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Embedding Science in Politics

"Complex Utilization" and Industrial Ecology as Models of Natural Resource Use

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Keywords

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boundary object
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metaphor
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Summary

Throughout the short history of industrial ecology, issues of implementation have been heavily emphasized. Less attention has been given to the ways in which the technical models of industrial ecology interact with social processes. Yet the practitioners of industrial ecology frequently encounter challenges pertaining to contextualization when embedding a general model in different local contexts. In addition, there are reasons to believe that the models of industrial ecological systems become politically meaningful only when they are carefully contextualized and linked to localized needs. In this article, we aim at a better understanding of the political embedding of industrial ecology. In order to demonstrate some general mechanisms of embedding, we first conduct a frame analysis of complex utilization—a scientific policy instrument analogous to industrial ecology, developed in the Kola Peninsula, Russia. We identify five frames in which complex utilization has been promoted between 1935 and 2005. These frames are then compared to six frames identified in the industrial symbiosis in Kalundborg, Denmark. We find that effective political embedding relies on frames that function both on a general level and in specific contexts. General frames, such as efficiency, economy, and environment, need to be aligned with localized perceptions of particular issues. What is more, sensitivity to purely context-specific frames is necessary for effective political embedding. Finally, the political processes of framing also shape the scientific-technical models that are being promoted.

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Introduction

Industrial ecology (IE) is a science-based concept and model that is offered for use in policymaking in both industrial and public planning at various scales. To date, IE has not become a widely institutionalized principle outside the scientific arena (Ehrenfeld 2004). It has been claimed that the difficulties of implementing IE on the grassroots level result largely from a lack of social legitimacy and poor political embedding (Lifset 2005; Cohen and Howard 2006). What is more, the numerous studies puzzling over the difficulty of replicating the Kalundborg industrial ecosystem illustrate the challenges of overcoming contextual differences in implementation. The dilemma is that, on one hand, Kalundborg is seen as a benchmark for IE, but on the other hand, its success is frequently attributed to its unique characteristics (Desrochers 2002b; Heeres et al. 2004; Ehrenfeld and Chertow 2001; Cohen-Rosenthal 2000; Ehrenfeld and Gertler 1997; Andrews 1999; Brings Jacobsen 2006; Mirata 2004; Schwarz and Steininger 1997; Gibbs and Deutz 2005; Cosgriff Dunn and Steinemann 1998). Although we do acknowledge the risk of failure in transferring environmental policy or technical solutions from one social context to the next (Roe 1994), we claim that generalizing from the specific context is not an impossible task. For this task, however, we need a better understanding of how such generalizations function in political embedding and how this affects the technical models of IE.

In this article, we identify a number of prerequisites and mechanisms for politically embedding a general scientific model in different contexts. We start from an understanding that a scientific community needs to redefine, or translate (Fujimura 1992; Callon 1997; Andrews 1999), scientific concepts and ideas in order to render them politically meaningful and to diffuse them into planning and public policy. In IE, champions (Hewes 2005) and proponents (Cohen and Howard 2006) have been shown to play a central role in the translation process. In line with research by Benford and Snow (2000), we argue that the political translation efforts of such champions and proponents rely on processes of framing. Moreover, we maintain that the reception and success of proffered frames is influenced by how well they are chosen and aligned to resonate with the salient issues and concerns of the targeted audience. Analyzing the political dimension of IE through frame analysis reveals some central aspects of contextualization. This framework also allows us to compare cases that come from very different cultural contexts but reflect the essential technological and philosophical features of IE.

To find out more about the problem of IE's political embedding across varying contexts, we first explore the mechanisms of embedding through a frame analysis of complex utilization (CU)—a scientific idea and policy instrument originating from the Russian Kola Peninsula of the 1930s. Briefly, CU is a set of methods and principles that aim to increase resource productivity and reuse of production waste in mining and minerals processing. During its long history, CU has been repeatedly suggested as a model for the use of natural resources and as a solution to diverse ecological and economic problems of the Kola Peninsula. Although the concept of CU does not stem from the same intellectual origin as IE, the two are analogous in several important respects. First, both CU and IE are *metaphors* and *boundary objects* that imply an ideal of using nature as a model for society's use of natural resources. Second, CU and IE are similar in their *prescriptions* regarding ecologically viable industries: both promote regionally integrated production systems and the flow of material between industrial production facilities. They thus represent an alternative to the current means of organizing industrial production and are confronted by similar challenges in trying to confirm their superiority over prevailing models of production. Finally, both CU and IE are *scientific policy instruments*, that is, science-based concepts that have primarily been developed by scientific communities for use in environmental and natural resource policy.

We will show that due to its long history and theoretical proximity to IE, CU offers a useful lens through which the implementation of IE can be critically examined. In particular, we argue that although direct policy recommendations from the CU case would be unjustified due to the different sociocultural contexts of CU and the Western cases of IE, our findings in the CU case can be used as a platform for examining the political embedding of IE. By comparing the frames of CU with those of IE in the Kalundborg industrial symbiosis, we are able to discuss the generalizability of IE frames as regards both political context and the physical environment. For this research design, we have structured this article in the following way. First, we give a detailed account of the analogy between CU and IE. We do this by comparing the two concepts in the light of their qualities as metaphors and boundary objects, on one hand, and as objects of political embedding, on the other. Second, in the empirical sections, we introduce the frames of CU in the context of three time periods between the 1930s and the 2000s. Third, we conduct a literature analysis in order to extract frames presented for the viability of the Kalundborg industrial symbiosis. These frames are then evaluated in the light of the findings from the CU case. Finally, we summarize the results and touch upon how framing as a political activity influences the technical models of CU and IE.

The Viability of Analogy: Why Is CU a Good Case of IE?

IE and CU as Metaphors and Boundary Objects

The metaphor of IE suggests that natural ecosystems can be used as models for industrial systems and their material flows. Similarly, the metaphor of CU links properties of nonliving nature into industrial practices. It conveys the idea that a *complex* mineral ore should be *utilized* in its complexity; in other words, the idea of extracting all the components of an ore and converting them to products. It does so by deriving design imperatives from one of the most important minerals in the Kola Peninsula, *apatite–nepheline of the Khibiny Mountains*. Apatite–nepheline is found in complex formations, which means that the mineral's constitutive compounds form strong physical bonds that require a number of processing stages if any single compound is to be extracted. Thus, the word complex refers not only to the Khibiny ore, but also to the entire industrial process that the ore is a part of. The following three quotations illustrate how the metaphor of CU has been inherent in the language of mining specialists in the Kola Peninsula, and how it has retained its core metaphorical meaning. The third quotation, from 2002, has been extracted from an interview with a specialist on apatite mining. The interview is part of our empirical material, which we will define in more detail later in the article.

> Prime among these (general scientific-technical problems) is the complex utilization of raw materials and the complete conversion into practical values of the entire mineral mass. . . . Thus, the famous apatite deposits in the Khibin mountains yield, after concentration and separation not only apatite of the first order but also nepheline; and the waste products of the latter separate out an iron ore rich in two elements alloying with steel—titanium and vanadium. (Fersman 1944, 51)

> There is a concrete possibility to acknowledge the special characteristics of nature: The complex form of the Kola Peninsula deposits does not recognize the boundaries of the state hierarchies. This claim is in accordance with the scientists' understanding of the development of new regions. As regions develop, their forces of production increase and undergo qualitative changes, the production processes of many enterprises become intertwined, the initial choices of production methods are refined towards more progressive forms that are based on the co-operation and specialization of companies from different sectors. (Luzin et al. 1988, 7)

> Being complex in the Khibiny Mountains the ores should be utilized completely: there is a way of separating nephelin but also fluoride and rare metals from the ores should be used. The amount of these elements would not only cover the Russian demand but of the whole world. (Interview 11)

The epistemic nature of metaphors has been subject to much debate within IE. Although metaphors are recognized as sources of some of the most revolutionary discoveries in natural science (Johansson 2002), it has been argued that the IE metaphor should be used only in contexts of discovery and application, not in the context of scientific justification (Isenmann 2003).

