on what the consequences will be. And more information often stimulates the creation of more options, resulting in the creation of still more information. Indeed, in our current world situation, opening oneself or one's group to a larger 'database' reveals the terrifying prospect that the world is now so complex that no one really understands its dynamics and that even rational efforts tend to be washed out or misdirected by processes not

understood and consequences not anticipated. Of course, as suggested earlier, those intent on pursuing their interests seldom can risk socio-cultural ostracism by acknowledging this to others, and usually not even to themselves."

And, to bring the circle around to the industrial term of 'industrial ecology', Senge (1990, p.69) notes with regard to industrial management that:

> ". . . we are being overwhelmed by complexity. Perhaps for the first time in history, humankind has the capacity to create far more information than anyone can absorb, to foster far greater interdependency than anyone can manage, and to accelerate change far faster than anyone's ability to keep pace. Certainly, the scale of complexity is without precedent."

Perhaps unintentionally, then, industrial ecology has stumbled into two very new, and very difficult, challenges: complexity of a degree that current institutions and disciplines do not facilitate either perceiving or understanding (Luhmann, 1989), and an underlying ontological profusion that can be avoided by a disciplinary structure, but not by industrial ecology.

To begin with the first, it is becoming increasingly apparent that the single most overwhelming reality of our age, dubbed the Anthropocene by the journal *Nature* in 2003 (Anonymous, 2003), is its complexity: the static complexity of economies, cultures, natural cycles, and biological systems, and the dynamic complexity of their internal and external unfolding over time as networked systems. Beyond that is the increasing complexity introduced by technological evolution and, particularly, the increasing convergence of four foundational technologies: nanotechnology, biotechnology, Information and Communication Technology (ICT), and cognitive sciences and technology (Allenby, 2005). Moreover, one effect of technological evolution is the increasing integration of human and natural systems – thus, for example, as genetic codes and resultant protein systems are identified, their information becomes integrated into economic activity through operation of the intellectual property regimes. The result is to integrate the dynamics of human systems – including their contingency and unpredictability – into natural systems that previously displayed far different dynamics (Allenby, 2005; 2003).

There is an increasing literature on complexity and 'complex adaptive systems', led by work at places like the Santa Fe Institute in the USA (Kauffman, 1993; Harvey, 1996). But this field is in its infancy, and the difficulty of the challenge cannot be overstated. Again, drawing on his experiences with adaptive management regimes, Michael (1995, p.462) notes (emphasis in original):

> "*Our conventional ways of thinking and speaking about language and social reality are inadequate for coping with our current circumstances* . . . Our semantic baggage from past experiences is not matched to a reality of systemic interactions, circular feedback processes, non-linearity, or multiple causation and outcomes. Implicitly, our conventional language relates us to a world of linear relationships, simple cause and effect, and separate circumstances, be they events, causes, or effects. But that is not the world we live in."

It is not just that we lack the methodologies for understanding the complexity of the systems that industrial ecology purports to treat. It is deeper than that. We lack the language to not just express the relationships, the system structure and behaviour, and even perhaps to perceive them. And Jencks (1977, p.55), drawing on a lifetime of experience in architecture, notes that the result may be a challenge that cannot even be expressed, even when dimly perceived:

> "If one wants to change a culture's taste and behavior, or at least influence these aspects, as modern architects have expressed a desire to do so, then one has to speak the common language of the culture first. If the language and message are changed at the same time, then both will be systematically misunderstood and reinterpreted to fit the conventional categories, the habitual patterns of life."

In short, the field of industrial ecology necessarily involves increasing our sophistication regarding, and integration of, the growing literature on complexity and complex adaptive systems. This does not mean that at the individual level, we all need to become experts in complexity theory, but it does mean that good researchers will gain at least a greater awareness of complexity, and that the field itself should welcome opportunities to integrate work on complexity theory and complex adaptive systems. To some degree, this is already embedded in the history of the field, as it can be argued that one of the major values of the analogy between industrial and ecological systems is to encourage the application of the understanding of the complexity of the latter to questions involving the former. But it is important both to expand that particular project within industrial ecology, and to reach out to other studies of complexity, especially those regarding social and cultural complexity.[8] Biological ecology is not the only form of complexity, nor is it adequate to completely explicate the forms of complexity found in human systems.

It is not just the static and dynamic complexity of the systems with which industrial ecology is concerned that complicate matters (static complexity arises from the number of nodes, and their linkages, in any system; dynamic complexity arises from their interactions with each other, and external factors, over time). More profoundly, the subject matter of industrial ecology involves differing, and mutually exclusive, ontologies, or sets of assumptions regarding the nature of being and reality. (The philosophic term should be differentiated from the concept of 'ontology' as used by the artificial intelligence and other technical communities, where it generally means the specification of a set of concepts and relationships that can exist for a set of data or agents (Gruber, 2005)).

