DESIGNING ECOSYSTEMS: SYNERGIES AND TENSIONS BETWEEN ENVIRONMENTAL ENTHUSIASMS AND MATERIALITY

by

SARAH HUNT

(Under the Direction of Peter Brosius)

ABSTRACT

In examining a processes of environmental technology innovation this research investigated a particular processual idea, designing with ecosystems, and adopted a meso-level for investigating the socio-technological change processes. This project involved multi-sited ethnography which followed a diffuse array of actors through the spaces of their production of alternative technologies and new disciplines related to the idea of using ecosystems as a core element of design. The thesis is organized around an exploration of the histories and content of the two realms of Living Machines™ and Ecological Engineering, discussing the institutional, regulatory, capital and material constraints to their development. Drawing on the dual problematics laid out by first ecological modernization theory and secondly by David Hess's proposals on science and technology studies and social movements, the question of concern in this project was: What *are* the processes and means by which ecological ideas and technologies are becoming incorporated into mainstream practice? Answering this question for the development and adoption of designing with ecosystems aids in building the answer to how under ecological modernization, science and technology can develop or incorporate new socio-technical practices wherein environmental considerations are included at the earliest design stage. And similarly, the analysis of designing with ecosystems as technical and disciplinary practices that respectively have roots in the 70s environmental movement and strong social change values allows for a reevaluation of the distinction drawn between social movements and scientific practice. Thus, find congruence with the ideas of science movements this dissertation posits that it is out of the maintained interests, engagements, and actions of individuals that new alternative ecological technical and practices are developed and deployed into mainstream practice even in the face of structural and material constraints.

INDEX WORDS: science movements, social movements, ecological modernization, technology innovation, environmental movement, boundary work, engineering studies, anthropology of science and technology, ecological engineering, living machines

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DEDICATION

This dissertation is dedicated to the memory of

Dr. Frank Golley,

ecosystem scientist and mentor, whose wise words inspired me to move from the

Ecology Ph.D program to the Anthropology program at UGA.

And to

Dr. Todd Crane

Whose multiple forms of support throughout my life have made this dissertation possible.

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INTRODUCTION

> I don't know if you have had the same experience, but the snag I always come up against when I'm telling a story is this dashed difficult problem of where to begin it. It's a thing you don't want to go wrong over, because one false step and you're sunk. I mean to say, if you fool about too long at the start, trying to establish atmosphere, as they call it, and all that sort of rot, you fail to grip and the customers walk out on you. Get off the mark, on the other hand, like a scalded cat, and your public is at a loss. It simply raises its eyebrows, and can't make out what you're talking about…Right-ho, then. Let me marshal my facts (P.G. Wodehouse 1962, *Right Ho, Jeeves*).

The environment, ecology and environmentalism; renewable energy, compact fluorescent light bulbs, and climate change; carbon offsetting, highspeed rail lines, and green jobs. As some one who has had a long interest in environmental concerns, I have been feeling increasingly like Alice down the rabbit hole over the last number of years. The last decade seems to have consisted of a vast burgeoning of popular exploration of such ideas as green consumption, green building, sustainability, and renewable energy to name a few. Popular media seems saturated with tips on how to be a greener consumer[1] and newspapers dedicate whole sections to green business.[2] Large scale goods and services corporations flaunt their Eco-Magination℠[3], and car companies tout biofuels[4]

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[1] USA Weekend, August 19-21, 2005 "Green Living: We reveal the smartest steps you can take to "go green." It's never been easier to embrace an eco-friendly lifestyle."

[2]The New York Times, "The Business of Green." The earliest instance of this section found through a Goggle search is May 17, 2006. The publication on this date had many ancillary and linked commentaries on eco-blogs commenting on the new section, which supports the conclusion that May 2006 was the start of this new section. More concretely, the paper's 'Business of Green Blog, titled Green Inc, lists its inception date as March 23, 2007. http://greeninc.blogs.nytimes.com/2007/03/23/3/

[3] Branding campaign of G.E. One of the most iconic elements of this campaign was an ad that did not feature any particular electronic elements but rather simply portrayed a computer animated elephant dancing in a forest. In the May 16 2006 New York Times special section on Green Business an article on G.E. entitled "General Electric bolsters 'green' revenues" states that the Eco-magination brand was launched in 2005 and stated that revenues from the products gathered under that brand "rose from $6.2bn in 2004 to $10.1bn in 2005. The article also states "The increase in revenues seems to bear out chief executive

and global oil firms lay claim to alternative energy initiatives.[5] Even purported bastions of conservatism like The Washington Post[6] and Popular Mechanics[7] have something positive to say about 'green' initiatives. Beyond these growths of green consumerism, ecological ideas have increasing presence in political agendas as sustainability has moved from a counterculture back–to-the-land movement to an underlying principle in major international governmental agendas.[8] And similarly, in science and technology disciplines there are ecological up swellings in formation of new disciplinary practices such as green chemistry, green engineering, sustainability science, industrial ecology, ecological economics and ecological engineering.

This burgeoning instantiation of green or environmental ideas raises many questions for scholars of social movements and science and technology studies. In particular, a range of scholars in sociology of science and policy research address the questions of both how these technological transformations are occurring, as well as making prescriptive analysis of how to further expedite these transformations (Geels 2010; Mol, et al. 2009b; Morlacchi and Martin 2009; Peine 2008; Smith, et al. 2005; Smith, et al. 2010). Other scholars investigate the relations between these new technical

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Jeff Immelt's assertion a year ago that 'green is green.'" Accessed from http://listserver.njit.edu/pipermail/njheps/2006-May/000424.html

[4] GM ad campaign with the catch phrase 'Live Green and Go Yellow' One t.v. commercial featured a man standing in corn field saying "What if our dependence on oil was right here"

[5] BP, no longer stands for British Petroleum, but rather Beyond Petroleum. In one t.v. ad (March 1 2006) a spokesperson quizzed individuals about their carbonfoot print and showed people responding with confusion. The end text ran "Reduce your carbon footprint. First find out what it is www.bp.com/carbonfootprint"

[6] The Washington Post, Business Section D, Monday November 2007. The lead article of the section was titled "Can Green be Gold?"

[7] This is perhaps my favorite Alice moment. On the March 2008 Popular Mechanics cover the second headline was "Your Green Home: 16 Products and Projects." My excitement at seeing a 'green' element in Popular Mechanics was tempered by the lead story and cover photo. A large tank like object with a gun turret dominates and the lead story tag is "America's Robot Army: Next-gen fighting machines are smart, tough and armed to the treads."

[8] For example UN Agenda 21, initiated at the 1992 United Nations Conference on Environment and Development colloquially called the Earth Summit

practices and social movements; these scholars address questions about the existence and nature of 'science activism' or 'science movements' (Frickel 2006; Woodhouse and Breyman 2005), as well as addressing the more specific question of the relationship between current implementations of environmental practices and ecological technologies and the historic actions and goals of the environmental movement (Hess 2007a; Jamison 2001; Smith 2005). Through an investigation of the development of the practice and discipline of designing with ecosystems this study adds to these debates and furthers the understanding of the processes of ecological technological transformations.

Background

> The nineties will be the decade of genetics, immunology and environmentalism; clearly these are the leading vehicles for the infiltration of techno-science, capitalism and culture into what the moderns call technology (Rabinow 1996)

The environmental movement of the seventies incorporated many different strands of concern, ranging from pollution, to resource extraction, to environmental degradation. New scientific understandings coupled with social movements led to critiques of many existing institutions and practices (Carson 1962; Dubos 1968; Ehrlich 1968; Ellul 1964; Jacobs 1961; Reich 1970; Roszak 1972; Schumacher 1975; Toffler 1970). Though the environmental movement involved much protest against the negative products of science and industry, at the same time wide ranging interest in the possibility of new social-technological practice emerged under various names such as intermediate technology, appropriate technology, soft technology, and alternative technology (Stefflre and McClaran 1977). Many of these 'alternatives' were premised in ideas of the need for more local or community scale economic and technological development. As such, the 60's and 70's engendered large back-to-the-land and other counter-cultural movements (Jacob 1997). These 'alternative technology' movements investigated and implemented new technical practices in energy production (solar and wind), food production (organic, local markets, greenhouse production), construction methods (straw-bale construction, earthships, bioshelters), and waste management (composting, recycling, decentralized wastewater treatment)[9]. Subsequently, with the economic and political changes that occurred in the 80's, these social movements underwent various declines and reformulations (Mol 2000; Pursell 1993). However, "as the initial radical energy of the AT [alternative technology] movement diminished, so activists tended to refocus their activity into more modest forms in discrete, specialized area closer to the limited openings presented by mainstream society" (Smith 2005). The entry of the environmental movement into mainstream practice is called "the cultural appropriation of environmentalism by Hård and Jamison (2005, p.279) or incorporation and "complementarization" by Hess (2005, 2007). Though acknowledging the partial success of modest ecological trends through these appropriations, these scholars focus more on the *loss* of the more impassioned and social goal oriented environmental movement of the 70s.

However, the existence of the partial uptakes, coupled with the continued activities of some scholars, activists and institutions from the 70s environmental movement, means that if one currently becomes interested in the possibilities of alternative technologies, upon investigation they may find institutions and individuals that link back to the 70s appropriate technology movement. Or, if not linked back themselves to the appropriate technology movement, there will be linkages with other current scholars who themselves have those linkages. This is because there is currently in

[9] See *An Assessment of Technology for Local Development* (OTA 1981) for an interesting overview of many of these types of technologies and the assessment of the problems and barriers to their implementation.

the U.S. a core group of highly visible scholar-activists who write and speak about the ways and means to change from unsustainable to sustainable forms of technology and culture. Though they come from different trainings and affiliations (from academic to corporate to non-profit) these individuals are iconic in their fields and are associated with particular ideas, technologies or applications. For example this cadre includes William McDonough who writes and speaks on architecture, green design and cradle-to-cradle design; David Orr who is a leader in the movement for the greening of college campuses, and writes on ecological design and sustainability; Paul Hawken who is known for his work on alternative economics, industrial ecology and the idea of Natural Capitalism; Amory Lovins who also writes on economic issues and is widely known for his work on energy policies and technological transformations through his Rocky Mt. Institute; Kenny Ausubel and Nina Simons who are known for their development of the eco-technology and inspirational conference Bioneers; Wes Jackson who works to develop stable agriculture systems based on perennial grain crops at The Land Institute; Janie Benyus who is known for the development of the inspirational idea of biomimicry; and John Todd who is know for designing with ecosystems, living machines and eco-machines.[10] These individuals have both written defining texts, and established institutes that are know for their work on alternative energy, technology, design and economics. There are many inter-linkages of mutual referencing, co-creation of material objects and shared histories among these various visionaries

[10] See for example Ausubel 1997; Benyus 1997; Hawken 1983; Hawken, et al. 1999; McDonough and Braungart 2002; Orr 2004; Orr 2006; Todd 2005 ; Todd and Todd 1994. See also www.bioneers.org, www.biomimicryinstitute.org, www.naturalcapital.org, www.rmi.org/rmi, www.oceanarks.org, www.landinstitute.org

A major focus of these thinkers and designers is the development of new forms of technological practice that ameliorate environmental problems associated with current forms of production. Rather than being anti-technology, these visionaries premise their solutions on the development of new forms of technological and social practice. Thus, in these cases science and technology innovation is specifically oriented to the development of social transitions toward sustainable societies. Similarly, social change scholars have been investigating the mechanisms by which alternatives become developed and adopted, and have formed various theories on the best ways to study and stimulate socio-technical transitions to sustainability (Geels 2010). Interesting questions are also raised by the explicit conjoinings of value oriented motivations with the production of science and technology; especially in light of the connectivity of these current innovations in science and technology with the appropriate technology movement of the 70s. As such, should the new science and technology productions also be considered a form of movement? Utilizing one of the above mentioned alternative technologies as a starting point, this dissertation seeks to address these varied questions.

Ecosystems as Alternative Technology

The intentional redesign of the interactions of humans with each other and with the natural environment are common goals of the above ecological and sustainability scholars. For example, the alternative wastewater treatment technology of living machines, as developed by John Todd, was posited as a lower cost, no chemical method of treating wastewater. (See Appendix A for an overview of conventional wastewater treatment technologies). The integrated ecosystems on which the technologies were based provided not only a treatment process, but also had the potential of generating horticultural material from the waste stream. And even more radically, these systems were developed in greenhouses, and the lushness and beauty of the systems was an important component of the design. These systems were meant not just to treat wastewater but also to regenerate feelings of connectivity for humans with nature. Though the living machine as an individual technology was not developed until the 1990s, it followed from a line of alternative technologies that John Todd had been developing since he had been the leader of a prominent alternative technology and experimental living project in the 70s. The goal of all these technologies has been the design of ecosystems that could provide particular amenities to humans and to nature. In the 70s the focus of the systems was on integrated food production, but in the late 80s and 90s John Todd started focusing on the production of alternative wastewater treatment technologies. Within the alternative technology community these ecosystem based technologies became very iconic of radical alternatives.

What Happens to Alternatives When They are Adopted into Mainstream Practice

> Any contemporary discussion of science, technology, governance and processes of modernization must take account of the ways in which conceptions of the environment are shaping them. (Berkhout, et al. 2003 p. 1)

Over time other developments of the ideas of 'designing with ecosystem' occurred, such that now the concept is the basis of the developing disciplinary subject ecological engineering. Thus 'designing with ecosystems' may not be the radical concept it once was, and technologies premised on the used of designed ecosystems are expanding in their scale and range of operation. In light of such changes, what now are the goals for the technologies that are developed using ecosystems? Do such technologies still have normative values guiding their design? These questions are relevant, because it has been postulated by some science studies scholars (Hess 2007a; Jamison 2006) that as alternative technologies become developed and adopted into mainstream practices many of the more social, or values laden elements associated with the technology get stripped away. Instead of being about social change or having larger goals like reformulating society, the alternative technologies become merely technologies, and the individuals now involved with them care less about advancing larger ideological goals. Under Hess and Jamison's constructs it is through the process of incorporation that these value shifts occur in relation to the technology. As such this research project asks the question: what are the processes and means by which the ideas and technologies of designing with ecosystems are becoming incorporated into mainstream practice? By attempting to answer this question this research project develops a means to test the notions of incorporation and values loss as posited by Hess and Jamison while simultaneously engaging with the larger questions in regards to the best ways to stimulate technical innovation and the socio-technical transitions to sustainability.

Outline

Chapters 2 and 3 introduce the theoretical and methodological foundations of this study. Chapter 2 explores the synergies between three different research traditions to develop a framework for analyzing the development and changes in the practices and field of designing with ecosystems. First the macro-social change theory of Ecological Modernization is discussed. Highlighted in the discussion are the ways in which the theory has been variably used and interpreted by both advocates and proponents of the theory. At the end of this section, discussion returns to the problem of understanding the development of alternative science and technology practices, and the usefulness of ecological modernization theory for analysis at this level is questioned. The second section introduces and analyzes David Hess's (2005, 2007a) proposed framework for the study of social movements and their intersection with the development of innovative science and technology practice. Hess posits the existence of technology- and product-oriented movements (TPMs) that work to develop and diffuse new technologies that work to 'redesign' social–environmental interactions. The interaction of these TPMs with mainstream practices can lead to the incorporation and subsequent changing, or complementarization, of the proposed alternative. The usefulness of the idea is discussed in relation to Hess's own tendency to focus on the complementarization process of capital to the dearth of exploring other possible constraints. However, the section concludes with the idea that Hess's TPMs and complementarization provide a framework for the analysis of the development of the practices and field of designing with ecosystems. The final section discusses the general trend in studies of science toward reevaluations and reworking of the idea of social movement. Exploring the research trends in the Anthropology of Science and Technology, Science and Technology Studies and the Sociology of Science, this section demonstrates how the constructs of paradigmatic practices and boundary work are being redeployed alongside notions of social movements to develop the frame of 'science movements' as a means to analyze science and technology as intentionally constitutive of positive ecological change. This chapter ends with a brief discussion of the synergy between ecological modernization, complementarization and science movements.

In a further introduction of this study Chapter 3 explains the methods of study used to address the research goals. The chapter starts with a brief discussion of the need to do meso-level multi-sited investigation coupled with data collection that draws from a disparate number of sources. The next section of the chapter discusses the three methods that were deployed during the field work portion of this study, these being participant observation, semi-structured interviews and a pile-sorting task. The next section of the chapter provides overviews of the various field sites of the study. Site descriptions are given for the longer stay field sites to help contextualize the spaces of research. The final section of this chapter touches briefly on the process of writing up the research and the necessity for a mixed style of attribution and anonymization.