Moreover, concern has been expressed for the risks embedded in overdoing the IE metaphor (Commoner 1997; Johansson 2002). We take a slightly less problematic approach by acknowledging that metaphors are powerful tools of scientific innovation and, in fact, constitutive of many scientific concepts and theories (Holyoak and Thagard 1999; Kuhn 2002; Gentner and Wolff 2000; Brown 2003; Boyd 2002). We further emphasize the creative and organizing potential of metaphors in science, and, more precisely, in a phenomenon that is embodied in the concept of a boundary object. This concept originates from the sociology of science, where it was created to represent objects that "both inhabit several intersecting worlds . . . and satisfy the informational requirements of each of them" (Star and Griesemer 1989). Boundary objects are abstract or concrete matters—for example, databases, prototypes, standardized forms, or concepts—that permit multiple use and interpretations. They have some form of constant and recognizable identity, but are, at the same time, flexible enough to serve different communities or needs (Star and Griesemer 1989; Bowker and Star 2000).

Concepts and especially metaphors are important types of boundary objects (Kanfer et al. 2000; Hellsten 2002; Keulartz et al. 2004; Åkerman 2003; Allender-Hagedorn 2001). In order for any concept to be able to serve as a boundary object—or *boundary concept* (Löwy 1992)—it needs to have interpretative flexibility. The use of metaphor, by definition, is a way of confronting something in terms of something else, thus inducing creative thinking with flexibility of interpretation. Metaphors can become nexuses of perspectives when individuals or groups recognize, use, or identify themselves with the same term, but elaborate it in different ways. Launching a catchy new metaphorical concept, for example, in an organization or on a political or scientific arena is just a starting point for different parties to engage in discovering the meaning and significance of the metaphor relative to their interests or practices. The selection of the metaphor, such as "IE," "sustainable development," or "natural capital," certainly implies a set of likely connotations, but the meanings evoked by the metaphor are not fixed or limited. New meanings are generated when different actors align the term with their specific background knowledge and context and draw further inferences.

Both IE and CU can be conceived of as boundary objects that have provided a common nexus for various kinds of research. The expression of IE started to emerge in the literature during the 1970s, but the concept and idea itself is somewhat older (Erkman 1997). Having gained more influential articulations (Frosch and Gallopoulos 1989), the metaphor proved forceful and inspiring enough to aggregate scholars from various disciplines and to lay the foundation for a new field of research (see the article by Ehrenfeld (2004) for an assessment of IE as a field). The abstract concept and metaphor of IE represents the lowest common denominator among different scientific interpretations of the term. Conveying a fresh and unexplored perspective on industrial systems and their relation to the natural environment, the metaphor triggered multidisciplinary research on a chain of theoretical and practical questions. Similarly, the metaphor of CU has provided a fruitful starting point and boundary object for multidisciplinary research. Ever since the very birth of the idea and the industrial and scientific exploitation of the Kola Peninsula in the 1930s, it has connected research themes, researchers, and scientific managers across disciplinary fields and generations. It has suffused a considerable part of the research carried out at the Kola Science Center (KSC)—as a principal area of research in the Center's mining, chemistry, ecology, and economics institutes—and has during the past 70 years resulted in a number of solutions for specific technological problems.

In conclusion, the metaphorical character of the two boundary objects has entailed a significant creative power in their scientific development. The metaphors of IE and CU are analogous in the sense that both of them are metaphors taken from nature. The natural metaphors (the ecosystem in IE and the mineral crystal in CU) are not, however, the same and do not originate from the same historical period and public debate (the emergence of ecology and environmental debate in IE, and the industrialization of the Soviet Union in CU). It is therefore important to highlight that CU has not, from the start, had the strong ecological undertone so characteristic of industrial *ecology*. Rather, this undertone appeared in CU around the beginning of the 1980s. This notion is important, as it suggests that the political meanings of IE and CU may not bring about equally deep metaphorical explorations: although the metaphor of IE may be approachable to the laity because of its ecological connotations, understanding the metaphor of CU may require a more in-depth understanding of the specific community. These differences aside, the concepts of IE and CU can serve as boundary objects and "means of translation" (Star and Griesemer 1989) not only within science but also across the worlds of science and politics. It is this latter crossing of boundaries we turn to next.

The Political Dimension of IE and CU

The other two relevant analogies between IE and CU—in addition to their being research-organizing metaphors and boundary objects—relate to their practical implications and political roles as scientific ideas. First, IE and CU are directed toward the industrial processing of natural resources and have similar prescriptions for industrial systems. According to IE, industrial ecosystems are supposed to optimize the use of energy and material through internal circulation. In the case of CU, the complex constitution of the natural resource dictates that, in order for it to be fully utilized, the resource needs to be processed in a complex production system. In 1988, this imperative led to the design of a production system with a multitude of unit processes and material flows from one process or facility to another, as depicted in figure 1. The construction of the CU plan, according to figure 1, was started in 1989 and stopped at the collapse of the Soviet Union in 1991. During those two years, some of the new facilities in figure 1 were erected, but the plants were not put into operation. Technical references to the CU model in the following will point to the system as a whole, that is, to the interconnections drawn with both the dashed and the solid lines in figure 1. With respect to the prevailing industrial reality, the ideas of both IE and CU thus represent alternative ways to organize industrial production and are no less than challenges to the firmly institutionalized and materialized ways of thinking and acting upon industrial production and the use of natural resources.

Second, both IE and CU have been created and cultivated by scientific communities, which have also become the principal constructors and communicators of the societal meanings and justifications of the scientific metaphors. Through this political dimension of their activities, the scientific communities—including scientists and possibly other intimately connected proponents who are initiated into the science-based concepts—have become involved with natural resource policy.

The relation of IE to public policy has long been debated and has also recently been taken up in this journal (Lifset 2005; Cohen and Howard 2006). Much of the discussion has revolved around whether IE as a concept and research field is or should be objective/descriptive or normative/prescriptive. Because strong objectivism is no longer a tenable view, it is safer to believe that no science is independent of its political context. In the case of IE, the issue is strikingly evident; the metaphor is clearly a cultural and inherently normative construction (Boons and Roome 2001). The growth in interest in IE was a product of its time. The culminating environmental degradation and resource depletion that have been occurring since the 1970s called into question linear production systems and end-of-pipe mitigation, thus calling for alternative approaches (Erkman 1997). Research in IE primarily focuses on manmade industrial systems. To select a perspective such as IE for the consideration of such a fundamentally political activity can be taken as a political comment in itself. In addition, despite the diversity of views ranging between description and prescription within the IE research community, practical implications lie at the core of IE's metaphor and scientific endeavor (Cosgriff Dunn and Steinemann 1998; Allenby 1999; Gibbs and Deutz 2005).