Consider the industrial ecology literature. The first observation, made above, is that it combines scientific and technological dimensions, and that those involve very different ways of thinking about the world. Both groups, however, tend towards a belief in the objective nature of their research. But, writing in the *Journal of Industrial Ecology*, others have strongly challenged that assumption. Boons and Roome (2001, p.51) take a somewhat postmodernist position, arguing that both the linking of industry with an ecological metaphor, and any pretence at objectivity, is itself normative: "Our point of departure is that industrial ecology, as a field of research and practice, is inherently normative." Isenmann (2002, p.39) analyses the reliance of industrial ecology on concepts of 'nature', emphasising that all such concepts are both constructed and contingent:

> "Nature does not automatically or clearly speak to humans. Nature appears to humans only by several ways of *mediation*. . . . humans must translate nature with language and into language. . . . Reading in the 'book of nature' requires an understanding of both the reader (representing human self-experience and self-awareness) and the reader's perspective (representing the process of reading) . . ."

Korhonen (2004a–b) has focused on the question of translating descriptive results derived from engineering and natural sciences into practices involving human societies and cultures, arguing that crossing these boundaries requires very different assumptions about epistemology (and, one could add, ontologies).

One of the interesting aspects of dealing with complex systems is that the boundaries of the appropriate system are determined by the query which one poses to the system (Allenby, 2005). Thus, for example, if I ask what the police arrest rate is for New York City, I have implied by my query the existing political boundaries of the City. If, however, I ask what the water supply infrastructure is for New York City, I have included at least a third of the State of New York, which has been legally structured, and engineered, to provide water supplies through a complex infrastructure to the City (Gandy, 2002). Following Sarewitz (2004), therefore, one can make the observation that any industrial ecology study is equivalent to querying a complex adaptive system (the economic and industrial system) and thus implicitly defining the relevant boundaries for the inquiry. This necessarily involves at least two inseparable but very different ontologies: the personal and cultural normative ontology the individual researcher brings to the query, which defines a set of boundaries that, from the perspective of the overall systems, are essentially arbitrary, and the 'scientific' and more objective process the researcher applies to the particular study. Moreover, for most people these are conflicting ontologies, as expressed by the 'normative versus objective' dichotomy that seems so comfortable to most of us.

5 Conclusion

The question of the appropriate boundaries of industrial ecology is much deeper than it initially appears. There are indeed practical questions of institutional relationships with other disciplines and interdisciplinary efforts, and of the degree to which industrial ecology grows beyond engineering and the natural sciences to include social sciences. But these lead to an understanding of the reflexivity of industrial ecology not just in terms of the industrial system – the traditional activist approach – but the identification of significant intellectual challenges arising from the existence and structure of the field itself. Prime among these are the challenge of applying the nascent work on complexity and complex adaptive systems to industrial ecology, and ensuring that the field becomes sophisticated in understanding the implications of the complicated systems with which it necessarily deals. Beyond that, however, is the understanding that industrial ecology necessarily involves the interplay of quite different, and indeed mutually exclusive, ontologies.

This may at first be considered problematic, a community display of cognitive dissonance that requires remedial action, presumably by stifling those ontologies that conflict with the comfortable ones characterising the scientific and technological communities. That would be unwise for several reasons. Among other things, it would limit a unique chance for different scholarly communities to both learn from, and contribute to, the continued evolution of the field of industrial ecology. More importantly, however, industrial ecology has as its subject matter complex adaptive systems, which cannot be completely captured by any single approach (even as elements of them can be explicated). Thus, the existence of mutually exclusive ontologies is not an accident of industrial ecology's evolution, but arises instead from the essence of the subject matter of the field – any single ontological structure that can be explicated is just too simple to capture the complexity of the reality that industrial ecology explores. Indeed, it is likely that other discourses such as the sustainable development or climate change discourses will eventually come to the same recognition, and that the experience of industrial ecology will thus be an important contributor to the sophistication of those projects as well.[9]

In many cases, this underlying ontological complexity will not affect the work of an individual researcher, or a specific project or methodology. At that level, a particular zeitgeist or ontology will in most cases be appropriate, and not overly simplistic. At the level of the field of industrial ecology, however, it is a different matter, and the challenge of complex adaptive systems, emergent behaviours, integration of powerful normative and objective elements, and mutually exclusive yet entirely appropriate ontologies cannot be avoided – indeed, must be embraced.

It is quite rare that one can participate in the evolution of a new field, and even rarer that one attracts scientists, technologists, and social scientists to such a complex subject matter. The extraordinarily fertile cross-disciplinary dialogue that has been stimulated as a result, where to some extent industrial ecology is reflexively generating its own social critique as it continues to deconstruct and re-define itself, is both stimulating and relatively unique. Despite the fact that the author, among others, has been challenged in this process, it is a wonderful and highly desirable learning opportunity. May it continue.

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Notes

1 Whether industrial ecology is a 'field', a 'discipline' or a less defined 'area of study' continues to be a subject of dialogue among practitioners, as illustrated by the recent article 'Industrial ecology: a new field or only a metaphor?' by Ehrenfeld (2004). For simplicity I will refer to the practice of industrial ecology as a 'field', and the broader dialogues around industrial ecology, including practice, as a 'discourse', in this article, without thereby intending to deny its obvious power as a metaphor, nor the possibility, discussed by Ehrenfeld, that industrial ecology fails of its promise, and becomes simply another historical buzzword.