The second section of this dissertation provides two case studies of the development of practices and discipline based on designing with ecosystems in Chapter 4 and 5. Chapter 4 provides a historical overview of the development of the particular living machine family of designed ecosystem technologies arising out of the environmental work of John Todd and the New Alchemy Institute. The technological innovation of NAI and John Todd are traced, the subsequent iterations of designed ecosystem technologies are followed through their different material designs and the different institutions that developed and deployed them. This chapter ends with a brief discussion on the usefulness of Hess's complementarization as a means to understand and explain the changes that occurred with the living machines over time.

Chapter 5 also looks at practices utilizing ecosystem design, but this time focuses on the attempts to develop and formalize a discipline. This chapter starts with a brief overview of some of the historical markers in the development of the discipline of ecological engineering in the United States. The chapter then reports on the definition and content of the field as explained by members. Following this, the various realms of boundary work that ecological engineers do to distinguish the field from general engineering, environmental engineering and applied ecology are explored, and the contested relation with ecological design is examined in more depth. The final section of this chapter looks at the goals that ecological engineers ascribe to the field, as well as exploring the ways in which boundaries between the ecological engineering practice and environmentalism are variously enacted. This chapter concludes with a discussion of ecological engineering as a developing inter-discipline with subsequent boundary work difficulties that are partially overcome by the goals for the field. These goals lead to the conclusion that ecological engineering can be interpreted as an example of a science movement working to develop new forms of science and technology practice which incorporate ecological goals from the inception of the design.

Having discussed two major realms in which individuals are utilizing the construct of designing with ecosystems in the first section of the dissertation, the second section turns to an analysis of the major constraints that impinge upon the development and deployment of these practices and technologies. This section not only discusses social structures that constrain developments, but also adds a discussion of materiality as a constraint. Though acknowledging the interconnection of various structural realms, these four chapters are divided into Institutions, Chapter 6; Regulations, Chapter 7; Capital, Chapter 8; and Materiality, Chapter 9. In Chapter 6 the section analyzes the professional nature of engineering as a constraint to curriculum development and interdisciplinary innovation. Following on this, a number of case examples of attempts to develop ecological engineering programs are used to explore the way in which academic institutions also can constrain innovative interdisciplinary initiatives. The last section of this chapter discusses further ways in which innovative practice inside of universities are influenced by institutional reward structures. Chapter 7 focuses on the role of regulations in setting zones of opportunity for innovation as well as driving the adoption of technologies though an analysis of the effects of the Clean Water Act in generating interest and support for certain types of technologies while dis-incentivizing others. The role of regulations in providing space for innovation through performance standards rather than prescriptive standards is then discussed, and is followed by a discussion of the role of individual regulators themselves as possible constraints in localized deployments of designed ecosystem technologies. Chapter 8 then turns to an exploration of the role of capital as a barrier to innovation, especially with regard to the ability to maintain steady funding streams for maintenance of experimental ecosystems over long periods of time. Following on this section, the role of capital and the need for returns on investment for private innovators is discussed as a potential impediment to the diffusion of technologies. And finally, in Chapter 9, the analysis turns to materiality, and explores the three categories of place, bodies and things as material realms that intersect with the three structural realms to both engender and constrain innovation. Research labs and business all need physical spaces in which to experiment and demonstrate concepts. These places then become zones of interaction for, and between humans, and the embodied knowledges that individuals build through the practices of hands-on design and research itself becomes a resource to share with others. And finally, this chapter analyzes the way in which the very materiality of the technologies themselves has to be dealt with as a potential constraining factor. Not only are these systems trying to use living things, but they are also made of component technical things, and the functioning, or non functioning of these things has to be accounted in a roster of constraints to the development of practices and technologies based on designing with ecosystem.

In Chapter 10, the dissertation returns to the question of “What are the means and processes by which the ideas and technologies of designing with ecosystems are becoming incorporated into mainstream practice? Utilizing the case of living machines as laid out in Chapter 4, the first section of this chapter discusses the way in which complementarization does not fully function as an explanatory frame for this case due to the material conditions of the technologies. In the second section the case of ecological engineering is explored as an exemplifier of the ecological modernization of scientific and technical practice as well as an instantiation of a science movement. Complementarization as an explanatory frame does not work in this instance. The third section then explores the role of individual interests in problem solving and practical action as driving factors in how people become involved with the concepts and practices of designing with ecosystems. It is out of the maintained interests, engagements, and actions of individuals that new alternative ecological technical and practices are developed and deployed into mainstream practice even in the face of structural and material constraints.

CHAPTER 2

THEORY

> For while there appears to be widespread agreement, in principle, about the need to infuse an ecological consciousness as broadly as possible into our increasingly "globalized" societies, there is an enormous and highly diverse range of activity that has emerged in the quest for more sustainable paths to socio-economic development (Jamison 2001, p. 20).

Introduction

Though no one is claiming that a green ecotopia has been, or is being created, scholars from many different disciplinary traditions are acknowledging general trends toward inclusion of environmentally inspired ideas, such as sustainability, into realms of policy, industry and consumerism (Eder 1996). The role of science and technology in formulating these ecological transformations thus has become a research arena in many social science disciplines. The scales and methods of analysis vary widely in accordance with the disciplinary traditions in which these studies of technological change are grounded. In the following chapter, different approaches that have been applied to the study of these ecological transformations will be explored. In the first section, the macro-social change theory of 'ecological modernization' will be discussed and its value as a explanatory theory of science and technology change will be evaluated. Following a brief introduction to the current conceptualization of ecological modernization, an analysis of the early history and changing nature of studies carried out under this name will be discussed. This is followed by an analysis of the usefulness of ecological modernization as a research frame for studying transformations of science and technology practice. In the second section of this chapter, the idea of technical transformations being part of social movements will be explored and will focus on Hess's theorizations of 'technology and product oriented social movements' (Hess 2005) as a method of understanding transformations in ecologically oriented science and technology practice. This section begins with a detailed analysis of Hess' theory of technological transformations and his construction of the idea of 'complementarization' as a gateway process in the adoption of technological change. It ends with a critique of the underlying normative stance of Hess' work and compares this with the assumptions of ecological modernization theory. The third section of this chapter addresses the rising theorization of the existence of science movements through an explication of developments in the three (not necessarily distinct) fields of Sociology of Science, the Anthropology of Science and Technology, and Science and Technology Studies. This section ends with an analysis of how the interrelation of the three topics, ecological modernization, social movements and science movements informs the analysis of this research project.

Ecological Modernization[11]

> As a relatively young but still growing body of scholarship, ecological modernisation studies reflect on how various institutions and social actors attempt to integrate environmental concerns into their everyday functioning, development and relationships with others, including their relation with the natural world. As a result, environmental interests have become incorporated into more and more aspects of social relations and institutions, as well as into contemporary human values, cultures, and everyday practices (Mol, et al. 2009a)

Currently, ecological modernization theory's basic premise "is the centripetal movement of ecological interests, ideas, and considerations in social practices and institutional developments, which results in the constant ecological restructuring of

[11] In the literature both modernization and modernisation are used, with the European scholars dominantly using modernisation and the American scholars modernization. As this work was produced in the US, I am following the American spelling convention.

modern society" (Mol 2003 p.310). In this, ecological modernization can be seen to have overlap with the ideas of reflexive modernization popularized by Ulrich Beck (Beck 1992; Beck 1995). Under Beck's notion of the "risk society", late modernity is characterized as having generated a new set of social concerns and risks. To address and mitigate these risks, both modifications of existing governance practices and entire new realms of social action, technology development and governance are developed through the mapping, monitoring and mitigation of these risks. For Beck, the outcomes of the actions of modernity are cycles of risk, discovery, modification and change that continue and constantly reform the face of modernity. Thus the process of modernization continues, but in new and self-correcting forms. Ecological modernization (EM) is similar to reflexive modernization in that neither offers a critique of modernization in and of itself. Rather, EM scholars

> acknowledged the need for some fundamental transformations within the modernsiation project to restore some of its structural design faults that had caused severe environmental destruction, but claimed that these transformations do not imply that one has to do away with these institution of modern society that are involved in the modern organization of production and consumption (Mol and Spaargaren 2000, p.19)

That ecological reflexivity has occurred, and has been creating new forms of modernity, seems incontrovertible when one looks at the rise of such things as global regulatory and policy initiatives like the Kyoto Protocol and the UN Agenda 21; or at the creation of large-scale institutions for the mapping, measuring and reporting on environmental and ecological conditions like the International Biological Program, Millennium Ecosystem Assessment, and the IPCC; or the development of new ecological metrics like emergy analysis, ecological economics, triple bottom line accounting, life cycle analysis, footprint analysis, and carbon budgeting; or at the rise of environmental accountancy and labeling institutions such as the Forest Stewardship Council, the Marine

Stewardship Council, and the U.S. Green Building LEED. In light of these obvious examples of the institutions of modernity reacting to, and incorporating ecological concerns, it seems that it should be non-problematic to refer to a general trend of ecological modernization occurring in the world. However, ecological modernization is not an unproblematic descriptive, or analytic tool, for demonstrating and explaining "the centripetal movement of ecological interests." Rather, the early uses of EM as a descriptor of industrial change, coupled with its subsequent use as a prescriptive tool for policy creation has left EM with a legacy of theoretical debate and critique from other social change scholars (Deutz 2009; Fisher and Freudenburg 2001; Milanez and Buhrs 2007; Schnaiberg, et al. 2002; York and Rosa 2003). The outcomes of these exchanges has been a subtle reformulation and expansion of the realm of EM theory over time (Mol and Spaargaren 2000).

Ecological modernization theory has its roots in the 1980's work of Joseph Huber on technical innovation and industrial reform in generating environmental benefits. Subsequent scholars expounded on these elements of industrial change and analyzed the role of market dynamics and macro social economic changes (for example the works of Jänicke and Simonies) and regulation and policy initiatives (for example the works of Weale) in furthering such ecological transformations of industry (Christoff 2000; Mol and Sonnenfeld 2000; Murphy 2000). These early works in ecological modernization focused on the transformation of governance and industry in European countries (Young 2000). The early ecological modernization analyses of environmental reforms in Europe in the 80's gave rise to a linkage of ecological modernization to normative policy prescriptions. EM entered the policy arena as a governance practice, rather than as a descriptive theory of social change. This prescriptive element of EM was closely linked with another normative policy position, the precautionary principle (Anderson and Massa 2000). The normative claims in the early ecological modernization literature, and the adoption of ecological modernization as a prescriptive practice by economists and policy workers lead to some of the current confusion as to what ecological modernization encompasses. In the early 90's, ecological modernization began to coalesce as a analytical research field (Spaargaren and Mol 1992) In light of the ensuing critiques of EM, throughout the 90's theorists worked to broaden the scope of ecological modernization away from its northern European policy focus and expanded the use of EM analysis out of Europe and into other nations industrial transformations (Pellow, et al. 2000; Schlosberg and Rinfret 2008; Zhang, et al. 2007), into studies of green consumerism (Spaargaren and Vliet 2000) and also into studies of globalization and developing world ecological transformations (Huber 2008; Milanez and Buhrs 2008).

Critiques and Responses

However, despite these expansions, EM is still often characterized by outside scholars as simply a prescriptive practice, which favors industrialization and that fails to acknowledge the underlying problematics of capitalism (Schnaiberg, et al. 2002) and consumerism (Carolan 2004). For example, York and Rosa (2003) equate the position of ecological modernization theory (EMT) with a simplistic call to more industrialization. In the opening paragraph of their paper, they state "EMT theorizes that continued industrial development, rather than inevitably continuing to degrade the environment, offers the best option for escaping from global ecological challenge[12]. They then continue with a

[12] This is the position that was taken by the earliest ecological modenerization writers, such as Huber, Jänicke, and Simonis.

quote from Mol (1995) stating that "the only possible way *out* of the ecological crisis is by going further *into* the process of modernization." Further, at this point in the paper a footnote points the reader to other instances where EM theorists call for more modernization as the solution to environmental problems. At one level, this is a fair representation of the current position of ecological modernization. Mol (2003) acknowledges that unlike proponents of de-materialization solutions to the environmental crisis, the formulation of EM, in congruence with Beck's reflexive modernization, has "the perspective that *all* ways out of the ecological crisis will lead further into modernity" (emphasis added Mol 2003 p.309). However, the twist that York and Rosa have placed on modernization is similar to what other critics of ecological modernization have focused on. They equate *modernization* with *industrialization* and then ascribe a normative stance to ecological modernization by stating that "EMT theorizes... that industrial development… offers the best option" (see above for full quote). This characterization of EM is akin to the characterization given in Buttel (2003), wherein he equates ecological modernization theorists with advocates of industrialization or *superindustrialization* (*a la* the early work by Huber).[13] Similar to these equations of ecological modernization with simple industrial instrumentalization, Hård and Jamison (2005), having defined ecological modernization narrowly, as a "shift from pollution control and so-called end-of-pipe technologies to more preventive and precautionary approaches", they then set EM in opposition to "transformative strategies" such as

[13] Buttel's narrow delimitation of EM is easier to understand when one looks at it in the context of his paper. The argument of his paper is to establish the normative claim that environmental movements or activism are the only substantial way forward for creating lasting environmental reform. To make this argument he breaks the various 'methods' of reform into four categories: Environmental activism and movements, state environmental regulation, ecological modernization, and international environmental governance. The creation of these categories necessitated a limited interpretation of the each of these realms of action, and thus might explain why he chooses to offer such a limited field of action to ecological modernization.

“‘ecological economics’, ‘industrial ecology’ and ‘natural capitalism’” (Hård and Jamison 2005, p.290).[14]

These critiques of ecological modernization set up a straw man made up of two ideas: first that EM is a normative claim and second, that modernization is equivalent with industrialization.[15] However, ecological modernization theory in fact suggests multiple manners in which “modernization” can occur and the claim that “all ways out… will lead further into modernity” does not mean that this will be the same type of modernity that exists today. A number of different EM scholars have offered overviews of ecological modernization that demonstrate the breadth of scholarship that is arrayed under EM (Buttel 2000; Christoff 2000; Fisher and Freudenburg 2001; Hajer 1996), showing that EM incorporates more than industrialization and in fact can include the very “transformative strategies” that Hård and Jamison consider oppositional to EM. Christoff (2000) analyzes the history and practice of ecological modernization, pointing out that the concept of EM has been used descriptively, analytically and normatively. Going further, he shows that ecological modernization is constituted by a suite of processes and a broad range of outcomes. These outcomes of EM might be very technocentric applications or the processes of EM might lead to deep ecological consciousness. He suggests the need to think about the processes of ecological modernization along a spectrum from weak to strong (see Table 1). In this framing of ecological modernization, under its ‘strong’ formulation, EM can encompass critiques of technocratic green governance, non-hegemonic movements and calls for social justice. In this manner,

[14] These transformative strategies are what later I will be referring to as ‘processual approach’ as used by Hess (2007)

[15] As mentioned above, some of this confusion might not be so much intentional, as an outcome of the early more prescriptive uses of ecological modernization coupled with the fact that some scholars still do use ecological modernization in a normative manner.

ecological modernization theory can no longer be thought of as a completely oppositional stance to the theoretical positionings of anti-modernists, who argue against the perceived hegemonic and technologically narrow outcome of the ecological modernist view (Christoff 2000).

Table 1. Types of ecological modernisation (Copied from Christoff 2000 p.222)

Weak	Strong
Technological (narrow)	Institutional/systemic
Instrumental	Communicative
Technocratic/neocorporatist/closed	Deliberative democracy
National	International
Unitary (hegemonic)	Diversifying

However, a continuing form of critique of ecological modernization comes from the neo-Marxist perspective. The failure of ecological modernization to challenge dominant capitalistic paradigms is the general complaint of neo-Marxist theorists, and often ecological modernization is equated with a neo-liberal policy perspective.[16] While early formulations of EM did have a positive perspective on capitalism, the newer framings of it are more grounded in a materialist perspective and take realist positions on ecological limitation (Mol and Spaargaren 2000). As an outcome of this shift, "mainstream ecological modernization theorists interpret capitalism neither as an essential precondition for, nor as the key obstruction to, stringent radical environmental reform (Mol and Spaargaren 2000 p.23). In a paragraph explaining the general positioning of ecological modernization theory in regard to capitalism, Mol and Spaargaren (2000) state:

[16] Again likely arising from an understanding of ecological modernization from its early theoretical formulations and the dominant bent of its prescriptive policy use.