For the sake of analytical clarity, we choose in this article to make a working distinction between what might be called the "internalizing" and "externalizing" politics of IE and CU.[1] The internalizing politics is about how the perceived, ostensibly external, political imperatives influence the scientific-technical models of IE and CU. The main emphasis in this study, however,

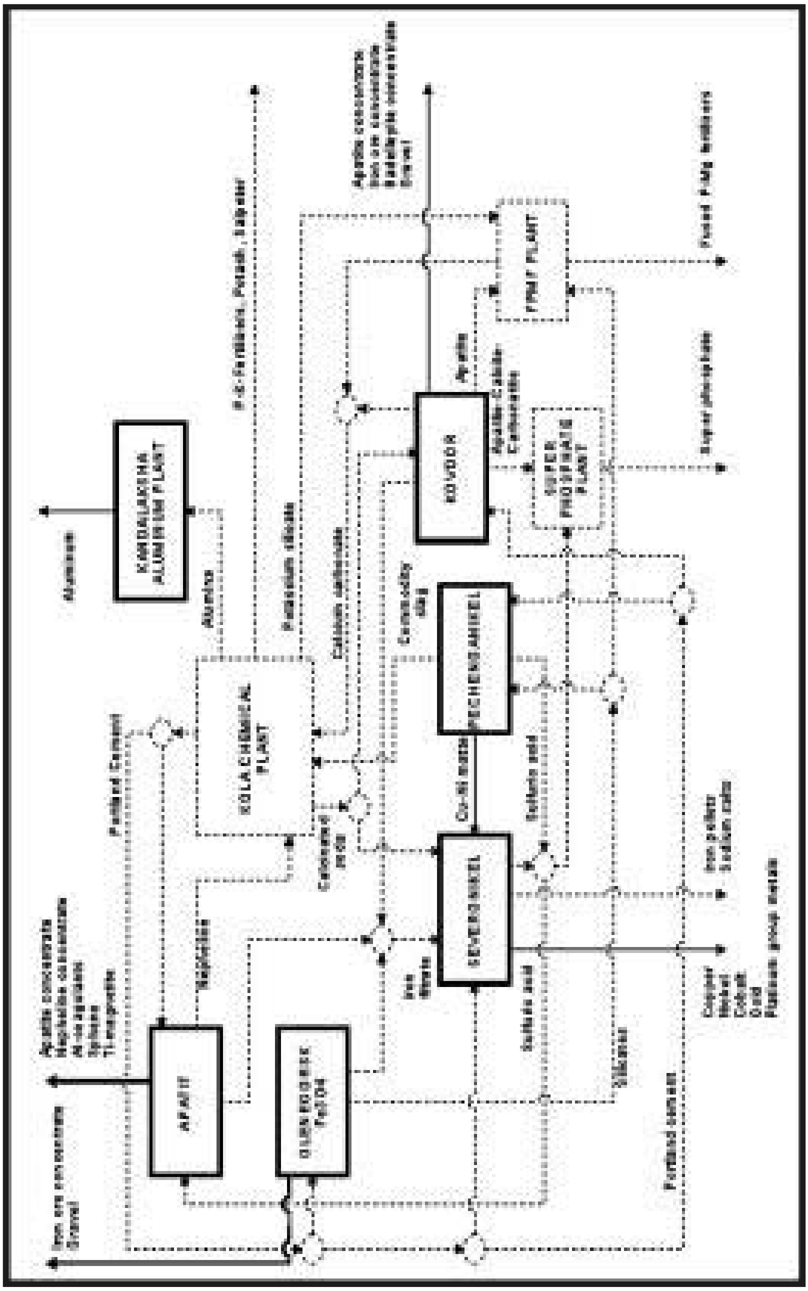

Figure 1 The complex utilization (CU) of mining and minerals processing in the Kola Peninsula. Operational plants (shown as rectangles) and material flows as of 2005 are drawn with solid lines; modeled plants and material flows (Luzin et al. 1988) are drawn with dashed lines. Acquired from Salmi (2006).

will be on the mechanisms of the externalizing politics of IE and CU, by which we mean efforts to advocate and embed the scientific-technical content in the society. In other words, we are interested in how IE and CU are made into resilient scientific-political boundary objects and marketed to the larger political world. Being scientific-political means that a scientific concept becomes politically or societally embedded by gaining a significant status in planning, design and regulation, or industrial practice and development. Being a boundary object, in turn, means that the concept is able to maintain a certain integrity or core content while being flexible enough to be scientifically or politically meaningful for different actors. Although focusing on externalizing politics, our empirical analysis will indicate an interconnection between the two aspects of politics. A detailed examination of this relation falls outside the scope of this article, but we will briefly take up the issue in the conclusion.

The concern about problems in political embedding is highly prevalent among IE scholars. Despite some occasional interest and practical attempts, the local applications of IE have seldom become success stories; clearly the principles of IE are not pervasively guiding decision-making and real industrial production on larger scales. As has been pointed out, the institutionalization of IE has been far more modest in the sectors of industry and government than in the academy. Without expanding its legitimacy to those areas, IE will not have much effect on the reality of everyday activities (Ehrenfeld 2004). In a similar vein, the problems in political embedding have been addressed by Cohen and Howard (2006). They identify the core challenge of "cultivating a viable clientele" for IE among entrepreneurs and political actors (Cohen and Howard 2006).

The actual prerequisites, problems, and mechanisms of political embedding have, however, received little empirical attention in the IE literature. One recent example is Anne Hewes's ethnographic study of the role of two consulting champions in establishing eco-industrial parks, indicating that it is social rather than technological connections that are fundamental to IE (Hewes 2005). O'Rourke has analyzed NGO market campaigns and called for a better translation of IE tools to make them useful for NGOs and consumers (O'Rourke 2005). Furthermore, others have argued that in order to be successful, IE has to demonstrate its superiority in terms of both business and environmental results (Cohen-Rosenthal 2000; Ehrenfeld and Gertler 1997), become attached to societal needs (Cohen and Howard 2006), translate its message to business and policy actors, and be sensitive to local contexts (Andrews 1999). Differences in culture, regulatory environment and other institutions have been identified as important factors affecting the realization of industrial ecosystems (Ehrenfeld and Gertler 1997).

Put bluntly, the aforementioned studies suggest that context matters. We want to go one step further, however, by adding that not even the central dimensions of IE—efficiency, profitability, and environment—are given and fixed but rather are culturally constructed. We will contribute to the debate on the social scientific side of IE by examining the necessary properties of translations in political embedding, in particular as regards overcoming contextual delimitations. For this purpose, we exploit the strength of CU as a single case with great variation in context. The long history of CU and of its proponents' efforts to make it a scientific-political boundary object in changing political contexts offers a rich empirical case.

Methods and Empirical Findings

Background: Frame Analysis

In this section, we analyze the translation efforts of CU's proponents through frame analysis, which is a method of addressing the construction of reality and meaning in sense-making and communication processes (Fisher 1997; Benford and Snow 2000). Frames can be understood as interpretative schemes that people use to make sense of the world (Fisher 1997). Framing an event or issue in a certain way highlights selected aspects, thus constructing meaning and suggesting guidelines for action. In other words, frames define problems, diagnose causes, make moral judgments, and suggest remedies (Entman 1993). The potential communicative success of a given frame depends on how well it resonates with the audience or recipient that is to be mobilized behind the framed idea. Better resonance, in turn, can be sought through frame alignment, which implies strategically designing frames to invigorate existing values or narratives, to encompass concerns of potential adherents, or to change the prevailing understanding of a particular issue (Snow et al. 1986; Benford and Snow 2000).

We acknowledge that even a careful construction of the scientific-technical solutions and alignment of the rhetorical frames cannot guarantee acceptance and success for the models of CU or IE. The examined processes of framing are thus not always a sufficient condition for implementation. Nevertheless, they are a necessary part of building legitimacy for the models and even for the scientific community itself (Suchman 1995). The most essential lesson of the story of CU for IE will be to indicate and explain the nature of framing as a delicate contextual activity. Framing science for external politics is undoubtedly a natural albeit hidden part of the work of most scientific communities and individuals. We therefore believe that the political embedding of IE could profit from IE's proponents being more conscious about the strategies of promotion, which often remain tacit. Even the actual contents of the identified CU frames will have relevance for the later comparative discussion of CU and the case of Kalundborg.

The Case Study: Frames of CU in the Kola Peninsula

The key actors related to CU in the past 75 years have been from science, industry, and regional government. The 1930s marked the beginning of the industrial exploration of the Kola Peninsula. During the previous three decades, Soviet and foreign geologists had unveiled significant ore deposits of mica, apatite–nepheline, iron, copper, and nickel in the region. By 1970, the region's mining industry had grown to consist of seven major and several smaller mining and processing centers. Prior to the Second World War, the development of the ice-free Murmansk shoreline for civil and military maritime traffic was begun and the city of Murmansk became the administrative center of the region. To support the development of the mining industry in the region, the USSR Academy of Sciences founded the Khibiny Mountain Station (later to be renamed the Kola Science Center, or KSC) in Kirovsk for mining-related research. Due to the remoteness of the region, the scientific-political elite of the Kola Peninsula bears a tradition of strong devotion to commonly shared goals. It has not been atypical for a person with a higher education to have a career path consisting of consecutive employment in industry, the KSC, and the Murmansk regional government. Thus, many experts in the region have a personal employment history that ties together the political, scientific, and technical aspects of CU.