2 Whether science is 'objective' is a different question from whether it is a privileged discourse. The former deals with a statement about the ontological foundations of science – there is a real world out there; it is knowable; the scientific process is the most valid way of knowing it – while the latter is an expression of the power of the scientific discourse as a cultural and sociological matter.

3 This conflict is exacerbated because in many cases environmental advocacy agencies are frequently major environmental research funding agencies as well. In the USA, for example, an EPA official complained that "It's hard to avoid being perceived as an intellectual gadfly or snob when you understand your mission to be cajoling [USEPA] program offices into taking science seriously and not playing games with the numbers to prop up a political position" (quoted in Powell, 1999, p.136). Similarly, an article in *Science* noted that "Some observers also worry that Environmental Protection Agency (EPA) funding of USGS research might taint the results. 'The risk is that users may view the information as less credible because it comes from an agency that has a political rather than a scientific agenda', says David Blockstein of the National Council for Science and the Environment in Washington, DC" (Stokstad, 2001, p.1040).

4 The author remains somewhat bemused that he is charged by some as favouring technological determinism and believing that science is 'norm free' (*e.g.*, Opoku, 2004, p.323). This apparently arises in part from the focus of much early industrial ecology work on industrial design and technology development, and in part from the author's belief that an industrial ecology that is simply an extension of a normative agenda becomes captive to ideological and political conflict determined by social and cultural power, rather than a source of information that is generally accepted by most parties to policy debates, and can thereby function to inform policy formation. To some extent, this debate reflects an unhelpful oversimplification of the different roles that industrial ecology plays. To focus on industrial design, for example, is not to argue that technology is independent of social and cultural context: most practicing engineers are aware from their own experience of the fallacy of such a simple view of technology and design (Bijker *et al.*, 1997). Moreover, it is generally accepted that creating methodologies that enable design teams to consider environmental and social considerations, as perhaps explicated in industrial ecology studies, is entirely appropriate when much of the environmental impacts associated with products are a result of design choices. Neither approach, however, logically implies that industrial ecology as an area of study is limited to such activities (or their underlying *zeitgeist*). Similarly, the author's argument against 'bad science' seems to some to signal that only science that is ideologically acceptable to the author is 'good science' (Opoku, 2004, p.323). This misunderstands the point: 'bad science' is science that is fraudulent, does not reflect the data to the best of the practitioner's ability, or substitutes the belief of the practitioner for the data. It is 'bad' in the sense that it fails to meet the internal criteria by which the scientific discourse establishes validity; not in some existential sense of good or evil. The latter is a completely different, and obviously highly normative, dialogue.

5 Of course, reality is much more complex than any set of data can express, or indeed than any ontology or worldview can capture. It is also reflexive, in that powerful cultural belief systems are acted out in the world and, over time, form it – so, for example, the island biologies of today reflect the Polynesian and European expansionary cultures, and the agricultural grid pattern of the American Midwest reifies a market oriented culture (the geometrical pattern reflecting not just the commoditisation of land, but the more subtle view that heretofore the land was 'empty' and 'unused', and thus could be treated as a commodity (Allenby, 2005).

6 Another way to phrase this somewhat simplistically is to note that science tends to ask 'what' questions, while engineering tends to ask 'how' questions, and that industrial ecology tends to ask both.

7 Of course, one can take the position that external reality does not exist, a la the idealism of Bishop Berkeley (see, for example, A Treatise Concerning the Principles of Human Knowledge (1710)), or more recent postmodern and poststructural writings, which sometimes verge on an absolute solipsism (Lyotard, 1979; Rortym, 1989), but in the context of this discussion that simply becomes a means of negating any foundation for further dialogue. If nothing exists except in mind – a proposition that cannot be disproved, but is held in its strong form by relatively few – then the entire question of objective versus normative science is not only moot, but unapproachable. To paraphrase Lord Acton, 'absolute skepticism corrupts absolutely'.

8 Human complexity is of a different order than the complexity displayed by natural systems, in part because of the overlay of technological and cultural evolution on biological evolution, and in part because of the contingent and creative dimension of human intentionality (Allenby, 2003). Indeed, going to Jenck's point regarding language, it is a characteristic of the anthropogenic earth that the dynamics and structure of 'natural' systems are increasingly determined by human activity, albeit usually unintentionally – thus the language that we try to use currently is arguably itself already archaic and increasingly dysfunctional (Allenby, 2005).

9 The relationship between a multi-ontological industrial ecology project, and other discourses such as the climate change and sustainable development discourses is indeed critical, as several reviewers of this paper noted. But this relationship is quite complicated and difficult once multiple ontologies are admitted to exist, and a separate article is required to explore them. For example, it has been argued that 'sustainable development' is powerful in part because it reflects a single worldview; while it can equally well be argued that 'sustainability' is ambiguous precisely because it can be modified to fit many worldviews (Allenby, 2005). Exploring this terrain should be done with full attention, not as a passing effort.