> While initially the contribution of capitalism to the 'expansion of the limits' was celebrated by Ecological Modernisation Theory, more recently a nuanced position regarding capitalism is presented. It is not that capitalism is considered to be essential for environmentally sound production or consumption (as neo-liberal scholars want us to believe), nor that capitalism is believed to play no role in environmental deterioration. But rather that (i) capitalism is changing constantly and one of the main triggers is related to environmental concerns, (ii) environmentally sound production and consumption is possible under different 'relations of production' and each mode of production requires its own environmental reform programme, and (iii) all major, fundamental alternatives to the present economic order have proved unfeasible according to various (economic, environmental, and social) criteria (Mol and Spaargaren 2000 p.22-23).

In this framing, it is clear that these EM scholars have a more nuanced perspective on the role and limitations of capitalism and do not see ecological modernization theory as simply part of the neo-liberal paradigm. However, many neo-Marxist scholars still paint ecological modernization with a broad brush and denigrate it for accommodating capitalism. Guldbrandsen and Holland (2001) state "Ecological modernization is a voice of rationality that uses cost-benefit analysis rather than moral argument. It eschews biocentrism and other more radical strands of environmentalism in favor of accommodating capitalism" (Guldbrandsen and Holland 2001, p.126). They go on to quote from another neo-Marxist theorist:

> Indeed, it is not impossible to imagine a world in which big industry (certain segments), big governments (including the World Bank) and establishment, high-tech big science can get to dominate the world even more than they currently do in the name of "sustainability," ecological modernization and appropriate global management of the supposedly fragile health of planet earth." (Harvey 1996 p.382-383 in Guldbrandsen and Holland 2001).

At the core of these critiques is the concern that ecological modernization strengthens hegemonic institutional forms[17] and selects for solutions to environmental crisis that privilege the realm of capital over alternative value systems. Though ecological modernization brings environmental concerns into capital "it squeezes out consideration

[17] This is a major position of postmodern critiques of ecological modernization processes. The centralization of ecological and environmental discourse become generative of new forms of measuring, mapping and monitoring, both in the realm of the biophysical world as well as new justifications for managing and controlling human action. Drawing on Foucault's biopower and governmentality, these scholars dissect the ways in which the creation of 'ecological master narratives' are generative of new forms of green governmentality.

of biocentric view and has no place for issues of environmental justice or other alternative forms of environmentalism" (Guldbrandsen and Holland 2001). This is akin to the dichotomy offered by Hård and Jamison (2005) between eco-modernist solutions and more transformative strategies. For them, the potential outcome of the domination of ecological modernization is the possibility that "environmentalism will be so taken over by other interests that its ultimate meaning will only be "greener, cleaner" production (Hård and Jamison 2005 p.291).

The various critical representations of ecological modernization offered in the above examples are akin to the "weak" version of ecological modernization in Christoff's continuum[18] (Christoff 2000). If this were all that EM was, then these criticisms might have validity. However, these critiques are based on the idea that the normative stance of EM is also solely in alignment with this "weak" version. But for Christoff, the normative stance of ecological modernization can just as validly be said to be represented by the "strong" program. As such, EM theorists can be seen as amenable to systemic change, processual approaches, and forms of modernization that increase representation and democracy. What stays constant between the "strong" and "weak" framings is the ecological modernist base assumptions of the "centripetal movement of ecological interests" and that "all ways out of the ecological crisis will lead further into modernity."

Usefulness of EM in Studying Science and Technology Transformations

Though Christoff's continuum in useful is showing that EM can have a range beyond a fetishization of industrialization, it doesn't provide much operational direction

[18] It is noteworthy that Christoff in introducing this typology writes "ecological modernisation lie along a continuum from 'weak' (one is tempted to write 'false') to 'strong', according to their likely efficacy in promoting enduring ecologically sustainable transformations and outcomes across a range of issues and institutions."

for analytical approaches. What does ecological modernization look like? What *are* the outcomes of ecological modernization if it isn't just ecologically attuned industrial production and state level technocratic policy initiatives? The main ecological transformations that are of analytical interest to ecological modernization theorists have been laid out as a set of five heuristics (Mol 2003; Mol 2000; Mol and Sonnenfeld 2000, with slight variations among them). These five realms of transformations are given these short descriptors "1) Changing role of science and technology; 2) Increasing importance of market dynamics and economic agents; 3) Transformations in the role of the nation-state; 4) Modifications in the position, role and ideology of social movements; 5) Changing discursive practices and emerging new ideologies" (Mol and Sonnenfeld 2000). Realm two and three have the most extensive history of exploration by ecological modernization theorists as, they are under the analytic purview of the older ("weak") form of EM, as well as having been in the spotlight of many ecological modernization analyses that were done in the 90's and early 2000's. Within the main corpus of EM literature, realm 4 and 5 have not been highly researched, barring Hajer's (1995) analysis of the discourse of EM policy. With regards to realm 1, changes in institutions of science and technology, ecological modernization theory states that:

> 1) Science and technology become contributors to environmental reform. First, science and technology are not only judged for their role in causing environmental problems but also are valued for their actual and potential role in curing and preventing them. Second, conventional curative and repair options (such as 'end-of-pipe' technologies) are replaced by more preventive sociotechnological approaches that incorporate environmental considerations from the design stage onward. Finally, despite a growing uncertainty with regard to scientific and expert knowledge concerning environmental problems, there is continued appreciation of the contributions of science and technology to environmental reform (Mol 2003 p.311-312).

The second point in the above is of particular interest in that new forms of sociotechnical systems and design process are posited as being part of ecological modernization. The rising practices and discipline arrayed around the idea of designing with ecosystems represents just such an attempt to incorporate "environmental considerations" as the basis and starting point of design. However, left undetermined in this heuristic of EM is how, and where, such reformulations would occur. As science and technology are embedded in social institutions, would this form of ecological modernization be an outcome of policy level pushes or from market-driven demands within particular industries or from other interactions? Would these reformulations start with business practices, or be outcomes of research action in universities? Ecological modernization research has been largely dominated by national level analyses of change and policy oriented studies, but is this the right or only scale and institutional focus if one is interested in precisely how science and technological practices are changing to incorporate "environmental considerations from the design stage onward"? If ecological modernization, as a theoretical framework, does in fact cover changes in all 5 realms of action, then studies of ecological modernization will have to change their scale and method of research. In order to move beyond macro level overviews of "the centripetal movement of ecological interests, ideas, and considerations in social practices and institutional developments" (Mol 2009), ecological modernization scholars need to turn to tools of analysis arising out of other scholastic traditions.

Social Movements

One way to study the centralization of environmental concerns has been developed by anthropologist David Hess. Combining studies of globalization, science and technology and social movement studies, Hess has mapped a framework for analyzing what he terms "alternative pathways" (Hess 2007a). In his text *Alternative Pathways in Science and Industry: Activism, Innovation, and the Environment in an Era of Globalization*, Hess analyzes the ways in which civil society and social movements intersect with, and even inspire changes in, science and technology. In his book, he lays out four major pathways in which social movements encounter and interact with the technoscientific complex in a globalizing world. Hess's analysis focuses on the ways in which these different pathways end up articulating with, and being modified by, mainstream practices.

> Although the alternative pathways attempt to articulate an alternative to the world of corporate globalization, they are also caught up in it, and their best-laid plans, technologies, knowledges, organizations, and products often go agley when the mainstream political and economic institutions refashion the alternative. Again, it is the dialectic of opposition and compromise, of incorporation and transformation that I hope to illuminate (Hess 2007a p.15).[19]

One of the four pathways that he analyzes is what he titles *technology- and product-oriented movements* (TPM) which are activity spheres aimed at actually generating new technological objects or new forms of practice in science and technology[20]. For Hess, a key issue in TPMs is that by their nature of being focused on materially grounded objects, or technical practices, they are amenable to processes of adoption by mainstream institutions. However, the process of "incorporation" (Jamison 2001) will favor the technologies that are complementary to mainstream practice over more radical alternatives. Simultaneously, as technologies or products are adopted they can be subjected to selective pressures that can affect the technological application.

> As the TPMs achieve success, the targeted industries often begin to show an interest in incorporating or co-opting the alternatives, and in the process the design of the technologies and products undergoes a transformation. The usual direction of the transformation of the design involves "complementarization," that is, modification of aspects of the design that are in conflict with the dominant technologies in an industrial field, so that the alternatives become complementary (Hess 2007a p.125).

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[19] Agley: awry, amiss, wrong.

[20] The other three pathways are *industrial opposition movements* (IOM), which are typified by protest against various technical or industrial developments; *localism movements* that are concerned with scale issues and counter globalization with calls to regionalism and local economies; and *access movements*, which deal with social justice related to uneven distributions of access to resources.

Drawing on his own extensive fieldwork in complementary and alternative medicine (CAM) for cancer treatment (Hess 2003a), as well as extensive research into other alternative social movements, such as on the organic foods movement (Hess 2004b), wind energy production, open source computing (Hess 2005), and urban redesign (Hess 2007a), Hess demonstrates these process of incorporation and complementarization. For example, with the CAM movement Hess points out that the original movement included support of radical dietary changes as a form of cancer treatment that was advanced as an alternative to undergoing chemotherapy. However, under the incorporation of CAM into the rubric of mainstream practice, dietary modification became an ancillary process to chemotherapy, not a replacement of it and the dietary changes themselves became a more ad hoc treatment than a complete overhaul of foods and diet (Hess 2003b; Hess 2004a). In another example of complementarization, Hess argues that as the organic movement became adopted into mainstream practice, the process of complementarization moved the movement from also including notions of locality and farmer-consumer social equity issues, and transformed it into a technocratic set of standards of on-farm soil and crop treatments (Hess 2007a; Hess 2004b). In yet another example of complementarization, Hess used the wind energy movement that occurred in both Europe and the U.S.A., and lays out the case that the early innovators in the field were motivated by ideas of locally situated, off-grid energy production. As such, the technologies pursued were small voltage and spatial distributed windmills. With the rise in interest in alternative energy production by mainstream electrical companies, the further development of wind mill technology moved toward much higher voltage capacity mills aggregated in industrial sized wind farms (Hess 2007a).

Out of these and other case studies, Hess has developed the thesis that the process of complementarization follows from a series of events. First, technological process or products are developed as alternatives by actors who are on the outside of mainstream science and industrial practice. This is often necessitated by the structures of power (from institutional reward systems to funding structures) that leaves forms of knowledge production undone, or undoable in mainstream institutions.

> Because the system is set up so that certain areas of science will be well tended while others will be left to wither on the vine, the scientific field will develop historically to have large areas of undone science. The pockets of undone science will tend to include knowledge that would be especially valuable to the building of alternative pathways (Hess 2007a p. 42).

These actors and their products are associated with larger social change movements. As the alternatives gain visibility, the actors and technologies end up interacting with mainstream institutions in a myriad of ways. Hess uses the idea of 'object conflicts' to label the sites of contentious interchange between individuals, institutions, and practices. The notion of 'object conflict' builds on the idea of 'boundary objects' (Star and Griesemer 1989) wherein particular objects, or even words, take on different meanings for different groups of actors. Definitional struggles over the boundary object become more than just semantic debates, but are also enactments of power, and thus represent potential control over larger fields of practice.[21] Perhaps an important distinction of Hess's object conflict from 'boundary objects' is that for Star and Greisemer, a salient feature of boundary objects is their ability to be the vessels of multiple meanings simultaneously. Thus a boundary object can become a point of connection and stability

[21] Hess also credits the notion of 'boundary organizations' as underlying his idea of object conflict. Boundary organizations are intuitions that work at the interface of science and politics mediating meaning and working to preserve the borders of science from non science (Guston, 2001). This notion of boundary organization draws heavily on the notion of Gieryn's 'boundary work' (Gieryn, 1983) (see next section); Interestingly, object conflicts also share similarities with the notion of "friction" as developed by Anna Tsing (Tsing, 2005).

between actors and groups whose shared use of the boundary object creates cohesion despite the differential meaning ascribed to the object. In contrast, Hess stresses the 'conflict' element in the differential meanings and highlights the ways in which 'object conflicts' become the sites of enactments of power as different groups contest and debate the meaning of the technology or process.

> Object conflicts are definitional struggles, simultaneously political, economic, and semiotic. The conflicts involve which objects should be release onto markets and within categories of objects, which designs should be given priority over others. They involve governments, firms, individual consumers, and civil-society organizations, which interact in relationships of cooperation and conflict across various fields of action where the definitions of the proper object are worked out (Hess 2007a 80).

For Hess, the various object conflicts are empirical points wherein the processes of complementarization can be observed. Unlike boundary objects, which create some degree of stability, Hess sees the outcome of object conflicts and complementarization to be an iterative recreation of the technologies and movements.

> Rather than focus on the design of objects as the stabilized outcome of a single controversy that leads to closure, I draw attention to the never-ending relations of conflict and cooperation over ongoing innovation in the design and construction of objects and their differential position in technological fields and markets (Hess 2007a p.81) [22].

Thus rather than stability, object conflicts create a continuous process of action, reaction and change wherein technologies, or portions of technological complexes, are taken up by mainstream institutions and other elements of the technological complex are rejected (like the idea of changing diet was accepted by medical practice, but the idea of radical dietary change as replacing chemotherapy was rejected). However, Hess stresses that this

[22] Hess's use of closure in this quote is an oblique reference to the social construction of technology (SCOT) school of thought, and in particular the work of Pinch and Bijker wherein the development of technologies is posited as an outcome of discursive positioning amongst the various actors, both technicians and users, termed 'relevant social groups.' Negotiated discourses play out overtime and a particular instantiation of the technological options is 'decided' on, with subsequent 'closure' of the debate and stabilization of a singular technological form. See Bijker et al 1987 and Pinch, 1984.

partial incorporation should not in itself be a point of despair, since the reinvention of the alternative social movement can occur.

> Yet, recognition of the reality of partial integration through incorporation should not lead to the paralysis of inaction. Instead, recognition merely highlights the process by which a new generation of social movements must be continually created within a new technological field with new contours of conventional and complementary and alternative technologies. In some cases and on some grounds there is progress (Hess 2003b p. 301).

Thus for Hess, the outcomes of complemtarization include the object or products that have been incorporated[23] into mainstream practice, as well as the possible continued existence of the alternative plus the development of new social movements around the elements that were not incorporated. In a classic example of this, Hess discusses the way in which, after organic production became a mainstreamed, and certified practice around technocratic standards, new social movements advocated 'buy local' campaigns, as well as developed ideas of 'food miles' to reinvigorate both the social justice elements and farmer to consumer connectivity goals of the original organics movement.

Agendas

In Hess's development of complementarization, he focuses on the ways in which technologies are partly incorporated by a mainstream practice. Though he acknowledges the heterogeneity of the subsequent fracturing of the social movement and its possible reformulation into disparate and new movement entities, he has the tendency to treat the Mainstream as monolithic. Thus, it is here necessary to discuss the larger normative agenda of Hess's work. In discussing the four types of alternative pathways (IOMs, TPMs, localization movements and access movements), Hess clearly positions his analyses in the neo-Marxist theoretical school that posits the need for fundamental reform

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[23] Jamison (2006) follows a similar line of argument to Hess in regards the relation of techno-scientific complexes and alternative social movements and utilizes the term "appropriation" to designate the way in which mainstream practices take on the objects and ideas that originated in the periphery.

of baseline systems of capital exchange. Hess's larger project has to do with deconstructing the rationality of neoliberal, capitalistic, market-based thinking. "In order to achieve a more just and sustainable society, fundamental changes in the basic structure of the private sector will probably be necessary (Hess 2007a p.242). For Hess, the modification of the current dominant forms of capitalism is a first necessity for achieving a "just" sustainability.[24]

It is necessary to point out this normative stance, not so much to argue for or against the validity of Hess's conclusions, but to point out the way in which his normative stance and subsequent views of capitalism impinge upon his interpretation of object conflicts and complementarization in regards to technology- and product-oriented movements. For Hess, the complementarization that occurs as environmental technologies are brought into mainstream practice is primarily an outcome of market forces.

> The new shape of the technological field is an outcome of the market growth of the alternative products, the incorporation of the alternatives into mainstream industries and markets, and the complementarization of the design of alternative products that occurs when the mainstream industries accept but transform the alternatives (Hess 2007a p.166-167).

Furthermore under these market forces, the major elements that are removed under complementarization are posited to be the more intangible elements of meaning and values.[25]

> … even when one begins to discuss sustainable technologies or a universal design for alternative technologies, the new products soon become caught up in the logic of commodity exchange that

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[24] Not that he does not dismiss capitalism in its entirety, but rather targets the current operations of publicly traded corporations, and calls for new forms of corporate structure such that "if the transition to a 'civil-society society' were to occur, it would involve not merely incremental improvements in human rights and remediation of worst practices but instead a fundamental change in the central mission of the publicly traded corporation so that it looks and behaves more like a non-profit" (Hess 2007a p.246)

[25] That some meanings are renegotiated, or 'lost' has been a major theme of his work on alternative cancer treatments (Hess 2003a) as well as part of his analysis of the switch in meanings of organic from local farmer to consumer to a more technocentric construction of the definition under corporate adoption and national standards production (Hess 2005).