The heterogeneous group of the *CU's proponents* was studied through an analysis of three series of semistructured interviews and the group's journal and newspaper publications. The CU's proponents are political, scientific, and industrial actors who take part in the promotion of CU. In order to learn about the significance of CU in both recent and earlier history, 44 semistructured interviews with representatives of the Kola Science Center, the city of Apatity, the Murmansk regional government, and the four major mining and processing businesses of the Kola Peninsula were carried out. The interviewees were chosen by the snowballing method, in which each interviewee was asked to give the names of additional people to be interviewed on the environmental situation in the Kola Peninsula. Three rounds of interviews were held, in 2002, 2003, and 2004, and conducted either directly, in English, or with the help of an English–Russian translator.[2]

In our frame analysis, the interview and literature data were screened for arguments as to why the implementation of CU in the Kola Peninsula would be of importance. The phrase *complex utilization* was sought from the interview transcriptions and texts written by the CU's proponents. This key-words-in-context analysis method (see, e.g., Ryan and Bernard 2000) was used with the help of Atlas.ti qualitative research software. After the initial keyword search, quotations including normative statements of why complex utilization should be implemented were extracted from the text. The quotations, which consist of consecutive sentences and are up to 233 words in length, are the units of analysis for the empirical study. A total of 55 documents and

113 quotations were used in the analysis. Quotations with similar arguments for complex utilization were coded with the Atlas.ti program and sorted into five groups. The groups—nature, science, economy, efficiency, and self-sufficiency—represent the frames of CU. As regards the reflexivity of our research approach, the frames that we present in this study are generalized constructs of how we perceive the ways in which the subjects of our study communicated their convictions in their interviews and publications. Although we cannot avoid the possibility of misunderstanding and misinterpreting the frames communicated by our interviewees, we have tried to ensure credibility through gathering an ample amount of data and letting the interviewees comment on the article manuscript.

The arguments within each frame present the more detailed political rationale for CU. In order to assess how the content of the frames has changed throughout the history of the Kola Peninsula mining industry, our five frames were sorted into three temporal categories: from the 1920s to the 1940s; from the mid-1970s to the early 1990s; and from the early 1990s to the mid-2000s. The first period, the 1920s to the 1940s, was the era of the initiation of CU. This is when the industry in the region was created and, also, when there was great excitement over the idea of CU. It is apparent from the interviews and literature sources that the development of CU stopped at World War II and was suspended until the early 1970s. This explains the gap between the 1940s and the 1970s. The second period, the 1970s to the 1990s, is when the CU plan was revived and when it was available to be recognized and accepted by the highest-level decision making in the Soviet Union. Finally, the third time period has a special character as the "post-Soviet era."

In table 1, an overview of the framing process from the 1920s to the 2000s is presented. Depending on the emphasis on the data, table 1 can be read in two ways. The columns craft a picture of CU as a composition of the five different frames at a given time. In particular, the columns reflect the thoughts of the central CU's proponents. In the first time period, the frames reflect strongly the writings of A. E. Fersman, a leading developer of the Kola Peninsula's industries, and the founder of the KSC. In the second period, the frames are based on a set of scientific and newspaper articles by politicians and scientists in the Kola Peninsula and in Moscow. Finally, the third period represents both articles written by the scientists in the Kola Peninsula and the interviews with the KSC managers. The rows, in turn, show rhetorical *changes* in the political rationale behind the CU model within each frame. They also indicate salient changes in the scientific-technical contents of the proposed model through time. Thus they reveal an intimate interplay between the externalizing and internalizing politics of CU. In the following subsections, we introduce the frames in more detail.

Nature

In the frame of nature, a fundamental change has occurred in the way in which nature relates to industry. At the beginning, between the 1920s and 1940s, CU was seen as the key scientific method by which the natural environment was to be "conquered." A. E. Fersman saw that the primary task of science, economy, and culture was to overcome the natural environment of the Kola Peninsula (Fersman 1931, 9). The argument that nature was to adapt to industrial practices persisted into the late 1970s, when the Soviet government was ready to acknowledge that the fact that industrial practices destroy nature is a problem to be addressed. The first shift in the frame of nature implied that rather than helping industry to take over nature, CU would allow the coexistence of nature and industrial production, if designed carefully. A leading economist of the KSC, N. G. Peshev, noted that with the production model depicted in figure 1, the environmental impacts of mining would be reduced, whereas production capacity could be increased (Peshev 1985). A second shift in the frame of nature occurred at the collapse of the Soviet Union. Production volumes of the mining companies in the Kola Peninsula fell by as much as 68% between 1991 and 1994 (Salmi 2006). Reductions in production volumes, together with improved environmental technologies, allowed the level of environmental degradation in the Kola Peninsula to cease growing for the first time in 70 years. Currently, CU's proponents believe that

Table 1 The framing of complex utilization (CU)

Frame	Time period 1920s to 1940s	Mid-1970s to early 1990s	Early 1990s to mid-2000s
Nature	(7) CU allows industry to take over nature	(8) CU allows industry to protect nature	(4) New technological innovations in CU need to be adapted to nature
Science	(6) CU as pure natural science can best benefit society	(5) CU as trans-disciplinary natural science has greatest potential for societal benefits	(5) Science for CU should focus on the acquisition of strategic minerals
Economy	(4) Development of national economy requires centralized CU	(11) Losses to national economy from wasting raw materials need to be reversed with centralized CU	(16) The regional economy can be revitalized with decentralized solutions of CU, combining private and public actors
Efficiency	(5) CU yields a maximum output of valuable products with minimum inputs of labor and mineral resources	(10) CU as diversification and specialization of production helps against inefficiencies caused by diminishing ore quality	(11) CU can yield competitive products due to high, environmentally sound input-output efficiency
Self-sufficiency	(6) CU turns the country from an importer to an exporter of mineral commodities	(5) CU eliminates the need to import minerals	(10) CU secures the domestic production of military-strategic minerals

Note: The table summarizes the key rationale for each frame in a given time period. The columns give a snapshot of CU at a certain time, whereas the rows indicate the intertwined changes in the political and the scientific-technical contents of CU from one time period to the next. Each cell contains the number of quotations used in our interpretation of a frame at a given time. The total number of quotations is 113. The quotations were extracted from the 24 documents (55 in total) in which CU was mentioned. These 24 documents were consulted for each cell in a given column.

although CU no longer is needed to curb the emissions from main production, the utilization of the old mining wastes may well become profitable. It has been maintained in the frame of nature, however, that industry also needs to protect nature from emissions. As interviewees from the KSC noted, CU would in fact force the privatized industries into more careful environmental protection—not because of the large waste volumes, as was the case in the 1980s, but because of the new types of pollution that accompany new production innovations (Interview 1, Interview 12). This highlights the transition into an argument that industry should adapt to nature. In summary, the frame of nature has experienced a transition, first from the exploitation of nature to nature protection and second, from nature protection to adaptation.