> will separate the products from the meanings and practices in which they were originally produced (Hess 2003b p. 295)

But by taking such a stance, Hess ends up with a de facto treatment of the "mainstream" as a monolithic entity of "corporate capital" or "market forces". An outcome of this view is that the object conflicts and complementarization that Hess analyzes remain focused on the outside, on the alternative. As mentioned above, the process of complementarization and partial adoption is posited to set off a reordering or restructuring of alternative technology movements. However, what is left out of these descriptions or analyses is a discussion of the way in which "mainstream practice" itself is modified, changed or "complementarized" through the course of these object conflicts. Rather, the mainstream always remains simply *mainstream*:

> As the recolonization of the newly diversified market develops, object conflicts shift from the stark contrasts of the alternative technology and product versus that of the established industry to the more complex choices of a continuum of alternative, complementary, and mainstream technologies.

However, a more nuanced analysis of the mainstream is necessary; perhaps rather than the mainstream merely adopting, incorporating or complementarizing alternatives, it will be found that frictions and fractions inside of the mainstream exist such that alternatives are also born inside of "mainstream" industries and not just incorporated from without.[26] Similarly, by including a more detailed analysis of the "mainstream", one might also find that the meanings and values, or social movement aspects, are not necessarily lost as TPMs are mainstreamed.

A second problem with starting from the assumption that it is market forces which require complementarization, is that this leaves out other potential reasons which might

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[26] The framing of environmental movements as being 'incorporated' or appropriated is a common descriptor For example "We can trace the cultural appropriation of environmentalism through three main phases, by which the ideas and practices that were originally formulated in the 1960s have come to be embedded into our societies and economies" (Hård and Jamison 2005 p.279).

drive technological modifications. In particular, by focusing on market forces as the structuring element, Hess neglects to analyze the *materiality* of the technologies themselves. Do these changes really occur just because the new forms are more amenable to capital control; or because the changed technologies more easily fit within existing industrial practices? Or rather, do these changes also occur due to real material constraints, making them outcomes of the design process in reaction to nature itself rather than just to capital?

Overall, Hess's text *Alternative Pathways in Science and Industry: Activism, Innovation, and the Environment in an Era of Globalization* provides a synthetic view of "alternative pathways" to what he sees as the dominant pathway of globalization under the expanding regime of corporate capital control. His outline of one of the forms of pathways, *technology- and product-oriented movements*, provides a starter set of concepts for asking questions about how science and technology become modified under processes of ecological modernization. In looking at a particular TPM, such as designing with ecosystems, or using designed ecologies to treat wastewater, it thus becomes important to pay attention to how technologies change over time, and the various points of object conflict, and complementarization. By doing so, we can start to understand how "conventional curative and repair options (such as 'end-of-pipe' technologies) are replaced by more preventive sociotechnological approaches that incorporate environmental considerations from the design stage onward" (from Mol's 2003 description of ecological modernization).

Science Movements

Hess's 2007 work lays out an overarching theory of how to study changes in science and industry in reaction to the many intertwined concerns of environmental, social justice, human health, and sustainability movements (to name a few). However, it is not just Hess who has had an interest in the intersection of social movements and practices of science and technology. Rather, there is a small but growing body of literature that addresses the question of science and technology change as a component of social movements and thus has opened up veins of research into notions of science activism and the existence of science movements. This interest in the relation of science to social movements has been developing within the interconnected realms of Sociology of Science, the Anthropology of Science and Technology, and Science and Technology Studies. Developments in these realms will be discussed sequentially below, and then this chapter will end with a discussion of how the idea of science movements adds extra questions to a study of science and technology innovation.

In contrast to sociology, social movement studies in anthropology has been a relatively small field in itself (Edelman 2001; Escobar 2008; Nash 2005) but it too has been called upon to extend the conception of movement (Casas-Cortes, et al. 2008; Price, et al. 2008). Similarly, scholarship in the anthropology of science and technology has been challenged to broaden its topical and methodological scope and attempt to generate studies that are amenable to at least limited generalization about the realms of action of social movements (Hess 2007b). In the past, anthropologically inspired ethnographic studies of science were largely initiated by feminist scholars demonstrating the ways in which science practices create, and recreate, categories of nature and culture (Haraway

1991; Martin 1987, 1994; Strathern 1992), and this focus on natural categories and biopolitics has continued to dominate in the Anthropology of Science and Technology (AST) (Dumit 2004; Franklin and Lock 2003; Haraway 1997; Hayden 2003; Helmreich 2001; Helmreich 2009; Layne 2003; Rabinow 1999). AST has also included studies of information science, engineering, nuclear power and weapons, and artificial intelligence, analyzing such concepts as identity formation (Downey 1998; Tonso 2007), cultural differences (Fujimura 2000; Traweek 1988), gendered communities of practice (Forsythe 2001, Tonso 2007), risk society (Perin 2005), nuclear identities (Gusterson 1998; Gusterson 2004) and constructions of expertise and knowledge in science and technology (Hakken 2003). However, in these AST works the overall emphasis has been toward the internal dynamics of these science and technology cultures, and in the places where the anthropology of science and technology studies has intersected with social movements, the focus has been on the protest of science and technology (Berglund 2001; Downey 1986; Harper 2004).

Similarly, throughout STS the major focus on the construction of science knowledge (Golinski 1998; Knorr-Cetina 1998; Latour and Woolgar 1986; Merton 1973) and construction of technologies and technical practices (Bijker 1987; Callon 1987; Constant 1987) has been on the ways that science and technical practices become stabilized and bounded by the actions of the scientific actors. A major research trend in STS has been in the notions of paradigms and boundary work as mechanisms of creating stabilized fields of practice. The creation of scientific paradigms (Kuhn 1970) is an outcome of the social element of knowledge construction as much as the ontological reality of the scientific facts. The existence of paradigms, and subsequent disciplines of practice, are enhanced through the actions and discourses of practitioners which work to develop the boundaries of a stabilized practice (Gieryn 1983, 1999). Such boundary working mechanisms include the of control of terminology (Hedgecoe 2003), delimitation of acceptable methods of practice from non acceptable (Hesketh 2008), solidarity building through professional meetings (Amsterdamska 2005) and active distancing from similar practices deemed to be non-scientific or "quackery" (Fishman, et al. 2008). Similar to the study of how scientific practices become disciplined into stabilized paradigms, scholars of technology developed the idea of technology paradigms (Johnston 1972), and subsequently worked to show how technological practice also becomes bounded in acceptable, or normal forms (Dosi 1982) which may limit what is seen as feasible technical developments (Nelson and Winter 1977). Overall, technical change was seen as being dominated by slow incremental steps (Constant 1980; Dosi 1982; Lauden 1984) which were outcomes of both the material nature of the technologies as well as the ideological action of the experts within the disciplinary paradigm (Dosi 1982).[27]

Work by STS scholars has continued to analyze the notions of paradigms and boundaries, but has increasingly been looking at the ways in which the boundary work concept needs to be expanded, especially in regards the developments of interdisciplinary research fields (Frickel 2004; Hinrichs 2008; MacMynowski 2007; Peine 2008), and the interactions of science, scientists and social change movements (Eden, et al. 2006;

[27] The early work in technology innovation following out of the sociology of knowledge studies has been largely subsumed in recent years by the rising field of Innovation Studies, which though itself an interdisciplinary field has a greater than 50% affiliation with economic studies (Fagerberg and Verspagen 2009). Within this disparate field there is a proliferating number of approaches to the study of technological change, such as Technology Innovation Studies (TSI) (Hekkert 2007), Science, Technology and Innovation (STI) (Morlacchi and Martin 2009) and Socio-Technical Transitions Systems (Smith, et al. 2010), but the overall emphasis of these is towards studies geared toward policy and management solutions and away from Sociology of Knowledge.

Frickel 2006; Kinchy and Kleinman 2003; Moore 2008). Interdisciplinary research fields offer challenges to the notion of boundary work as a primary consolidator of a field of practice, as interdisciplinary work by its nature conjoins disciplinary bounded practices and thus makes complete closure on a shared identity difficult (Hinrichs 2008). Similarly, Peine (2008) points out that attempts to bring together different scientific paradigms into the new innovation field of Smart Homes[28] is hampered by incommensurable science paradigms, which can not be resolved by Khunian paradigm shifts. The solution proposed by Peine for overcoming this incommensurability is that the 'stable paradigms' interact together through an overarching knowledge frame that does not attempt to resolve the difference in modes of operation in the different fields.[29] Likewise, in analyzing developments in the fields of environmental science MacMynowski (2007) shows that the achievement of interdisciplinary work between the paradigmatically bounded practices of social scientists and biophysical scientists requires a level of reflexivity on the part of the scientists on their own knowledge making constructs in order to generate a 'synthesis' model for conjoined action. In a different case, Frickel (2004) shows how inter-disciplines generate weak boundaries around the field through the development of a shared framework, and that it is the explicit spaces of overlap and permeable boundaries of the component fields that aids in this new framing.

It is this new questioning of the mutability of disciplinary boundaries that also gives rise to questions about the relation of science practice to social movements. Though

[28] Smart Homes refers to the concept of integrated communications and computing technologies that can sense and manage a homes many services (heating,, cooling) and internal technologies (lights, refrigerators, sound systems, etc.)
[29] Peine compares this coordinating frame to the Mode 2 form of knowledge production advanced by Gibbons et al (1994).

the field of Sociology in general has had a strong tradition of studying social movements, scholars in the Sociology of Science have only recently been working to reframe the categorization of social movements as “contentious politics” to a more inclusive understanding of movements, thus creating a space for the Sociology of Science to more directly intersect with social movement studies (Frickel and Moore 2006). Realizing that the boundary work done to separate science from perceived realms of non-science is in continual development (Gieryn 1999; Eden, et al. 2006), and that this boundary work can be done by scientists out of internalized concerns about judgments from others rather than their own fears about their scientific objectivity (Kinchy and Kleinman 2003), scholars are calling for reevaluations of the conceptualization of science practice as necessarily being distinct from social movements (Moore 2008). Frickel (2006) points out that scholars of social movements need to acknowledge the ways in which the normal processes of science, and the subtle choices of action pursued by science groups can constitute forms of social movement that can be just as effective as “noisy’ activism. Similarly, Woodhouse and Breyman (2005) analyze the way in which the development of an entire scientific field can be seen as an instance of a science movement through his historical evaluation of the development of Green Chemistry. Thus, rather than seeing technology only as bounded paradigms that change only slowly and in directions predetermined by the dominate paradigm, the possibility of change through the action of scientists and technologists working from within the paradigm is also possible.

Over the three realms of Anthropology of Science and Technology, Science and Technology Studies and Sociology of Science scholars have been converging on the need to reinvigorate studies of scientific and technical practice with a more nuanced understanding of how the processes of science and technology interact with, or are constitutive of social movements.[30] With ecological modernization positing "the centripetal movement of ecological interests, ideas, and considerations in social practices and institutional developments" (Mol 2009), questions about the role of environmental scientists, or environmental technicians thus comes to the foreground. Are individuals in these fields to be seen as merely reacting to concerns about environmental conditions that are generated by outside social movements, or are these individuals themselves, and the practices which they enact somehow also a movement, are they in fact better understood as a science movement?

Hess uses the idea of "processual approaches" to distinguish those TPMs that are focused on developing technology objects and processes that examine "more deeply design issues across the product life cycle" (Hess 2007a p.240). These processual approaches seek to change the way in which science and technological practice form their objects and to subsequently 'redesign' society. In regards these processual approaches Hess states

> Many organizations that advocate and practice ecological design have a processual approach; among them are advocates of zero waste, industrial ecology, biomimicary, cradle-to-cradle design, closed-loop manufacturing, and living machines. When combined with zero emissions and a renewable energy source, those approaches to ecological design best articulate the concept of "redesign" as environmentally oriented innovation. (Hess 2007a, p.240).

This idea of 'processual approaches' is similar to the posited outcomes to science and technology under an ecological modernization world

> Science and technology become contributors to environmental reform…[and] conventional curative and repair options (such as 'end-of-pipe' technologies) are replaced by more preventive sociotechnological approaches that incorporate environmental considerations from the design stage onward.

[30] As well as making calls for science studies scholars themselves to become more actively involved in social change themselves (Woodhouse et al. 2002).

The question then is whether these design reforms are best understood through Hess's lens of incorporation and complementarization, or are they better understood as instances of science movements in themselves.

Conclusion

Thus in the particular case of the practices and field of designing with ecosystems, the challenge becomes understanding the history and processes of the development of the various realms of action in designed ecosystems. Discovery of complementarization will rely upon understanding these technologies as they have changed over time as well as understanding the various constraints that might have lead to elements of complementarization. In contrast explication of these technologies as potential science movements in their own rights requires an investigation of the goals, desires and actions of the scientists and engineers involved in their production and dissemination. If designing with ecosystems is an instantiation of the general ecological modernization trend, then the theoretical frames of complementarization and science movements provide a means to investigate just how "conventional curative and repair options (such as 'end-of-pipe' technologies) are replaced by more preventive sociotechnological approaches that incorporate environmental considerations from the design stage" (Mol 2003 p. 311).

CHAPTER 3

METHODS

> In 'forgetting' the collective inquiry in which he is inscribed, in isolating the object of his discourse from its historical genesis, an 'author' in effect denies his real situation. He creates the fiction of a place of his own (*une place propre*). In spite of the contradictory ideologies that may accompany it, the setting aside of the subject-object relation or of the discourse-object relation is the abstraction that generates an illusion of 'authorship.' It removes the traces of belonging to a network -- traces that always compromise the author's rights. It camouflages the conditions of the production of discourse and its object. For this negated genealogy is substituted a drama combining the simulacrum of an object with the simulacrum of an author. A discourse can maintain a certain scientific character, however, by making explicit the rules and conditions of its production, and first of the relations out of which it arises. (Michel de Certau *The Practice of Everyday Life* 1988 p.44)

Methodological Theory

Meso-level Studies

Ecological modernization theorists have pointed out that the type of studies done in their bailiwick generally have a macro-economic and institutional structures level of analysis. Thus in attempting to look at the ways in which a science and technology have become inculcated in the ecological modernization process other theoretical/methodological framings are necessary. As discussed in Chapter 2, Hess's concepts of complementarization and the corollary development of 'science movements' provide a set of analytical frameworks for focusing on technology- and product-oriented movements, but leave open the question of how one should empirically address a study of a particular TPM. Because of the iterative process of change that accompanies the process of complementarization, coupled with the fact that for many TPMs this is a current and ongoing process, one cannot rely simply on historical analysis. For further guidance on how to approach a study of the changes in science and technology under ecological modernization it is necessary to turn to scholarship in technology studies. A number of different theoretical trends in technology studies exist. However these perspectives either focus too narrowly on the human element in technological innovation and ignore the larger societal structures that might be impinging upon that innovation, as has been the critique of social construction of technology (SCOT) theories (see Klein and Kleinman 2002), or take such a sweeping and total view of technological change and progress as to create grand master narratives of 'technological momentum' that leave little room for micro level processes in the analysis (Hughes 1987; Hughes 1989). Similarly, it is acknowledged that science and technology in practice happen in diffuse spots, and researchers are being encouraged to consider such production as occurring throughout networks of people rather than focusing narrowly on individual lab dynamics (Knorr-Cetina 1998; Latour 1987). Researchers are also being encouraged to consider such production as outcomes of interactions between multifaceted human and non-human actors (Callon 1986; Law 1987; Murdoch 1997). Sørensen and Levold (1992) proposes the necessity of meso-level analysis that bypasses the limitations of either the micro, or macro forms of study.

> Consequently we are in a situation in which innovation is usually explained either in action terms (individual scientist, engineers, or organizations) or in terms of the national economy and government polices. Moreover, we seem to be given the choice of strong assumptions of either the fluidity of sociotechnical relations (constructivists) or lack of such fluidity because of structural limits (economists). This is not satisfactory, because there are very important "intermediate" institutions and institutional arrangements (networks) involved in technological innovation, and they are neither fluid nor determined (Sørensen and Levold 1992 p.14-15)

The authors argue that technological enterprises, especially as practiced by engineers, end up occurring across diffuse spaces and networked institutions and that to study such technological practice, different praxis is required on the part of social science researchers (Sørensen and Levold 1992). They posit that to study technological innovation one needs to do it at the meso-level of institutions and inter-institutional linkages. However, drawing on Polyani's notion of the "tacit knowledge" that can underlie any set of practice (Polyani 1967), Sørensen and Levold stress that much of what is done in technological innovation comes from the tactile, hands-on, element of design and redesign that characterizes the doing of engineering.

> It is difficult to dismiss the claim…that technology, as a body of knowledge and institutions for producing knowledge, is far more than what can reasonably be subsumed under the concept of engineering science. Development of technology still involves activities better described by the metaphor of art than of science. Practical intuition and a developed "engineering gaze" are frequently more important than calculations and analysis (Sørensen and Levold 1992 p.19-20).

With this tactile doing, forms of knowledge are created that are embodied in the engineer and not easily amenable to communication. There are two outcomes of this attention to the tactile action of engineers. One is that the embodied knowledge of engineering practice, and thus the engineers and the network of institutional spaces in which they work, themselves become objects of interest.

> This [tacit knowledge] may prove to be another argument for the importance of the surrounding institutional arrangements in understanding technological innovation. Locally available knowledge – explicit and tacit – embodied in living persons is known to be critical to innovation. This availability depends upon the workings of different institutional arrangements, for example, mobility patterns of engineers and others with desired competence or the local market of materialized and immaterial knowledge (Sørensen and Levold 1992 p.20-21).

Secondly, a focus on the tactile, hands-on elements of engineering design not only focuses attention on the engineer, but also fixes the social scientist's research gaze fully on the material reality of the technology undergoing the design, redesign, manipulation and other actions of the engineer.

In Sørensen and Levold's meso-level studies the actions, reactions and obstinacy of material objects and the desires, actions, mediations and manipulations of human beings become necessary sites of observation in a study of technological innovation. By adding this focus on the material realm to the more historical, and process oriented complementarization as posited by Hess, a framework for the analysis of ecological modernization (wherein technological process are replaced by "approaches that incorporate environmental considerations from the design stage onward") can be constructed. However, such a conjoining of levels of analysis, through multiple spaces and incorporating a focus on the material reality of the technological innovation leads to a final consideration. As they state:

> There is also a methodological lesson here, bearing on the limits of 'following in the footsteps of scientists and engineers.' The problem is that the terrain on which engineers and technological scientists move has been thoroughly shaped by previous actions. To encounter the historical processes that have brought about, for example, the available infrastructure of competence, skills, and knowledge through observation of engineer/scientists, is –to put it mildly-difficult. For this task, a heterogeneous mix of historical, ethnographic, economic, and sociological competences seems required. The infrastructure of technology's analysts may never be the same (Sørensen and Levold 1992 p.32).

Polymorphous Engagements

> All the data that one collects to construct an understanding of a phenomenon do not necessarily come from the predetermined object of study (Gustavson and Cytrynbaum 2003, p. 267)

Concomitantly with intense discussions of what constitutes the location or site of anthropological enquiry (Gupta and Ferguson 1997; Marcus 1995) has come discussions on how studies can be achieved in light of the added difficulties that mulit-sited work can make for one of anthropology's key self identifiers – participant observation. If "site" is no longer a reference to a singular physical location, or even necessarily a physical location at all, and if the question of interest is about a problematic that intertwines scientific and technical and cultural milieus, than the research might need to adopt an approach that itself moves beyond the "citadels" of place-based science and engages with the material in a more diffuse or "rhizomatic" manner (Martin 1997). Gusterson (1997) proposes the concept of "polymorphous engagements" as a helpful denominator of the multiple and messy ways that one can collect data when studying up[31]. This polymorphous engagement acknowledges the eclectic sources – multiple sites, electronic communications, published reports and interviews – that one can, and might need to draw on to effectively study, or study within, some communities. Gusterson's polymorphous engagement not so much devalues participant observation as decenters it as "our own parochial rite of passage."[32] Thus the site of research may become multiple in space or even have to move to a virtual space, following individuals, conversations and metaphors. With a diffuse techno-scientific community whose practice exists in many places and who share and create community through publications, on-line communications and professional meetings, adopting Gusterson's prescriptive to polymorphous engagements makes sense.

Thus, in *toto,* this research project draws on work from multiple sites, including a number of physical sites, as well as on-line discussions, popular media, books and textbooks and peer reviewed journal articles on ecological engineering and ecological treatment systems. In the physical sites, the research draws upon participant observation for grounding and orientation on major themes. While at physical sites, interviews and pile sorts were also conducted. More detailed discussion of these follows.

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[31] Anthropologists are being encouraged to study-up, to engage with, and within, sites of power, such as banks, manufacturing firms, government agencies, military, or the very wealthy (Gusterson 1997; Nader 1972). However, it has been noted that in addressing these calls to study up "anthropology's traditional taste for the marginal and exotic has not so much been transgressed as imported and transposed" (Gusterson 1997). Repatriated anthropology has still focused more at the margins of power (e.g. sub-altern city cultures, drug culture, undocumented immigrants), and where anthropology approaches studying up, this too has often been done dealing with the edges rather than the center of powerful institutions, for example the intersections of feminist movements or alternative medicines with mainstream medical practice (Hess 2003a; Martin 1987; Rapp 1997). These moves have caused many to question and reconsider the notion of studying up, preferring instead to think of studying across, or studying within (Priyadharshini 2003; Reid 2000).

[32] But isn't this also already the case with the push towards research projects designed and constructed around a hypothesis testing model. The necessary emphasis of such manœuvre on formalized methods necessitates a devaluing of participant observation to simply an ancillary activity rather than the centralized space of discovery.

Methods

Participant Observation

Not all studying up projects are as limiting to participant observation as Gusterson's case (working on and in nuclear weapons laboratories), but the nature of research sites and the work done in realms of science and technological production do still lead to different forms of participant observation. One element of difference is that the place of immersion might be more narrowly circumscribed to the particular business or research center. Access to individuals and their work might be garnered in their office and research spaces, but that does not necessarily transcend to after hours interactions. But this isn't necessarily problematic, if the questions one is interested in have to do with the work space productions rather than whole life constructions of individuals. What this limitation does do, is make the participant observation more of a 9-5 job than a 24-hour emersion into another cultural milieu.

But, 'being there' is still an important element of anthropological work when it can be done. For my research being there in the *mise-en-scene* of the office spaces - with artistically painted adobe walls or tightly packed carrels, with desks layered with design plans and reports, with the ubiquitous presence of sacks of soil or jars of gravel scattered throughout the spaces, with the dank musty smell in the mud room and the notes in the kitchen admonishing those who would leave dirty dishes in the sink – one feels (and smells) work in progress. In each physical site being there allows one to hear the discussions of the mundane and trivial as well as those 'aha' moments of science making. Being there, one hears the day to day joking and jabbing of colleagues as well as the hard negotiations on the phones about timelines and contractors (and sub-sub contractors).

One hears the groans when the office manager says ‘we need to work on our billing reports’ and one can commiserate with the researcher whose auto-sampler is on the fritz (again). Being there in short allows for the richness in understanding of researching, scheduling, designing, selling, managing and compromising that goes into actual eco-technological implementation. Similarly, one can ‘be there’ in polymorphous ways – whether taking part in on line communications, or in the corridor talk at conferences, or digging deeply in the literature of the field.[33]

In some locations, after a certain point, ‘being there’ can have limited returns. Though every site likely has its nuances and its interplays such that whole studies could be made of individual offices, companies or research labs, if one has framed a research project that intersects multiple sites then the inflection point of returns to time investment might need to be more carefully watched for than in single site research projects. At some point, ‘being there’ and ‘participating’ will no longer yield as rapid a rate of insights. This is not because participant observation doesn’t provide important insights and understandings, but because access to types of participating, and thus types of knowledge acquisition, can be constrained by many barriers. Legal or security issues might prevent a company or research center from allowing a non-employee from participating in certain chores (“I can’t let you help on the system, as your not licensed”). Similarly, participation might be barred or hindered by lack of appropriate knowledge, and thus offers to engage in helpful activities in such settings might be limited to more menial activities – like washing lab equipment or organizing storerooms.[34] And finally participation in

[33] Perhaps even contributing to the literature if all goes well.

[34] Both of which activities I did and received what I thought were strangely perfuse thanks, until put in the context of the limiting factor for many researchers (whether at an NGO, or university or private company) is Time. And any time that you can spare someone from necessary menial labor is often highly appreciated.

engineering design companies (and even at a university research park), can be limited by the fact that much of what is done is done on computers.[35]

Throughout the time spent at various sites participating in whatever manner possible, notes were taken on activities observed and throughout the time many 'interviews' were taken opportunistically. These opportunistic interviews differed from the more formal interviews in that they were not recorded, and often only could cover a couple of questions of interest. These opportunistic interviews were important for rounding out understanding of observed activities as well as for directly addressing some of my more specific research questions. At the business fieldsites, the use of informal interviewing was very important as access to the time for a formal interview was limited.

Semi-Structured Interviews

A set of specific objectives guided the overall goals of the multi-sited field work in general and the interview template construction in specific. These research objectives were 1) To identify and describe the reasons why individuals became involved in the innovation and adoption of ecologically engineered ecotechnologies along with their goals and aspirations for ecotechnologies and ecological engineering; 2) To identify and describe differences and changes in the definitions of ecotechnologies and ecological engineering; and 3) To identify and describe differences and tensions amongst the participants in the innovation and adoption of ecotechnologies. From these objectives two interview guides were created. One was for individuals involved with an adopted ecotechnology, and the other was for individuals involved in the design, implementation or research on ecotechnologies and ecological engineering. Though the guides were used

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[35] This element of what constitutes work at one business I visited, was a key element in my decision to only stay for one month, there was not that much more to observe or participate in by staying longer in the role that I had.

to direct the interviews, these were more of a loose framework than a rigid set of questions that were asked of all informants. Some of the questions were unnecessary in some cases (that information having been collected in a prior conversation for example) or not relevant to the person or case under discussion. Also, at times the formal interview was being done under time constraints such that discretion had to be taken in which questions were the most important to get answered.

In total 48 'formal' semi-structured interviews were done and digitally recorded.[36] 47 of these were transcribed from the digital file. The remaining interview was reconstructed from notes taken during the interview when the digital file was found to have failed.[37] I designate the above as 'formal' as these were done in a context where both participants (interviewer and interviewee) were goal-directed including the ritual of setting up the tape recorder.[38] I distinguish this, as there are also 8 complete interviews that occurred under more spontaneous conditions (mostly at AEES meetings) that ranged over most of the questions that would have been included in a more 'formal' interview. These interviews were not recorded, but once I realized I was talking to an individual who was willing to talk for a while on the subject at hand, then I would do an informed consent and administer the formal questions of the interview protocol.

Pile-sort

A more structured element was also included in the interviews. A pilesorting task was used to understand the ways in which individuals thought about the relationship between various academic fields and disciplines and their relation to ecological

[36] On an Olympus DS-2200. One of these interviews had two participants, all the others were with individuals.
[37] Likely a user error, as this was one of the first interviews recorded. And which proves one should always take detailed notes even if 'recording.'
[38] And doing an informed consent, if they had not done one previously.

engineering. Pile-sorting and other systematic data gathering in anthropology is largely tied to cognitive anthropology and subsequent interests in determining informant accuracy and cultural consensus (Bernard 1995; Munck and Sobo 1998; Weller and Romney 1988). To develop models of consensus from pilesorts, researchers suggest both doing constrained pilesorts (where categories, and number of piles are given by the researcher) as well as doing sequential pilesorts in order to remove the lumper/splitter problem that limits the ability to compare across individuals. However, these sequential pilesort techniques require substantial time during the interview (Borgatti 1996; Gatewood 1999a; Gatewood 1999b; Weller and Romney 1988).

Other academic traditions use pilesorting (or card-sorting) tasks less as the basis for attempting to create valid representations of cognitive categories, but as a heuristic method for the task at hand (e.g. web interface construction, knowledge management tools). In these cases the criteria individuals use to sort and the categories they make are of import to the researcher perhaps even more than is the interest in finding the singular cultural consensus on those criteria and categories (Hannah 2005; Rugg and McGeorge 2005). The pile sort in this study was conducted to provide insight into critical differences and criteria for judging similarities of ecological engineering to other fields, rather than using the pilesort as an attempt to find a singular correct, or cultural consensus, on what that relationship is[39]. Using the pile sort as a heuristic tool in this way allows it to be employed in a manner that doesn't dominate the limited time available in interviews.

The pile sort task involved 22 cards that listed a variety of disciplines and fields. These 22 terms were: Ecological Engineering, Environmental Engineering, Civil

[39] Though there was a surprisingly high level of consensus found.

Engineering, Agricultural Engineering, Biological Engineering, Mechanical Engineering, Chemical Engineering, Industrial Ecology, Environmental Science, Sustainability Science, Green Engineering, Green Chemistry, Bioremediation, Ecology, Wetlands Ecology, Ecosystem Restoration, Restoration Ecology, Biology, Conservation Biology, Natural Resource Management, Ecological Design, Landscape Architecture. These terms were selected on the basis of their potential shared borders with ecological engineering and were derived from literature and preliminary fieldwork. This pilesort activity was beta tested on University of Georgia engineering students. From this beta testing a second pilesort on various ecotechnologies was eliminated as being too time consuming for the information garnered.

In the course of the research this pilesorting task was done with individuals who were academically involved in ecological engineering– whether as a faculty, or as a graduate students participating in some manner with ecological engineering. Individuals were asked to do an unconstrained pile sort[40] and then were asked to explain why they had sorted the way they had and to explain the groups they had created [41] (Bernard 1995; Roos 1998). Though this task was done at the beginning of the interview, and individuals were only told to sort the cards into piles of things that 'they thought go together,' this pilesort task functioned similar to an anchor point sort, in that ecological engineering was largely a defacto anchor point around which people sorted because of the nature of the structure of the interview and my very presence. Most people that I interviewed knew that I had an interest in, and was present at the University, to talk about designing with

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[40] In an unconstrained pile sort individuals can make as many or as few piles as they like
[41] One of the most common things said at the end of the pile sort was – "That was fun".

ecosystems and ecological engineering. This task was performed by 40[42] informants and data were analyzed using Anthropac 4.0 and SPSS 16 softwares (Borgatti 1996; SPSS 2008).

Sites

Preliminary Sites

Prior to setting off on the 'fieldwork' portion of my research[43], I had already been immersed in a number of actions which, in the larger frame of polymorphous engagements, can also be constituted as sites. As I was working in the US with a technical and scientific community, I needed to speak the 'language' of my field site. To this end I took a graduate course in wetlands ecology, and audited two undergraduate engineering courses. The first was Environmental Engineering and the second was Natural Treatment Systems.[44]

To further my understanding of issues in engineering education I also did a three month fellowship at the National Academy of Engineering in Washington DC. The fellowship opportunity was funded by the Christine Mirzayan Science and Technology Policy Fellowship Program. At the NAE my main task was working on the preliminary start up of a database on engineering education innovations and interventions (PR^2OVE-IT) for the Center for the Advancement of Scholarship on Engineering Education

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[42] The discrepancy in interview number to pile-sort number is one of those things that happens. Some folks did not have time for a full interview and only did the pile sort. A few folks only did the interview and not the pile-sort as we were conducting the interview in a moving car.

[43] Or framed another way, the portion of this dissertation that was conducted and funded under an NSF grant.

[44] The engineering courses not only familiarized me with technical language, but also gave me insights into engineering education and engineering culture making. See Downey and Lucena for a good discussion of the ways in which engineering classes produce engineers (Downey & Lucena 1997) This production of 'engineers' occurs at many different levels, from formal knowledge and skills to stylized and cultural behaviors. For example, after turning in my first homework on lined paper, the instructor (knowing I was an anthropologist learning about engineers) gave it back to me and said with a smile that I should get graph paper, and then he picked up my ink pen from the table and shook his head at me. "You need to get one of these" he said pulling out the mechanical pencil from his pocket. And I did.

(CASEE). However, I also participated in project proposal meetings on green engineering, helped organize the planning meeting of a national engineering challenge prize, participated in numerous NAE staff meetings, as well as generally interacting with staff working on other national Engineering issues. My participant observation at this national center helped frame my research questions in regards to the development of Ecological Engineering as a discipline.

Early in planning this research I made a preliminary visit to what I hoped to be one of my formal sites. I volunteered for a month at the not-for-profit Ocean Arks International. Establishing this contact had been difficult, but perseverance paid off[45]. At the time OAI had a small office in downtown Burlington and in South Burlington there was a green house complex with one of the classic Living Machines, and a couple of aquaculture experiments. In the green house I helped out with some general maintenance (mainly cleaning chores) and in the office I did data entry work and some preliminary library research on methane generation from cattle manure for one of the staff members. While there I was generously included in a weekend short course on living machines that was taught and I also tagged along on a number of tours that were given in the greenhouse. Unfortunately my desire to return to OAI during my formal fieldwork season was stymied by the downsizing of the OAI staff and the closing of both the office and greenhouse experiments that was occurring at that same time period.