Science

The core function of CU is to serve the mining and processing industry. That is why the science for CU has a strong applied characteristic and the proponents have repeatedly emphasized CU as a link between science and society. Changes in this frame have occurred when CU's proponents have redefined research objectives according to changing societal preferences. To Fersman, CU represented the way in which pure natural science would benefit society. He stressed the importance of pure science as opposed to political rhetoric and covert conventions, which had characterized the science of czarist Russia (Fersman 1931, 42; 1944, 4). But CU's proponents soon discovered that the ways in which the Soviet government separated one line of scientific research from another were so powerful that arguments for "pure natural science" in fact prevented CU from being implemented. That is, each research department in the KSC was allowed to focus only on the problems involved in processing a specific kind of mineral. Thus, as the directors of the KSC noted, the new CU of the 1980s would emphasize science that crossed disciplinary boundaries (Kalinnikov and Zaharov 1985). Although the science for CU peaked in the late 1980s, the research potential of the KSC has remained high. New objectives for scientific work have been found in the interlinked emerging oil and gas business and the extraction of strategic minerals from the Peninsula's eastern parts. In particular, the strategic minerals have gained interest among CU's proponents: the KSC managers have recently suggested that the Russian government, the KSC, and private mining industries should build a Kola Mining and Chemical Corporation, an integrated mining works identical to the one depicted in figure 1. It is claimed that in order for the state to secure its supply of wartime strategic minerals, it should take an active role and fully finance the Kola Mining and Chemical Corporation (Vinogradov et al. 2003). That is, although research on the CU of all mineral resources is considered old-fashioned, research on the strategic resources is seen as a way to reutilize the scientific potential of the KSC.

Economy

Suffice it to say that the frame of the economy has throughout the study period been strongly bound to the economic structure of Russia. In the planned economy of the Soviet Union, a centralized, tightly coupled CU was in favor. After economic liberalization, CU was framed as a contribution to site-specific innovations in private mining companies. But arguments for the first, centralized model of CU have undergone changes as well. First, in 1944, Fersman proposed that the entire Soviet economy should be based on technologies that secure the "utilization of all wastes and the smallest quantities of foreign substances" (Fersman 1944, 51). Second, in 1985, as the mining industries had failed to implement Fersman's proposition, the CU's proponents focused attention on the forgone economic benefits that the lack of CU had caused. According to two Moscow-based scientists, by not utilizing wastes as Fersman had suggested, the nation now suffered from "inconsiderate economic inefficiency" and would continue suffering considerable economic losses if CU were not implemented (Zavronkov and Sorin 1985). Finally, a second shift in the frame occurred with the downfall of the Soviet Union as it became difficult to argue for the overall profitability of a centralized CU. Instead, the proponents today highlight the economic benefits of plant-level processing of tailings into specialized products. Recently, a group of renowned KSC scientists noted that currently "only 3–4% of mining wastes are used in industry to produce competitive and marketable products of high quality" (Fedorov et al. 2003). In addition, the proponents have noted that the current Russian energy policy favors exploitation of virgin ore rather than utilizing old wastes. Alumina production from nepheline, an abundant mineral waste in the Kola Peninsula, is claimed to be inferior to alumina production from bauxite only because of the below-market price of energy (Interview 13).

Efficiency

In the frame of efficiency, changes over time have been less clear than in the three previous frames. Both ore depletion and changing political regimes, however, have had their impact on the perception of efficiency. At first, between 1930 and 1940, the efficiency of CU was argued for in terms of maximizing the value of overall production against invested effort—the "worker's toil" in Fersman's vocabulary—and expended raw materials (Fersman 1944, 51). Although this common expression of input–output efficiency has remained in the rhetoric of the CU's proponents until today, concern with the depleted ore body emerged as a strong argument for the efficiency frame in the 1980s. The declining ore concentrations, the increasing mine depth and amount of gangue, and the increasing specific weight of the ore resulted in decreasing input–output efficiency. Thus, the main architects of CU in the KSC argued for diversification of the product range in the region as well as for further specialization of production (Luzin et al. 1988). Today, ore quality remains a central problem of the mining industry in the Kola Peninsula, and CU continues to be framed in terms of input–output efficiency. Among the contemporary arguments and tools are competitiveness, environmental safety, and process design for waste reuse (Fedorov et al. 2003).

Self-Sufficiency

Given the closed nature of the planned economy and the history of heavy armament in the Soviet Union, it is not surprising that CU as well has been linked to issues of self-sufficiency. Just like many of the other frames, self-sufficiency has undergone changes hand in hand with the changes in political regime. In the 1930s and 1940s, Fersman wrote detailed descriptions on how the CU would turn the country from a mineral importer into an exporter. This would apply not only for the primary minerals nickel, apatite, and rare earth metals, but also for the by-products of these: potash, alumina, and soda (Fersman 1931, 1944). In addition, Fersman linked the nickel and cobalt deposits of the Kola Peninsula directly to the need to strengthen national defense (Fersman 1944, 45). In a similar vein, CU's proponents of the 1980s resorted to the dilemma that the country spent foreign currency on importing mineral commodities when the same commodities could be produced domestically from waste (Zavronkov and Sorin 1985). Perhaps the most surprising change has occurred during the 2000s when CU, once again, has been argued for in terms of national security by the KSC management. It is understood that a centralized technological structure, similar to that depicted in figure 1, would be possible if the state took action on its plans to secure the supply of strategic materials. The top management of the KSC has claimed that the technological and defense safety of Russia depends on these minerals. Cooperation of private and state interests has been called for in order to arrange the extraction and processing (Vinogradov et al. 2003).

Concluding Themes

The analysis shows two distinctive results as regards the characteristics of the frames. First, it becomes clear that the development of CU has followed the general political development of Russia. A society that is designed on command and control may arrive at very different solutions for environmental policy and planning than a society that exhibits democratic structures. Thus, although the fundamental metaphor of CU has remained rather unaltered throughout the transitions in governance structures in Russia, each frame exhibits a distinctive style that can be traced to the social order in a given time period. Second, and related to the previous notion on social order, the significance of some frames over others appears to have changed over time. In table 1, the number of similar quotations for a given frame in a given time may be used as a coarse indicator of frame significance. Between the 1920s and the 1940s, there appears to be little difference in the number of different quotations. Between the mid-1970s and the early 1990s, however, the frames of self-sufficiency and science appear less significant in comparison to the efficiency and economy frames. In particular, reduced numbers of quotations relating to self-sufficiency may be explained by the general decline in protectionist and militaristic undertones in Soviet society during the politics of détente. From the mid-1990s on, however, the strengthened militaristic undertone in Russian politics has offered possibilities for framing CU in terms of self-sufficiency in military-strategic minerals. Moreover, the frames of economy and efficiency continue to be particularly strong, whereas the arguments of CU for nature and science have been less visible.

As will become clear in the following section, the frames of economy, efficiency and nature are familiar from the IE literature as well. The frames of self-sufficiency and science, with their central roles in the development of CU, in turn, appear more specific to the case. That is, it would seem odd if eco-industrial parks in the Western world were framed as sources of seclusion and nationalistic interests. The results imply that some of the frames are popular under very different social orders whereas others are altogether more bound to specific contexts. In order to take a closer look into these issues, we proceed with a comparison between the frames of CU in the Kola Peninsula and those of IE in Kalundborg.

Empirical Findings in Comparison: Frames of Kalundborg

The well-known interindustrial recycling structures in the Danish city of Kalundborg have developed gradually since the beginning of the 1970s without a grand design (Ehrenfeld and Gertler 1997). Ever since the discovery of this industrial symbiosis in 1989, it has frequently been presented as the ultimate embodiment of IE, a model of how to design industrial systems to resemble natural ecosystems. The academic discourse inspired by Kalundborg has addressed many issues of relevance to the implementation of IE. One of these is the question of whether Kalundborg is unique as a naturally occurring network. Several historical and contemporary self-organized waste recycling networks have been reported (Desrochers 2002a, 2002b; Schwarz and Steininger 1997), but Kalundborg appears to be a rare case as regards its intensity of connections between different industries (Sterr and Ott 2004).