[45] Subsequently I learned that the staff there were overwhelmed with calls and emails requesting visits. The center was well known for its alternative technological approach, and at times was almost overwhelmed with individuals interested in visiting or working at the center. In fact one formal engineering internship that was offered by OAI had individuals with 20+ years experience applying for the non paying internship.

Longer Stay Sites

University

The first longer term field site was at The Ohio State University. This school was chosen as a field site for a number of reasons. OSU has high visibility in the ecological engineering community, with the lead figure of Dr. William J. Mitsch, a former student of H.T. Odum. Dr. Mitsch is credited with starting the journal of Ecological Engineering as well as being a prime mover behind the development of the American Ecological Engineering Society. But not only does this school have a lead figure (the other schools do as well) but the ecological engineering program is explicitly housed between three different departments and students involved in it could be getting degrees in four different fields (The School of Natural Resources, The Department of Food, Biological and Agriculture Engineering, the Department of Civil and Environmental Engineering and Geodetic Science, or The Environmental Studies Graduate Program). Though the OSU ecological engineering has high salience in the ecological engineering community, it itself is actually not that old. Following on negotiations at the University, three faculty positions were created specifically to create this program. These positions were advertised with the opening of "The Ohio State University is embarking on an ambitious plan to develop a comprehensive academic program in the new field of Ecological Engineering" and the hiring for the positions was in 1999.[46] Selection of OSU for the longer-term field stay was also supported by the fact that OSU had an active student Ecological Engineering Society (which other Universities were not manifesting) and was going to be the site of the fifth annual AEES conference. All of these factors contributed

[46] http://ces.iisc.ernet.in/hpg/envis/doc98html/jbfac99115.html "Subject: Three Faculty Positions in Ecological Engineering at the Ohio State University"

to my decision to approach OSU as a fieldsite, and as Dr. Mitsch graciously accepted my proposal, that is where I went.

At OSU my main base of operation was from the Wilma H. Schiermeier Olentangy River Wetland Research Park (ORWRP). This is the full name given to a space of land nestled into a bend in the Olentangy River. The research park includes the river riparian zone, the two internationally famous, constructed, kidney shaped wetlands, and the oxbow wetland (called the Billabong), a mesocosom compound, and the Heffner Wetland Research and Education Building

The kidney wetlands have been operational since 1994, but the Heffner building was newly constructed and newly occupied (since March 2003 only). The Heffner building was where Dr. Mitsch's students now had their workspace and where I too was given a desk. From this base, I attempted to integrate myself into the many activities at the center. After a time I got to help with some data collection activities among the students.[47] Indoors I participated in lab meetings and presentations. I also helped with some of the perennial tasks which included doing a stint of the daily wetland sampling and leading educational tours for visiting school kids.

Because the ecological engineering program is spread between many departments, I also visited those other 'labs' as I could (though I did not 'hang' out there as I did at the ORW, as they weren't situated for that as the students more worked from carrels or as in the case of the lab of the civil and environmental engineering faculty both of his current

[47] Early in my stay at ORW, Sandy approached me as I sat at my desk and asked hesitantly "were you serious about helping us in our field work?" "Oh, yes definitely" my voice probably loud with eagerness and hope. After the first days of sitting at my assigned desk, typing up such notes as "John, Anne, Carolina, Craig, and Jane are all at their desks working on computers. …." I was a bit in despair as to whether my participation would ever amount to more than companionably also sitting at my desk working on my computer.

students were in phases of their work that had them tied to the computer all day – one in finishing his thesis write up, and the other in working on his model of particle movement in turbulent stream flow – important, but not so interesting for an anthropologist to watch). While at OSU I also informally audited a course in Ecological Treatment Systems being taught by ecological engineering professor in the Food, Biological and Agriculture Engineering program. This was a mixed level undergraduate and graduate course and I participated in the lectures and observed the lab section (but didn't run my own experiment). Part of this class experience included a field trip to tour the Adam Joseph Lewis Center at Oberlin College and to interact with the living machine at the Center. While I was at OSU in the spring the Annual meeting of the Ohio Center for Wetland and River Restoration (OCWRR) met and I was able to observe there for the day. And finally I participated in meetings and activities of the student Ecological Engineering Group. In total I spent five months in and around OSU, split between the spring visit and a return visit in the winter.

Engineering design company

Another field site was an engineering design firm that specialized in decentralized water and wastewater technologies, whose logo reads "Hands-on, ecological engineering providing practical, innovative solutions." North American Wetland Engineering was founded in 1997 by two engineers, Scott Wallace and Curtis Sparks, who saw the need and opportunity for a company specializing in decentralized systems and wetlands. From starting on their own in 1997 and securing the firsts permits for a 'cluster wastewater' system in their home state of Minnesota, they rapidly grew and by 2005 were a company of 19 employees, with two sister-companies as well.

One of these sister companies, EcoCheck was formed in 2002 to provide operations and maintenance for the small decentralized treatment plants that NAWE was constructing. In 2005, which was the time of my visit, NAWE had been "involved in over 200 wastewater and water projects in throughout the United States, as well as in 3 foreign countries"[48] and EcoCheck was managing over 40 systems (many of which were designed by NAWE) in their home state. The company designs water and wastewater systems for municipal entities as well as for particular residential areas and developments. They also do wetland designs for industrial clients for water and pollution management through phyto and bioremediation[49].

In starting up the company the principle engineers also invested time and money into research. Their original workspace in a garage, included both office cubicles and work space where in they investigated how to improve wetland functionality. Out of that research came the five patents on wetlands for wastewater treatment filed by Scott Wallace, the Executive Vice President of NAWE.[50] The rapid growth of the company lead to their moving to a larger office complex in 2002, but they maintained the garage as their store room. During my visit in 2005 they had just signed a lease for an even larger work space, which would join their offices with storage and research space in a building that was being newly built. Though not the complete green building that NAWE's President Curtis Sparks hoped to be able to build in the future, the plans for the move and making the office as green as possible were ongoing while I was with them at the old

[48] From company promotional material
[49] In 2007 they joined with the large 100% employee owned environmental consulting services firm Jacques Whitford and for a period of time were known as Jacques Whitford NAWE. Jacques Whitford was then acquired through favorable employee shareholder vote (98%) by Stantec. That acquisition was completed on Jan 2 2009. http://www.stantec.com/news.html#news97
[50] 4 in the US, one in Canada

office space. Discussions of which brand of office furnishings they would go with and the relative greenness of the different companies occurred at the staff meetings and tasks like researching and planning a kitchen vermiculture bin, and the selection of green cleaning supplies were parceled out among the already very busy employees.[51]

While I was with NAWE I was not given any specific tasks to do, but was rather given the opportunity to oversee (and overhear) a wide diversity of the projects and issues that were occurring while I was there. The move to the new office was much looked forward to while I was at NAWE, as the rapid growth of the company (4 new engineers in the last year) had made the current office that much more cramped. This office can be imagined largely as a giant squared off U. In the left hand (or east side) of the U were the offices of the president, the business manager and her assistant and the much in demand CAD[52] guru and the desks of the EcoCheck workers.[53] Along the bottom of the U was the conference room and kitchenette. In the space between the arms of this U, was a large open and inviting reception area. On the right hand (or west side) of the U was the office of the Vice-president[54] and the crowded work spaces of the design engineers, soil scientist and construction oversight engineers. The top of the arm of the U had four carrels and a library shelving unit stuffed with books on water regulations, wastewater treatment systems and many journals including Ecological Engineering. Down the center of the arm was the walking path. On either side were two bays, completely lined with desk-counter space which left only a small opening out to the walking path. These

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[51] While I was there, the company was so busy with projects that many of the engineers were working 10-12 hour days regularly to get the design work done.

[52] Computer-Aided Design- takes the conceptual models of the engineers and formulates them on the computer. At the time I was there NAWE was looking to hire another CAD worker.

[53] Who often were not around the office, as their job was to travel all over the state checking and maintaining the wetland treatment systems

[54] Which contained a totally article covered pool-table.

counters ran along the walk path and were generally clear of the paperwork and folders and office detritus that covered the inside of these work bays. Two workstations were inside each bay. When I showed up at NAWE I was shown to this section of the office and I was installed in the open arm of the left hand bay. I was thus set in the center of the engineering complex. I could overlook a number of desks, and hear most conversations (but that was just like all the other engineers, it was tight quarters). Overall, the office was dominated by the essence of its functionality – but with the standard office fluorescents and crowded cubicles the ambiance of the physical space was such that one could understand the excitement for the move.

However, by the vary tightness of the quarters and the centrality of my desk I got to see and hear a lot of the daily work and conversations of the engineering side of the company. I was also actively included in a number of staff meetings, client meetings and I was even invited to sit in on a phone consultation between one of the construction oversight engineers, the business manager and the company's legal counsel. I was taken into the field and witnessed projects at many different stages, including initial site surveying and soils testing, a project report for a township, and systems maintenance. Throughout my stay, I was able to follow up on my observations with directed questions about what I was seeing and hearing and was even able to squeeze in some formal interviews.[55]

Green architecture and engineering company

The second company that I spent time with was a joint enterprise of architects and engineers that specialized in integrated building designs that incorporate elements like

[55] One of which got so involved while we were driving back from a site visit, that we forget that we had planned to get off at the next exit for gas, and then did actually run out of gas. I guess my interviews were pretty intensive.

passive solar, geothermal, and solar voltaics for energy, and have integrated water and wastewater management systems that consider both the interior water systems, and water that runs off the buildings and over the building grounds. At the time in 2005 these enterprises were conjoined under the parent company Dharma Living Systems and was comprised of the architectural group, Living Designs Group, and the water and wastewater engineering group known by the moniker Living Machines. The ecological designer and lead engineer[56] of Living Machines had been with the earlier incarnation of the company, Living Technologies, when that firm was based in Vermont. The current company was now the owner of the Living Machines trademark and after having spent a couple of years in research and development, now had 7 patents on file (5 granted, 2 pending in 2005) for the newer generation of living machines.

The company office was located in Taos (though a sister office was being opened in Florida that year as well), and though a small company, it was doing design work throughout the US. The character of the office was set by the adobe building material and its house-like layout. Arched doors and tile floors complemented the cool tan adobe walls sprinkled with detail painting around doors and on walls. A large center area dominated the space when you entered, with the office manager's desk on the right. Through out the main room was an arc of tables and cabinets liberally covered with large sheets depicting various forms of architectural drawings and renderings. The desk of the company president, and lead architect was in this space, as was another workspace. Off to the left of the room an open doorway led to another room. This room was dominated by the presence of computers more than design drawings – but they were present there as well.

[56] Another engineer who had been with Living Technologies had only that spring (2005) left Living Machines. These three individuals were the inventors of record for the 7 patents on hypdronic and wetland style waste water treatment that are owned by this firm.

In this space worked the design technician, another CAD guru as well as an architecture intern who had spent her summer with the company. To the right of the main door and office manager's desk a slight step up through a painted archway led to a galley off of which hung a number of offices. One of these offices was for the chief engineer of the company and the other for the lead ecological designer and landscape architect. At the right end of this hallway was a large kitchen and at the other end, a full bathroom including an inviting tub with artistic tiling and a generous stack of architecture and outdoor magazines next to the toilet. To the left of the bathroom, and basically tucked behind the main room was another room containing a large draft desk, a plotter and a workstation for one of the design engineers. In all the atmosphere of the office, by both the structure of the building and the attitude of the employees, was warm and almost familial. The well used bike rack in the front of the building and the large organic garden in the adjacent lot added to the overall tone and quality of the company environment. Environmental concerns and activities pervaded the company atmosphere and individual lifestyles of the architects and engineers. My interview with the lead engineer was done while he and I were in the kitchen cooking up organic greens fresh picked from the garden for our lunches.

During my month stay at this company I was treated more as an intern than just an observer and as such was included in meetings and given tasks to do. Throughout my stay I had more interaction with the engineering side of the firm than with the architectural working group. I was given a desk space (actually the large drafting table) in the large back room with one of the engineers and the plotter.[57] Throughout my five week stay I worked on a number of tasks including writing a PR statement about a new facility,

[57] The plotter gets a mention because it is so HUGE, and its physical presence dominated in the room.

creating (or attempting to create) some new marketing pamphlets on the new generation of the Living Machines™ and updating a couple of databases, including the data spreadsheet on their current and pending patent applications.[58] While with DLS I was able to visit the research facility that they had run and also was taken to the recently completed Living Resort that featured a newer generation of Living Machine. Overall, though this company was small, and everyone very busy all of the time with multiple projects, I was generously given the time and space to ask my questions and do my interviews.

Short Visits

University programs in Ecological Engineering

In between visits to my longer stay sites I also did short visits at number of other schools that are related to the ecological engineering field. These were University of Arkansas, University of California, Berkeley, University of Maryland, University of Florida, and the University of Vermont. The bias that exists in the sample is toward schools that have listed programs in ecological engineering and are (or were) active at the AEES meetings.

These schools were selected largely on the basis of opportunity (I was at Berkeley for the AEES conference, otherwise I wouldn't have had the opportunity to visit this school). But the schools represent a range of differing histories and current trajectories. Two of these, Florida and Maryland are usually listed with OSU as being the earliest promoters of the discipline. Berkeley is also considered one of the original schools with an ecological engineering program, but that program was largely centered around one

[58] And that was a true learning experience. The US Patent and Trademark Office website is really informative to search around in.

prominent scholar[59] who is now emeritus, with subsequent effects on the school's program. Arkansas represents the newer generation of ecological engineering programs. Some of these schools have ongoing and growing programs where as others have all but ceased having an active presence in ecological engineering (this would be the Vermont program). Some are more institutionally linked to Environmental Engineering (Berkeley, Vermont), whereas others are part of the Agriculture and Biological Engineering school (Arkansas). These visits ranged from a few days to a couple of weeks and had less participant observation than opportunistic foraging. I did interviews with faculty directly and indirectly involved with the ecological engineering programs. I also interviewed as many masters and Ph.D students who were linked to ecological engineering as I could cajole into sparing some time for an interview. Where possible I did pile sorts along with the interviews.

Eco-technology adopter sites

My other short visit sites were various sites that have or had adopted an ecologically designed wastewater treatment system. The sites I visited and did interviews at were: Paws in Muncie Indiana, Ethel M in Henderson Nevada, Smugglers Notch Ski Village in Vermont, The Anita B. Gorman Conservation Discovery Center in Kansas City Missouri, The Darrow School in New Lebanon, New York and the Center for Sustainability at Penn State in College Park, Pennsylvania. In these short visits I focused on the particular high visibility living machine technology (rather than wetlands in general). All of these sites were identified from internet searches on living machines. These sites were chosen on a basis of proximity to my longer stay sites and their visibility and salience in the literature. Other sites were identified and initial contacts made, but

[59] And past AEES president

due to timing circumstances I was unable to visit. At the sites visited, I largely ended up interviewing the current operator of the system. Due to the popularity of these systems, many of the operators were well versed in giving tours and a general overview of the system. At a few sites I was also able to talk to business coordinators or other managerial personal who knew some of the history of the technology adoption.

Corridor Talk

A final important site that developed over the project was the annual meetings of the American Ecological Engineering Society. I attended the first meeting in 2001 by serendipity, as it was taking place at my home university, the University of Georgia. Having read about Living Machines and having been enthused by the ideas of designing with nature I attended this first meeting and was thus introduced to Ecological Engineering as a concept. Subsequently as I was planning my research I attended the 2004 conference at the University of Arkansas, and then during my work at OSU in 2005 the conference was there. In 2006 the conference was in Berkeley, but I intentionally attended as the previous conferences had been so informative. In 2007 I both attended and presented at the conference at Kansas State University. And in 2008 I made it to the last half of the conference at Virginia Tech.

I kept returning to the conferences not just because of the fun, dynamic nature of the conferences but because they were amazing sources of information about the on going struggle to define and develop the academic and professional field of ecological engineering. Not only were the conversations in the business meetings, hall ways and in sessions great for general insight, but there was also at each conference highly reflexive panels and discussions on what the field was, how to develop curriculum and where the society was going. Of particular note in the last three years at the end of each conference a session titled "Open Forum" was lead for all conference attendees to reflect and discuss on the state of the profession and education. In 2005, for an entire morning after the conference a mini workshop was run on the current state of ecological engineering design knowledge and educational initiatives. Panels throughout the years have also included discussions of what a certification program should include and a panel with current professionals discussing their jobs and what they see as necessary inclusions in an ecological engineering curriculum.

Write Up

> "Who speaks and who acts? It's always a multiplicity, even in the person that speaks or acts. We are all groupuscles. There is no more representation. There is only action, the action of theory, the action of praxis, in the relations of relays and networks." [60] (Deleuze 2003, p.207)

Throughout this dissertation, various forms of representation are employed. By the nature of the research (a science and technical field that is small and unique) complete anonymity of subjects is impossible. This is similar to the problem Gusterson has had when writing up on research done at the national nuclear research laboratory in California (Gusterson 1997). The solution is to have flexible disclosure dependent on the type of information and the manner in which it was achieved. One can not very well discuss the field of Ecological Engineering while hiding the names of key developers and the same is true for the history of ecological treatment systems. Nor does it seem possible or proper to hide completely the company names and personnel who so generously allowed me to linger among them. Thus when speaking of historical events, or drawing upon published material (both peer reviewed and popular articles) proper appellations and affiliations are

[60] I really like the word groupuscles – not least because it brings to mind the corpsicles (reanimated dead) of sci-fiction. Not only are our actions and thoughts made up of myriad theoretical inputs which brings forth from us multiple positions, multiple interpretations; but alas sometimes these multitudes are nothing but the reanimated dead of outmoded ideas that perhaps should have been left to molder.

mentioned. Similarly, material from personal conversations and interviews is tied to the proper name of an individual when it bears upon laying out timelines and non-personal claims. In these cases the companies and company histories are not obscured. However, in the most part names are changed, interview data and personal conversations are anonyomized and where necessary identifying markers (jobs, school names or gender) are removed or changed.

Writing up and including material from the conferences also calls for careful consideration of both context and content. Conference talks and discussions are public events in so far as all attendees could participate, but they are private events as well as they are meant to be a venue for colleagues. I am a multi-year member and attendee of AEES, but my relationship to the field is inherently different then other members as I have been studying the field and its practitioners rather than being a practitioner and studying the subject. Many individuals at the conferences knew me, and my study interest, whereas others did not. My status as social science researcher and not just another conference attendee places me in a similar situation to the Professor who enrolled for a freshman year of college and then wrote an ethnography on student life (Nathan 2005). In these cases our unrevealed status as a researcher necessitates treating some conversations as off-limits for writing up, and for other material careful consideration of how it is denoted. In this write up, materials that were presented in formal presentation – whether conference papers or key note speeches are identified with the proper appellation. However in drawing material from the more informal and open discussions that occurred in the Open forums, at the business meetings and at the 'state-of-the-art' workshop, this material is anonyomized..

SECTION 1

DESIGNING WITH ECOSYSTEMS: PRACTICE AND DISCIPLINE

> If there are connections everywhere, why do we persist in turning dynamic interconnected phenomena into static, disconnected things? (Wolf 1982 p.4 *Europe and the People without History*)

In investigating the production, adoption and transformations in ecotechnologies that are premised on "designing with ecosystems", one quickly finds an interwoven network of individuals and technologies that are arrayed throughout academic and corporate settings. In the academic setting, a core group of actors is working to develop ecological engineering as a recognized discipline, with subsequent programs, certifications and standards. Outside of academia, companies and individuals are in the active process of designing projects and ecotechnologies based on using complex ecosystems as elements of the design. Constructed wetlands for the treatment of wastes and the remediation of pollution are a lead business application of designed ecosystems. In fact, constructed wetlands are often referenced as the flagship of ecological engineering, as these systems were where much of the original research and application were achieved.[61] Another example of "designing with ecosystems" is the family of wastewater treatment technologies that arose out of the appropriate technology movement of the 70s. The original iterations of these technologies, and their inventor John Todd, are well known in the alternative development community and these technologies have become iconic in the alternative technology world. However, these technologies are not only linked to alternative technology social movements, but are also considered examples

[61] Restoration of wetlands and streams are other major areas of active ecological engineering practice.

of the formalizing discipline of ecological engineering. These systems have been used as modules for lab experiences in "designing with ecosystems" for ecological engineering classes and are included in the rubric of ecological engineering in both of the recent ecological engineering textbooks (Kangas 2004, p 63-68; Mitsch and Jørgensen 2004, p.26).

Thus, messy inter-linkages of people, ideas, technologies and histories are found when one delves into the realm of designed ecosystems, the production of alternative technologies and the development of new fields of practice. However, it is possible to separate out two separate action zones of technological innovation in regards to designing with ecosystem. One is the social movement element of designing with ecosystems which is exemplified in the history of the development and deployment of living machines for wastewater treatment. Separate from this is the development of the new technical practice and discipline of ecological engineering. In the following section, I will provide detailed description of these two arenas of technological innovation. In Chapter 4, I will trace the history of the development and deployment of living machines and in so doing provide ground work for a critical examination of the usefulness of the concept of complementarization in understanding the processes of incorporating new ecological technologies into mainstream practice. In Chapter 5, I explore the development of the new disciplinary practice of ecological engineering and in so doing formulate the argument that it is possible to understand this case not just as a simple instantiation of disciplinary development through boundary work within science practice, but rather as an example of the subtle relationship between science and technical praxis and 'science movements'.

CHAPTER 4

DEVELOPING ECO-TECHNOLOGIES – FROM CREATION TO INCORPORATION

Introduction

Currently, if a person becomes interested in concepts such as ecological design or ecological technologies, it is likely that they will discover the idea of using ecosystem functions to provide solutions to problems. In particular if investigating alternative waste management or water management strategies, one is very likely to discover a particular set of eco-technologies and their inventor and advocate, Dr. John Todd. Dr. Todd is a highly referenced visionary in regards to the possibility of humans redesigning their interface with the natural world. In particular, he is known for his innovation and advocacy of environmental technologies related to the use of complex ecosystems to remediate environmental pollution. Todd's leadership in the environmental technology movement started with the development of integrated food production systems at the New Alchemy Institute. Following on this work, he developed a range of technologies that relied upon the use of interlinked ecosystems to perform water remediation functions. In the 90's, he began using the term 'living machines' to describe these general ideas, and over time this term became linked to a particular set of processes with a distinct image.[62] This chapter traces the evolution of both the idea, and material enactments, of living machines, and the institutions and individuals involved in their

[62] The classic image of a living machine was a series of large round tanks, topped with verdant growth all enclosed in a greenhouse.

development. The goal of this chapter is to trace the history of a particular appropriate technology from its roots in the environmental movement to its current deployment, and by so doing, to lay the ground work for evaluating the usefulness of Hess's idea of complementarization in understanding these developments in the idea of designing with ecosystems.[63]

The Environmental Movement and The New Alchemy Institute

The New Alchemy Institute (NAI) was an iconic and leading back-to-the-land and appropriate technology organization during the 70s.[64] The New Alchemy Institute was formalized in 1969 by Dr. John Todd, Dr. Bill McLarney and Nancy Jack Todd while they were living in San Diego, when the two men were working at San Diego State University; and was an outcome of the desire to do something solution-oriented rather than just "doom-watch biology".[65] Subsequently in 1970 when both McLarney and Todd took jobs at Woods Hole Oceanographic Institution, New Alchemy Institute became an

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[63] In tracing developments and deployments of the Living Machines technology the overlapping genealogies, intermingled personal and shared involvement on some projects makes it unclear at times which companies were developed when and with whom, and which projects were done under whose provenance. Even in interviews with technology adopters it was sometimes difficult for the informant to give a clear history of the adoption and development of the technology as either they were not present, or even if present, it was still unclear which company was doing what in relation to the development of the technology. (Though this can be typical of many engineering projects, as there are often many different firms contracted and subcontracted on particular projects). Concomitantly, in discussions and interviews around the subject of histories and relationships especially in regards to 'living machines' having been part of a legal struggle, some informants gave terse and carefully parsed stories, others were more expansive. Overall, in regards to this chapter and the history I narrate, due to various claims and counterclaims, the personal nature of some of the stories, and the legal issues in regards to proprietary technologies, this chapter will rely mostly on material that can be found in the public record, either through published articles, or online postings and discussions.

[64] (Clarke 1973)

[65] McLarney and Todd had been graduate students together at the University of Michigan, both with research interests in fish (Todd, 2005 p.6). The establishment of the legal entity of New Alchemy was itself the outcome of years of discussion on what could be done to enable "humanity to satisfy its needs without destroying the resources that provide them." (*Ibid.* p.12) Nancy Jack Todd (in Gilman1990) stated "We spent a year or so exchanging absolutely dismal news with each other, and then one day, with our friend Bill McLarney, we decided that this doom watch biology wasn't a very rewarding way to spend a lifetime. Wasn't there anything we could do to create an alternative dynamic to the very destructive one that we were currently engaged in, as members of industrial society? And that really was the birth of New Alchemy" See also (Brown 2001).

on-the-ground research center in Cape Cod, Massachusetts with the rental of a 12 acre farm.[66] Conceived as a research organization, the goal was to tackle the large problems of human-environmental interaction in integrative and interdisciplinary ways. Throughout the years work at the institute was conducted by combinations of paid staff, interns and volunteers. Most individuals lived in the surrounding area and traveled to work at the institute. Initially the institute only had two paid staff members,[67] but overtime the center grew to as large as 20 full time researchers.[68] Both Todd and McLarney left their jobs at Woods Hole and became full time at the institute in 1974.[69] Funding for the institute came from individual membership subscriptions[70] and grant funds. Throughout the years funding was a perennial issue.[71] In the 70's and early 80's, a number of larger research projects dominated the work of NAI which included research on aquaculture production and the construction of structures that interlinked agricultural production space with living quarters. In the early 80's, John Todd and Nancy Jack Todd became less involved with NAI as they branched off into other pursuits (see below). John Todd has been characterized as one of the driving 'synthesizers' in the NAI milieu and this, coupled with funding shortages in the early 80's, instigated some institutional reforms which

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[66] Which they later purchased in the mid 80's (Todd 2005 p.119).
[67] *Ibid.* p.15
[68] The size of the institute is hard to determine from the literature. Greene (1978) reports 20 paid staff and 8 volunteers; Slambrouck (1979) reports 14 paid staff in 1979.
[69] (Wade 1975)
[70] At 25$ a person, which came with the in-house publication *Journal of the New Alchemists,* published from 1973-1981 (7 issues) and the New Alchemist Quarterly, published from 1980-1990 (40 issues). http://www.nature.my.cape.com/greencenter/home.htm. Until 1975 all funding was "exclusively from private sources" (Todd & Todd 1980 p.37)
[71] "has been through some hard time financially" (Wade 1975); "Despite the familiar, recurring problems of lack of funds" (Rivers 1976); "our income did not effectively support the institute during this period" (Todd 1976); staff missed paychecks (Slambrouck, 1979); "Things got really bad here in 1983-1984. Federal budget cuts were coming through, foundation money was very difficult to find and our budget dropped from $600,000 to less than $300,000. We were all being paid a fraction of our abysmally low salaries." (Quinney 1989).

resulted in NAI becoming more narrowly focused.[72] In the early nineties, NAI was again struggling to define its role, and in June of 1992 it was disbanded as an institution.[73]

When established, the Institute was dedicated to changing the relationship of humans and the environment. As such their mission statement was:

> Among our major tasks is the creation of ecologically derived human support systems - renewable energy, agriculture aquaculture, housing and landscapes. The strategies we research emphasize a minimal reliance on fossil fuels and operate on a scale accessible to individuals, families and small groups. It is our belief that ecological and social transformations must take place at the lowest functional levels of society if humankind is to direct its course towards a greener, saner world."[74]

The early emphasis of New Alchemy was on generating alternative food production systems and was coupled with the idea of providing the means for families and individuals to be self sufficient upon the land.[75] Overall, NAI staff experimented with aquaculture, hydroponic systems, wind power, greenhouse designs, energy efficient design, organic gardening, integrated pest management, and composting.[76] Concerns that the modern agricultural system was both damaging to the environment and heading towards collapse led the Alchemists to focus on forms of agriculture production that were intensive in scale but sustainable in practice.[77] Thus they experimented with combinations of enclosures, aquaculture, and organic agricultural practices to try to generate high yields in small areas. A main idea was that by doing production in enclosures (greenhouses, domes, or bioshelters) primary productivity could be increased

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[72] (Jacob 1997 p. 196-198)
[73] (Todd 2005 p141-142, Quinney 1989)
[74] Quote taken from http://www.nature.my.cape.com/greencenter/newalchemy.html, where it is credited to the Fall 1970 Bulletin of the New Alchemists.
[75] We seek solutions that can be used by individuals or small groups who are trying to create a greener, kinder world…Among our major tasks is the creation of ecologically derived forms of energy, agriculture, aquaculture, housing and landscapes, that will permit a revitalization and re-population of the countryside.' (Rivers 1976)
[76] (Quinney 1989)
[77] "the new alchemist are a small group of people who consider that modern American agriculture is a mighty edifice built on sand. They expect it to collapse, maybe within the next 10 to 20 years, either from intolerable price increases in the fuel and fertilizer needed to sustain it, or because of the accumulating weight of biological damage caused by agricultural chemicals" (Wade 1975)

in rate as well as extending the growth season. Most specifically, NAI became known for a major experiment in combining housing structures with production systems in an experimental bioshelter building referred to as the Ark. The Ark was built under funding from the Canadian government on Prince Edward Island in 1976. A second Ark was built at NAI as well, but it focused more on integrated production systems and did not include the living facilities.[78]

NAI was also known for having progressive social policies as well. Initially, the management structure of NAI was set up non-hierarchically, with decision making run through consensus. In 1975, they implemented a policy wherein all staff received the same salary.[79] Similarly, NAI worked to make their research efforts accessible to the public by emphasizing publishing their research in their journal which was sent to supporting members, rather than focusing primarily on publishing in scientific journals.[80] NAI was also made visible to the public through its frequent presence in the Whole Earth Catalog and the CoEvolution Quarterly. Subsequently, New Alchemy Institute is reported to have been a significant institutional presence in the environmental movement of the seventies and their work and publications influenced other leaders in the field.[81]

The Roots of Living Machines at NAI: Inspirations

John Todd was a substantial element in the visionary guidance of NAI. As one of the founders, he invariable influenced the goals of the Institute and it seems that he was also

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[78] The design of the Arks was done in collaboration with the architects Ole Hammarlund and David Bergmark of Solsearch Architecture (Baldwin 1976, Todd & Todd 1980).
[79] $9,000 plus a $2,000 addition for each dependent (Todd 1976, Wade 1975)
[80] (Todd 1976)
[81] Both Wes Jackson, of the Land Institute, and David Orr are reported to have been influenced by NAI (Todd 2005 p.75).

a charismatic and dynamic interlocutor for the group in general.[82] As such, a major talking point in early interviews was the use of diverse poly-cultures or interlinked systems to create higher levels of production.[83] Conceptually, NAI emphasized this use of diverse poly-cultures in order to mimic the functioning of ecosystems. This emphasis of designing with nature was partially catalyzed through John Todd's exposure to Howard T. Odum's writings. In a 2003 interview Todd stated

> In 1971, I was a oceanographer at the Woods Hole Oceanographic Institute, when I read a small book by the ecologist Howard Odum, titled "Energy, Power and Society," in which he laid out a whole new view of how we might create the infrastructures for a sustainable human society. I had just co-founded The New Alchemy Institute a year earlier with two friends, one of whom is my wife, and its goal was to create a new science and practice of earth stewardship…Howard Odum's ecological models showed that our current fossil fuel-based society was not sustainable. He argued that only sustainable models could be modeled on the 3.5 billion year old experiment of life itself, and we had to design our modern world as if we had an understanding of the evolution of life over this vast reach of time. He suggested that we needed to somehow decode the language of nature - how does the coral reef work, how does it sustain life, same with the forest, the prairie, etc. I would characterize my life as one of the first people to attempt to decode the language of nature and use it as a blueprint to design the infrastructure for human society.[84]

Similarly, in the history of NAI in *A Safe and Sustainable World*, Nancy Jack Todd tells of how during the time of the OPEC oil embargo "John attended a conference and returned with new and far-reaching insights based on the energy analysis of ecologist Howard Odum." Crediting the particular paper *Energy, Ecology and Economics*, Nancy Todd explains in detail how Odum's thinking influenced the practices and thoughts of John Todd and NAI:

> As relevant as we found Dr. Odum's analysis of energy systems, we considered his ideas on the relationship between human societies and the natural world even more catalytic. His thinking profoundly influenced John and, eventually, the discipline of ecological design, Howard Odum maintained that nature, in a way, could be viewed as a vast bin of spare parts, which were available for integrating into human support systems. This thinking, John saw, could be harnessed to create adaptive technologies to serve human needs. Already inclined in that direction, John and Earle particularly were stimulated to become more innovative in their design strategies. They observed the natural world more closely, turning to it as a resource not to be mined or raped, but