Another, and even more crucial, question is whether the Kalundborg model is replicable elsewhere through conscious planning and how this could be accomplished. The dilemma is that, on one hand, the model is considered promising with great general potential, but, on the other hand, it will be—and has already proven to be—extremely difficult to replicate through planning in both brownfield and greenfield developments (Gibbs and Deutz 2005; Mirata 2004; Ehrenfeld and Chertow 2001; Sterr and Ott 2004; Grann 1997). The challenges posed by contextual differences have not, however, in any way prevented scholars and practitioners from using Kalundborg as a model for implementing IE. The example of Kalundborg, therefore, allows us to explore the problems in politically embedding the general model of IE in different contexts.

A frame analysis of existing literature on the Kalundborg industrial symbiosis quickly converges toward six frames (table 2). The model of Kalundborg is said to improve *environmental* quality by reducing the amount of natural and human-made substances released into the biosphere and preserving the productivity of the earth (Grann 1997; Cosgriff Dunn and Steinemann 1998). It also yields *economic* benefits through savings from more rational and cost-effective use of resources, shared expenses, and elimination of wastes (Cosgriff Dunn and Steinemann 1998; Heeres et al. 2004; Ehrenfeld and Gertler 1997). *Efficiency*, too, is improved in the model's use of material and energy resources (Ehrenfeld and Gertler 1997; Cosgriff Dunn and Steinemann 1998; Lowe and Evans 1995; Brings Jacobsen 2006). Furthermore, to make good use of the politically topical catchword, the model will operationalize *sustainability* and sustainable communities in an economically feasible way (Erkman 1997; Cosgriff Dunn and Steinemann 1998). In the further promotion of industrial symbiosis, scholars and consultants alike emphasize the *mental proximity* between the actors in Kalundborg—a small and relatively isolated community where private and public decision makers interact frequently outside of office hours (Ehrenfeld and Gertler 1997; Pedersen 2006). In addition, it has been argued that favorable cultural features, such as environmental awareness and an atmosphere of trust (Schwarz and Steininger 1997), and the open and flexible Danish regulatory system (Ehrenfeld and Gertler 1997) have encouraged proactive measures and continue to do so in the future. We can summarize these features under *awareness* (table 2). All these frames together craft an image of the Kalundborg industrial symbiosis and enhance the search for and the establishment of pairings of positive economic and environmental factors in the form of material linkages (Ehrenfeld and Gertler 1997).

Table 2 The frames of CU and IE in comparison

Complex utilization	*Industrial ecology in Kalundborg*
Economy	Economy
Efficiency	Efficiency
Nature	Environment
	Sustainability
Self-sufficiency	
Science	
	Mental proximity
	Awareness

The frames in the right-hand column of table 2 represent the frames of IE as they have appeared in the case of Kalundborg. In other words, they are first and foremost the frames of one specific instantiation of the more general model of IE, which itself is detached from any particular circumstances. The presented frames should thus not be taken, by definition, as equal to IE's general frames, even though this distinction tends to be blurred in the literature. Rather, our critical account focuses on the feasibility and limits of using the frames of Kalundborg as universal IE frames regardless of context.

The comparison between the frames of CU and IE generates three overall observations. First, three common frames could be identified: economy, efficiency, and nature/environment. This result is not surprising, given the significant prescriptive similarities between the scientific models of IE and CU. Moreover, several frame analysts have pointed out that effective frames typically rely on shared and common-sense knowledge (Schreiber et al. 2003); generally accepted principles and norms (Triandafyllidou and Fotiou 1998); core human values (Menashe and Siegel 1998); or larger cultural themes (Gamson and Modigliani 1989). Efficiency, economic development, profitable use of natural resources, and a decent environment can be regarded as universal values and frames that are easily accepted and applicable across different contexts. In addition, sustainability has gained similar universality in the Western industrialized nations. In the Kola Peninsula, however, sustainability was not raised as a solution to environmental, economic, and social problems.

Second, we found that although frames such as nature/environment, efficiency, and economy seem to be universal, their actual meaning and significance in a certain time and place is an empirical question that requires attention. Thus, nature/environment as a common frame bears very different meanings in the Kola Peninsula and in Kalundborg. This emerges from the fact that there is no universally applicable perception of local environmental quality or problems. Therefore, environmental indicators such as eco-efficiency frequently fail due to their universalistic assumptions about human–environment interaction (Hukkinen 2003). The long time perspective in the CU case reveals that the recognition and evolution of environmental concerns has not always been in any direct relation to observable ecological degradation. That is, the nature-based arguments for CU have evolved from exploitative to protective and from protective to adaptive. What is more, the environmental implications of efficiency in Kalundborg and in the Kola Peninsula are very different, even though the frame of efficiency is clearly a central one for both CU and IE. When the industrial system in the Kola Peninsula was at its peak efficiency in the early 1990s, it at the same time had the most destructive implications on the ecosystems. In Kalundborg, in contrast, efficiency has typically been linked to absolute indicators of environmental impacts (Grann 1997; Chertow 2000). As regards the frame of economy, profitability considerations have not been straightforward in Kalundborg, although the role of cost calculations in the creation of waste exchanges has been emphasized (Schwarz and Steininger 1997; Ehrenfeld and Gertler 1997). A recent analysis of Kalundborg has suggested that short-term economic considerations have been supplemented by more indirect and uncertain benefits. Therefore, a more sophisticated explanation has been called for that takes into account the variety of levels and perspectives as well as the minor and long-term environmental benefits and operational strategies (Brings Jacobsen 2006).

Finally, our second observation further clarifies the characteristics of contextuality. In addition to the three common frames, the comparison also reveals frames that are specific to each case. Science and self-sufficiency had great importance in Soviet society, largely because of both the political system and the special industrial-strategic properties of remote regions such as the Kola Peninsula. Mental proximity and awareness, in turn, have been argued for as factors that both promote IE in Kalundborg (Pedersen 2006; Schwarz and Steininger 1997) and might delimit its implementation elsewhere (Sterr and Ott 2004). This part of our findings suggests that in addition to the most general and obvious frames of IE, previously unknown but highly relevant frames are likely to be found also in different settings. For successful political embedding, therefore, sensitivity toward context-specific possibilities for framing is needed in addition to the careful contextualization of the key universal frames.

Conclusions

The aim of this article was to better understand the political embedding of IE and, more specifically, the dilemma of overcoming contextuality in using universal models of natural resource use. The article therefore contributes to the discussion of contextual limitations in marketing IE to formal policy communities. Throughout the text, we have used the concept of CU as a point of reference for IE. Although these two concepts emerge from very different cultural and political contexts, they are at the same time analogous in their being based on natural metaphors, implying similar prescriptions, and facing comparable challenges in science–policy interaction. We were thus able to use the case of CU to point out some general mechanisms of political embedding and issues of contextuality and, furthermore, to extend these insights into a discussion of IE. We started from the understanding that scientific-technical models need to be translated and justified by their proponents in order to become politically meaningful and acceptable. We used frame analysis as a method for revealing the rhetorical aspects of promotional strategies and for delineating between the generalized models and their particular contexts of application. Both general and case-specific frames were identified for CU and IE from the industrial systems of the Kola Peninsula and Kalundborg. We conclude that effective political embedding relies on frames that function both on the general level and in the specific context. Frames of the general level, such as efficiency, economy and environment, however, need to be aligned with localized perceptions of the particular issues as well. What is more, context matters in the relationships between different frames. On one hand, partly or completely different sets of frames are relevant in different locations. On the other hand, the emphasis among the different frames in the same location varies through time.

Given the limits of generalization, how is a practitioner to make the jump from a general model of IE to the specific context? We propose that a contextual adjustment or alignment of the general frames extracted from Kalundborg, for instance, is a necessary step. We therefore contend that in addition to each case-specific scientific-technical solution and plan, the proposed model needs to be made politically relevant to the people whose businesses or problems it is to perfect or resolve [see also Cohen-Rosenthal (2000, 253)]. Some frames may appear universal, but their particular meaning and significance is always an empirical question that requires attention. It is the time- and space-dependent arguments—specific to any case in IE—that render these frames meaningful to a variety of actors. The change that IE and CU represent must respond to novel—or enduring but redefined—needs that emerge from local or regional history and the prevailing political situation. Therefore, not only the most obvious frames but also the more subtle frames, such as self-sufficiency in the Kola Peninsula or mental proximity in Kalundborg, need to be accounted for. It seems plausible to believe that in every single new project of IE implementation, some new particular concerns, topics and specifications can be found, which even the successful and generalized model of Kalundborg cannot indicate. Finding the right frames in the right time and place is crucial for a successful political embedding and implementation of IE.

The article leaves for further research the detailed examination of how the externalizing and internalizing politics of IE mutually influence each other. We have given limited attention to how the scientific-technical models of IE are themselves shaped by political processes. Although we have focused principally on the externalizing political rhetoric of CU's proponents, our study does indicate that the political processes of framing and timely updates in frame alignment have influenced the promoted technical models as well. Some signs of this close interplay between the externalizing and internalizing politics of CU can be read in table 1. As the social order and ideas of natural resource use changed in the Kola Peninsula, so did the style of the technical solution of CU. For instance, the attempts to align CU with the prevailing perception of nature in the 1980s resulted in solutions that would enable industry to protect nature rather than exploit it. Another clear example of modification is the shift in emphasis from centralized to decentralized models of CU in accordance with external political processes and changing prospects of implementation. This suggests that the scientific-technical models of CU are subject to reflexivity (Giddens 1990), which requires the models to allow for framing-induced change. Similar conditions hold for IE. It has been claimed, for example, that the freedom for the symbiosis participants to choose projects on the grass-roots level is a prerequisite for successful implementation of IE (Pedersen 2006). In this respect, analytic deliberation (Dietz et al. 2003) may offer a way of managing IE by enabling effective sharing of knowledge between scientists, IE practitioners, and other stakeholder groups [for recent research on knowledge integration for ecodesign, see Tatum (2004) and Howard (2004)].

Finally, unfolding the mechanisms of political embedding through a focus on framing raises further topics for consideration. An enhanced awareness of framing strategies can shed light on how to cope with the trade-off between short-term economic benefits and long-term sustainability requirements (Mirata 2004), or between easily acceptable "political innocuousness" and IE's original revolutionary aims (Cohen and Howard 2006). On one hand, the results of our study are disturbing, as they confirm that revolutionary ideas must speak to already existing values and interests in order to be accepted. On the other hand, they give hope that skillful framing can build the needed bridge between familiarity and novelty and, finally, make a noticeable difference.

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Notes

1. We would like to acknowledge one of the anonymous reviewers for contributing with this observation.
2. Both authors are fluent in English and one of us has a limited command of Russian. The original Russian texts referred to in this article have been translated into either English or Finnish by professional translators. The translations have been double-checked by one of the authors. The references to specific pages have been made to the original Russian publications.

References

Åkerman, M. 2003. What does "natural capital" do? The role of metaphor in economic understanding of the environment. *Environmental Values* 12(4): 431–448.

Allenby, B. R. 1999. *Industrial ecology: Policy framework and implementation*. Upper Saddle River, NJ: Prentice–Hall.

Allender-Hagedorn, S. 2001. Arguing the genome: A topology of the argumentation behind the construction of the human genome project. Ph.D. thesis, Science and Technology Studies, Virginia Polytechnic Institute and State University, Blacksburg.

Andrews, C. J. 1999. Putting industrial ecology into place: Evolving roles for planners. *Journal of the American Planning Association* 65(4): 364–375.

Benford, R. D. and D. A. Snow. 2000. Framing processes and social movements: An overview and assessment. *Annual Review of Sociology* 26: 611–639.

Boons, F. and N. Roome. 2001. Industrial ecology as a cultural phenomenon. *Journal of Industrial Ecology* 4(2): 49–54.

Bowker, G. C. and S. L. Star. 2000. *Sorting things out: Classification and its consequences*. Cambridge, MA: MIT Press.

Boyd, R. 2002. Metaphor and theory change: What is "metaphor" a metaphor for? In *Metaphor and thought*. Second edition, edited by A. Ortony. Cambridge, UK: Cambridge University Press.

Brings Jacobsen, N. 2006. Industrial symbiosis in Kalundborg, Denmark: A quantitative assessment of economic and environmental aspects. *Journal of Industrial Ecology* 10(1–2): 239–255.

Brown, T. L. 2003. *Making truth: Metaphor in science*. Urbana, IL: University of Illinois Press.

Callon, M. 1997. Four models for the dynamics of science. In *Science and the quest for reality*, edited by A. I. Tauber. Houndmills, UK: MacMillan Press.

Chertow, M. R. 2000. Industrial symbiosis: Literature and taxonomy. *Annual Review of Energy and Environment* 25: 313–337.

Cohen, M. J. and J. Howard. 2006. Success and its price: The institutionalization and political relevance of industrial ecology. *Journal of Industrial Ecology* 10(1–2): 79–88.

Cohen-Rosenthal, E. 2000. A walk on the human side of industrial ecology. *The American Behavioral Scientist* 44(2): 245–264.

Commoner, B. 1997. The relation between industrial and ecological systems. *Journal of Cleaner Production* 5(1–2): 125–129.

Cosgriff Dunn, B. and A. Steinemann. 1998. Industrial ecology for sustainable communities. *Journal of Environmental Planning and Management* 41(6): 661–672.

Desrochers, P. 2002a. Cities and industrial symbiosis: Some historical perspectives and policy implications. *Journal of Industrial Ecology* 5(4): 29–44.

Desrochers, P. 2002b. Regional development and inter-industry recycling linkages: Some historical perspectives. *Entrepreneurship & Regional Development* 14(1): 49–65.

Dietz, T., E. Ostrom, and P. C. Stern. 2003. The struggle to govern the commons. *Science* 302(5652): 1907–1912.

Ehrenfeld, J. 2004. Industrial ecology: A new field or only a metaphor? *Journal of Cleaner Production* 12(8–10): 825–831.

Ehrenfeld, J. and N. Gertler. 1997. Industrial ecology in practice: The evolution of interdependence at Kalundborg. *Journal of Industrial Ecology* 1(1): 67–79.

Ehrenfeld, J. R. and M. R. Chertow. 2001. Industrial symbiosis: The legacy of Kalundborg. In *A handbook of industrial ecology*, edited by R. U. Ayres and L. W. Ayres. Cheltenham, UK: Edward Elgar Publishing.

Entman, R. M. 1993. Framing: Toward clarification of a fractured paradigm. *Journal of Communication* 43(4): 51–58.

Erkman, S. 1997. Industrial ecology: An historical view. *Journal of Cleaner Production* 5(1–2): 1–10.

Fedorov, S. G., A. I. Nikolaev, Y. E. Brylyakov, L. G. Gerasimova, and N. Y. A. Vasileva. 2003. *Chemical processing of mineral concentrates of the Kola Peninsula*. Apatity: Russian Academy of Sciences.

Fersman, A. E. 1931. *Neuvostoliiton uusi teollisuuskeskus napapiirin tuolla puolen* [The new Soviet industrial estate beyond the polar circle]. Leningrad, USSR: Kirjapaja.

Fersman, A. E. 1944. *Twenty-five years of Soviet natural science*. Moscow, USSR: Foreign Languages Publishing House.

Fisher, K. 1997. Locating frames in the discursive universe. *Sociological Research Online* 2(3). <www.socresonline.org.uk/2/3/4.html>. Accessed 23 March 2005.

Frosch, R. A. and N. E. Gallopoulos. 1989. Strategies for manufacturing. *Scientific American* 261(3): 144–152.

Fujimura, J. H. 1992. Crafting science: Standardised packages, boundary objects, and "translation." In *Science as practice and culture*, edited by A. Pickering. Chicago: The University of Chicago Press.

Gamson, W. A. and A. Modigliani. 1989. Media discourse and public opinion on nuclear power: A constructionist approach. *The American Journal of Sociology* 95(1): 1–37.

Gentner, D. and P. Wolff. 2000. Metaphor and knowledge change. In *Cognitive dynamics: Conceptual and representational change in humans and machines*, edited by E. Dietrich and A. B. Markman. Mahwah, NJ: Lawrence Erlbaum Associates.

Gibbs, D. and P. Deutz. 2005. Implementing industrial ecology? Planning for eco-industrial parks in the USA. *Geoforum* 36(4): 452–464.

Giddens, A. 1990. *The consequences of modernity*. Stanford, CA: Stanford University Press.

Grann, H. 1997. The industrial symbiosis at Kalundborg, Denmark. In *The industrial green game. Implications for environmental design and management*, edited by D. J. Richards. Washington, DC: National Academy Press.

Heeres, R. R., W. J. V. Vermeulen, and F. B. de Walle. 2004. Eco-industrial park initiatives in the USA and the Netherlands: First lessons. *Journal of Cleaner Production* 12(8–10): 985–995.

Hellsten, I. 2002. *The politics of metaphor: Biotechnology and biodiversity in the media*. Acta Universitatis Tamperensis 876. Tampere: Tampere University Press.

Hewes, A. K. 2005. The role of champions in establishing eco industrial parks. Ph.D. thesis, Antioch New England Graduate School, Keene.

Holyoak, K. J. and P. Thagard. 1999. *Mental leaps: Analogy in creative thought*. Cambridge, MA: MIT Press.

Howard, J. 2004. Toward participatory ecological design of technological systems. *Design Issues* 20(3): 40–53.

Hukkinen, J. 2003. From groundless universalism to grounded generalism: Improving ecological economic indicators of human–environmental interaction. *Ecological Economics* 44(1): 11–27.

Isenmann, R. 2003. Further efforts to clarify industrial ecology's hidden philosophy of nature. *Journal of Industrial Ecology* 6(3–4): 27–48.

Johansson, A. 2002. Industrial ecology and industrial metabolism: Use and misuse of metaphors. In *A handbook of industrial ecology*, edited by R. U. Ayres and L. W. Ayres. Cheltenham, UK: Edward Elgar.

Kalinnikov, V. T. and V. Zaharov. 1985. Bogatstvam Khibina—Kompleksnoe ispolzovanie [Complex utilization of the Chibiny Wealth]. *Polyarnaya Pravda* (Murmansk), 21 June, section I.

Kanfer, A. G., C. Haythornthwaite, B. C. Bruce, G. C. Bowker, N. C. Burbules, J. F. Porac, and J. Wade. 2000. Modeling distributed knowledge processes in next generation multidisciplinary alliances. *Information Systems Frontiers* 2(3/4): 317–331.

Keulartz, J., M. Korthals, M. Schermer, and T. Swierstra. 2004. Pragmatism in progress: A reply to Radder, Colapietro and Pitt. *Techné: Journal of the Society for Philosophy and Technology* 7(3): 38–48.

Kuhn, T. S. 2002. Metaphor in science. In *Metaphor and thought*. Second edition, edited by A. Ortony. Cambridge, UK: Cambridge University Press.

Lifset, R. 2005. Industrial ecology and public policy. *Journal of Industrial Ecology* 9(3): 1–3.

Lowe, E. A. and L. K. Evans. 1995. Industrial ecology and industrial ecosystems. *Journal of Cleaner Production* 3(1–2): 47–53.

Löwy, I. 1992. The strength of loose concepts—boundary concepts, federative experimental strategies and disciplinary growth: The case of immunology. *History of Science* 30: 371–396.

Luzin, G. P., N. G. Peshev, B. Z. Milner, J. M. Abahov, A. M. Belolipetskij, N. M. Volosnikov, and G. M. Psarjov. 1988. *Osnovnye polozheniya kontseptsii sovershenstvovaniya upravleniya predpriyatiyami Kolskogo gornopromyschlennogo kompleksa (nauchno-metodicheskie rekomendatsii)* [Basic Conditions for the Consensus of Improving the Management of the Kola Mining Complex Enterprises (Scientific-Methodological Recommendations)]. Apatity, USSR: Soviet Union Academy of Sciences.

Menashe, C. L. and M. Siegel. 1998. The power of a frame: An analysis of newspaper coverage of tobacco issues—United States, 1985–1996. *Journal of Health Communication* 3(4): 307–325.

Mirata, M. 2004. Experiences from early stages of a national industrial symbiosis programme in the UK: Determinants and coordination challenges. *Journal of Cleaner Production* 12(8–10): 967–983.

O'Rourke, D. 2005. Market movements: Nongovernmental organization strategies to influence global production and consumption. *Journal of Industrial Ecology* 9(1–2): 115–128.

Pedersen, E. 2006. Industrial symbiosis, Kalundborg Region, Denmark. Paper presented at Eco-Industrial Parks and Industrial Symbiosis—Industrial Ecology in Practice, Rantasalmi, Finland, 14–15 March 2006.

Peshev, N. G. 1985. *Kompleksnoe ispolzovanie fosfatnogo cyrya Kolskoga poluostrova* [Complex utilization of phosphate raw materials of the Kola Peninsula]. Apatity, USSR: Soviet Union Academy of Sciences.

Roe, E. 1994. *Narrative policy analysis*. London: Duke University Press.

Ryan, G. W. and H. R. Bernard. 2000. Data management and analysis methods. In *Handbook of qualitative research*, edited by N. K. Denzin and Y. S. Lincoln. Thousand Oaks, CA: Sage Publications.

Salmi, O. 2006. Eco-efficiency and industrial symbiosis—A counterfactual analysis of a mining community. *Journal of Cleaner Production*. doi:10.1016/j.jclepro.2006.08.012.

Schreiber, D., R. Matthews, and B. Elliott. 2003. The framing of farmed fish: Product, efficiency, and technology. *Canadian Journal of Sociology* 28(2): 153–169.

Schwarz, E. J. and K. W. Steininger. 1997. Implementing nature's lesson: The industrial recycling network enhancing regional development. *Journal of Cleaner Production* 5(1–2): 47–56.

Snow, D. A., E. B. J. Rochford, S. K. Worden, and R. D. Benford. 1986. Frame alignment processes, micromobilization, and movement participation. *American Sociological Review* 51(4): 464–481.

Star, S. L. and J. R. Griesemer. 1989. Institutional ecology, "translations" and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907–39. *Social Studies of Science* 19: 387–420.

Sterr, T. and T. Ott. 2004. The industrial region as a promising unit for eco-industrial development—Reflections, practical experience and establishment of innovative instruments to support industrial ecology. *Journal of Cleaner Production* 12(8–10): 947–965.

Suchman, M. C. 1995. Managing legitimacy: Strategic and institutional approaches. *Academy of Management Review* 20(3): 571–610.

Tatum, J. S. 2004. The challenge of responsible design. *Design Issues* 20(3): 66–80.

Triandafyllidou, A. and A. Fotiou. 1998. Sustainability and modernity in the European Union: A frame theory approach to policy-making. *Sociological Research Online* 3(1). <www.socresonline.org.uk/3/1/2.html>. Accessed 17 March 2005.

Vinogradov, A. N., V. T. Kalinnikov, V. P. Petrov, V. S. Selin, and V. A. Tsukerman. 2003. Kolskaya gorno-promyshlennaya korporatsiya kak klyuchevoe zveno gosudarstvennoga rezerva strategicheskih materialov [Kola Mining Corporation as the key component of the government reserve of strategic materials]. In *Sever—2003: Problemy i resheniya [The north—2003: Problems and solutions]*, edited by V. T. Kalinnikov et al. Apatity, USSR: Kola Science Center, Russian Academy of Sciences.

Zavronkov, N. and L. Sorin. 1985. Milliardy v otvalah [Billions in tailings]. *Moskovskaya pravda* (Moscow), 29 August, section I.

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