[82] He is more frequently the predominant voice being quoted in a number of the articles written about NAI in the early years (Baldwin1976, Greene 1978, Rivers 1976, Slambrouck 1979, Wade 1975)
[83] (Greene 1978, Slambrouck 1979, Wade 1975)
[84] From http://www.enviroeducation.com/interviews/john-todd/

> rather to be studied, consulted and imitated. Bolstered by the Odum report, New Alchemy stepped more confidently along the path of coevolution with the natural world.[85]

This adoption of Odum's "tinkering" with nature can clearly be seen in subsequent writings by John Todd in discussing the work of NAI:

> We wanted to participate in creating a body of knowledge that could lead to the replacement of the fuel consuming engines and hardware of present societies with equivalent support processes which would be derived from living systems coupled to sensitive technologies powered by the wind and sun. Nature in this context is our primary ally, the future must be nothing less than a transformation away from hardware intensive and exploitive societies to ones that are informationally rich, co-evolving in an intimate partnership with the living world.[86]

The Roots of Living Machines at NAI: Material Practices

These Odumesque ideas that underlay NAI projects can be seen to have been carried over into the later development of living machines. However, it is not merely the *conceptual* ideas of working with nature that was carried forward. Materially, a number of technological innovations at NAI were precursors to the development of the various living machine technologies. The initial fish production systems at NAI were shallow ponds under a dome structure. Subsequently, the Alchemists began experimenting with what became known as 'solar ponds'. These above ground round tanks were made from a semi translucent fiberglass so that solar energy could more effectively penetrate the system.[87] The increased light absorption of the aquaculture 'solar ponds' functioned to make the tanks both solar heat retaining masses for aiding in climate control inside the bioshelters, as well as increasing primary productivity in the water column. The increased productivity of algae and subsequent stimulation of zooplankton were considered food stock for the high density of fish that were being raised in the tanks.[88] In the Cape Cod

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[85] (Todd 2005 p.61-62) The Earle in this quote refers to Earle Barnhart a long term member of New Alchemy.
[86] (Todd 1976 p. 56)
[87] *Ibid.* p.44-45.
[88] The extent to which the fish relied upon the algae and zooplankton, versus how much they were supplemented by feedstock is unclear in the popular literature. The gloss story seems to be that "The ponds

Ark, the ponds were linked to each other on a downhill gradient and the polyculture of each pond was considered to provide a different set of ecological functions to the whole system.[89] Similarly in the Arks, agricultural production and aquaculture production were designed to be mutually-supporting through the use of the fish waste water as fertilizer for growing plants and the use of plant waste materials acting as supplemental fish food.[90] Overall, in the various production systems experimented with at NAI the emphasis was on generating diverse components that each had different biological communities and functions and which would then be interlinked to create synergistic higher levels of function and productivity.[91] In pursuit of such interlinked systems, the Alchemists also experimented with the idea of growing vegetables and flowers directly on top of the fish tanks.[92] Following on early experiments that had shown the fish waste water stimulated lettuce growth significantly, a hydroponic system that directly conjoined fish and lettuce production was developed for the solar-aqua pond.[93] Using a designed set

are largely self-nourishing, too, through an aqua cultural alchemy of sorts: algae thrive in the translucent containers, the plant-eating fish eat the algae and the fish's excretions in turn feed the algae" (Greene 1978). In discussing the Ark, one article quotes a fish production amount of 45 pounds of fish a year and then later in the article describes the Ark aquaculture as "In a self-perpetuating cycle the fish live mainly on the algae, the algae replenishes itself, and it consumes the ammonia, a toxic byproduct of fish waste. Very little other food is needed to supplement the algae" (Slambrouck 1979). However, the fish were in fact supplemented with fish feed and other materials from outside the tanks. Varying degrees of external supplementation are reported (Wolfe & Zweig 1977, Zweig 1986, Todd and Todd p.136, and Barnhart 2006). In a summary paper Wolfe and Zweig state that "Consistent good growth at NAI is 30-50 lb/yr (45 day 65 gm/day) over 100-trials using dry commercial feeds." They also state that a minimum food regime trial was "nothing but inedible organic inputs such as manure. The fish will eat the resulting algae, bacteria and zooplankton. Expect slow growth" (Wolfe and Zweig 1977). The difference in food regimes necessary for achiving the high productivity of 45lb/yr versus the goal of self sustaining systems seems to be indicated here for the solar ponds.

[89] (Greene 1978, Wade 1975)

[90] (Todd and Todd 1980 p.116)

[91] The high productivity of the solar pond aquaculture system become the basis of a large NSF grant to NAI in 1978 to model the ecosystem dynamics of the fish production system. (Barnhart 2006, Todd 2005 p.45).

[92] (Todd and Todd 1980)

[93] (Barnhart 2006, Zweig 1986)

of floats, lettuce was rafted on the surface of the pond, with their roots netted off from the fish below.[94]

The material practice of using above ground tanks with hydroponically grown plants would become a major design element in the range of technologies subsequently developed by John Todd. Similarly, the use of enclosures to maximize plant productivity that NAI emphasized would also become a recognized hallmark of the living machine concept in general. The emphasis on solar power and the use of light transmitting material both in the construction of enclosures and in the construction of the ecosystem components would also be carried over from this early work and inform the subsequent design of a number of technologies. In fact the specific practice of creating 'solar ponds' would become the hallmark of the early family of technologies deployed by John Todd to treat wastewater and would inform the design of the first patented technology "Solar Aquatics."[95]

A final linkage exists between the work at NAI and the development of living machines. This consists in the personage of John Todd himself in the form of embodied knowledge. The hands on tinkering and experiential learning that accompanied the interdisciplinary research carried out at NAI provided the groundwork for the attainment of a set of knowledge that is not wholly intellectual, nor merely technical in practice. As John Todd explains his various rationales for moving into waste water technologies, he references the learning that comes from practice:

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[94] (Zweig 1986)
[95] United States Patent Number 5,087,353 *Solar Aquatic apparatus for treating waste* "An important aspect of the apparatus is that the treatment tanks transmit energy into the wastewater substantially throughout its entire volume. The treatment tanks may transmit energy through their outer walls, preferably 100% around their perimeter and over their full height. The energy is predominantly in the wavelengths of light, both visible and non-visible".

> Reflecting on the state of the water reorganized my priorities. For over fifteen years beginning at New Alchemy, I had raised fish and had learned innumerable tricks to purify water in order to keep the fish healthy. It seemed logical to use the same biological techniques and apply them to purify water, sewage and other waste streams."[96]

Thus the "tricks", or embodied knowledge, that John Todd attained through his work at NAI becomes the groundwork for the development of the living machines technologies.

Designing with Ecosystems: Not-for-Profits and Businesses

In the late seventies John Todd began to explore new outlets for designed ecosystems. Conjoining an interest in boats with his explorations in designed ecosystems, John Todd's "first adventure into an ecologically-oriented business" was the development of new forms of ships called Ocean Arks.[97] The original agenda of Ocean Arks was in fact a fairly literal conceptualization, advocating ships that would be Arks on the ocean. These would be under sail power and would both grow and transport "biological materials like seeds, plants, trees, and fish to impoverished areas with the hope of reviving the local biological support base and thereby improving the means for the human population to sustain itself."[98] After the design and development of a scale model[99] demonstrated some proof of concept, the business venture was disbanded due to lack of a singular coherent business plan.[100]

It was this interest in boats and impoverished areas of the world that lead to the establishment of the not-for-profit organization Ocean Arks International, which was

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[96] (Todd 1989)
[97] *Ibid.*
[98] (Todd and Todd 1994 p.33-34)
[99] A fifty foot long vessel, sometimes described as a 1/5 (Todd 1989) and sometimes as a ¼ (Todd and Todd 1994) scale model of the full boat.
[100] "I was being innovative on too many fronts at once and investors became too nervous to go the next round. I had a dream of ships that would be working symbols for an age of ecology, but not a business. No number of MBAs could have made a business plan of what I had in mind. There were at least a dozen businesses in the plan and they were all fraught with risk. The idea was a financial flop – a 'what-not-to-do' case in Paul Hawken's book *Growing a Business*" (Todd 1989)

incorporated in 1981.[101] The original focus of Ocean Arks International was on the development of hardy, yet easily constructed, sailboats that could eliminate the need for fuel dependence by coastal fisherman. With the aid of boat designer Dick Newick, Ocean Arks developed the "Ocean Pick-up."[102] The prototype vessel was successfully demonstrated in Guyana and Costa Rica, but financial difficulties again thwarted the expansion of this project.[103] Subsequently, John Todd returned his attention to land based ecological issues and inspired by a number of experiences ranging from friends with cancer to general water quality decline at his home base of Cape Cod, John Todd turned the focus of Ocean Arks International to water pollution and remediation.[104]

As Ocean Arks International (OAI) already had an established network of supporters and followers from the "seagoing ventures" it was felt that "another identity change might be more confusing than helpful" and thus the name of Ocean Arks was retained.[105] However, at some point in the 1980s "The Center for the Restoration of Waters" was established as a part of Ocean Arks International, quite likely to designate the more specific water treatment goals of the organization.[106] In the mid-eighties, John Todd established his first business venture that would address waste purification.[107] This business, The Four Elements was formed in partnership with two friends and was also

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[101] In Todd and Todd (1994 p. 34) it is implied that the development of the original Ocean Ark, or Hope Ship was part of the newly founded Ocean Arks International. However the early article Todd 1989, states that the development of the Ocean Ark was part of a business venture.
[102] (Todd and Todd 1994 p. 35-38, Todd 1989)
[103] (Todd 1984, Todd 1989)
[104] (Todd 2005 p. 147)
[105] (Todd 2205 p.148)
[106] Numerous references to The Center for the Restoration of Waters @Ocean Arks International exist in publications in the late 80s, but at some point there ceases to be reference to The Center for the Restoration of Water and articles simply refer to the design work of Ocean Arks International.
[107] I have yet to find a formal source on the date of establishment of this business venture.

funded with capital from friends.[108] This business, in conjunction with OAI, designed and built an experimental pilot wastewater treatment plant for Sugarbush Ski resort near Warren, Vermont.[109] Referred to as a solar-aquatics plant, the system was housed in a greenhouse and relied upon both above ground and in ground components with diverse organisms to treat the wastewater.[110] At the same time that Sugarbush was experimenting with the solar-aquatic plant it was also running a test on a breakpoint chlorine system.[111] There is no evidence that the resort adopted the solar-aquatic system for full-scale production, nor does it seem that The Four Elements continued as a business entity.[112]

Following on the Sugarbush test facility, OAI further experimented with the possibilities of designed ecosystems to purify water both wastewater (at Providence, Rhode Island) and treating septage (at Harwich, Massachusets)[113]. Turning to the local problem of septage[114] lagoons in Harwich, Massachusetts, in the summer of 1988 John

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[108] (Todd 1989) In this article, the reference describes the two friends as an architect and a liberal-arts major with a woodworking company. Research on the internet identifies these individuals as likely being John "Sucosh" Norton and David Sellers.

[109] Constructed and operated sometime between 1987 and 1988. For reference to The Four Elements Corporation building the facility see Meadows (1987, 1988). For reference to OAI building the facility see Todd (2005 p.149). The intertwined work of the for-profit and not-for profit is discussed as an outcome of the hesitancy of venture capital in the face of new technologies. It was environmental foundations that "liked our ideas for greenhouse-based sewage-purifying ecosystems and backed the construction and operation of a fifteen-thousand-gallon-capacity prototype at Sugarbush, a ski resort in Vermont. Without the foundation help our eco-technology plans would still be in the drawer" (Todd 1989) 15,000 gallons is considered to be the "equivalent of about ten households (Todd 2005 p. 149).

[110] "As raw sewage enters the greenhouse it flows first through a cylinder of nitrifying bacteria gathered from Vermont ponds. Then into the raceways where algae multiply in the water, taking up nutrients. Freshwater shrimp eat the algae. Bass and trout in aquaculture tanks at the purified end of the system eat the shrimp (Meadows 1988)

[111] (Meadows 1987, 1988)

[112] An online communication by OAI president Michael Shaw in 1998 gave a brief overview of the companies involved with SASs and living machines and states "The first plant was built by a new company called The Four Elements Corporation which constructed and operated the first Living Machine for wastewater treatment at the Sugarbush Ski Resort in Vermont (1980's). Four Elements sold the rights to the technology to another new company called Ecological Engineering Associates of Massachusetts. EEA acquired the rights to John Todd's Solar Aquatic patents." From Internet Conference on Integrated Bio-Systems, 1998. Eds: E.L. Foo & T. Della Senta. http://www.ias.unu.edu/proceedings/icibs/todd

[113] The Providence facility started operation in 1989 and the full Harwich plant started in 1990 (Spencer 1990

[114] Septage is the collected wastes from septic tanks.

Todd set up a system of 21 solar aquatic ponds in series coupled to a constructed marsh.[115] Loading the system at one end with septage supernatant and running the waste sequentially through the tanks, the four month trial was deemed a success at demonstrating the ability of the solar aquatic cells to remove phosphorus and nitrogen and to also attenuate volatile organic compounds.[116] This project was the basis for both a national recognition of John Todd's contribution to innovative septage treatment,[117] as well as the basis for a state level fine for having failed to file the appropriate paperwork to work with polluted waters. [118]

The success of the Harwich lagoon system generated "signs of interest in backing a commercial enterprise"[119] as well as spurring John Todd's own interest in disseminating the technology more quickly through business application.[120] In August of 1988, John Todd "met a man who was to change our direction. He was a successful businessman and innovator who felt the next big challenge lay in biology."[121] John Todd formed a partnership with this businessman and established Ecological Engineering Associates. Ecological Engineering Associates (EEA) was set up as a partnership between John Todd

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[115] (Todd and Todd 1994 p.xvii- xix, Todd 2005 p.153)
[116] (Todd and Todd 1994 p.xiii, Todd 2005 p.153)
[117] Award presented June 22 by William K. Reilly, of the national EPA and Michael R. Deland, Boston agency chief (Anonymous 1989). In other references this award is cited as the first Chico Mendes Memorial Award.
[118] A $5,000 fine (Lord1989) which John Todd successfully appealed. (Todd 2005 p.157)
[119] (Todd 1989)
[120] "That experiment had a big effect on me, because it indicated the extraordinary, dynamic purifying power that nature has if the right organisms can be found to work in the right kind of concert together. Then several things happened. First, I was involved in establishing a business to take these ideas out widely. The old idea of just letting this information be assimilated slowly by the next generation of students, from whom it would spread into the academic world, engineering firms, and eventually into society, just wasn't fast enough – that takes at least twenty year. The only way I could think of compressing the process was through the corporate arena. So Ecological Engineering Associates was set up, with the kind of backing and management that was needed" (Gilman 1990).
[121] (Todd 1989) This investor is likely Barry Silverstein. Though the Gilman (1989) article doesn't name the business man, Barry Silverstein's web description of being a venture capitalist, coupled with his role as an investor in EEA and joint applicant on two patents with John Todd, along with another references to Silverstein's contribution to the idea of living machines (Todd 1991) makes it likely that it is Silverstein who is being referenced in this article.

Research and Design, Inc. and Ecological Engineering, Inc.[122] Susan Peterson, who was the former associate director of Ocean Arks and who had worked on the four month test project at Harwich,[123] became the president of the newly established EEA.[124] John Todd's role in the new company was as "ecological designer" as he self-acknowledged that he did not "belong running a company."[125] Further formalization of the solar aquatics technology was established through patenting. Two different patents on the solar aquatics processes, the first filed in 1988[126] and the second in 1991[127] were filed under the joint inventor names of John Todd and Barry Silverstein and when granted were assigned to Ecological Engineering Associates.

The newly minted Ecological Engineering Associates first project was to develop the pilot Solar Aquatic System (SAS) to treat the septage waste of Harwich, Massachusetts. [128]Construction started in 1989 and the system came on-line in 1990. The primary treatment system consisted of 3 parallel tracks of 10 solar aquatic tanks followed

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[122] John Todd Research and Design was incorporated in 1989 in Massachusetts, and is now doing business as John Todd Ecological Design. Ecological Engineering, Inc was incorporated in Delaware. The business partner referred to by John Todd is likely Barry Silverstein, who along with Dennis McGillicuddy and D. Stevens McVoy had founded Coaxial Communications Companies and who were also jointly involved in a number of other companies, one of which was Nortek, Inc. The business arrangement of Ecological Engineering Associates is partially elucidated by this disclosures passage from an Annual report to the SEC by Nortek, Inc in1995 (note 'the company' herein refers to Nortek, In): "Ecological Engineering Associates Limited Partnership (EEA) is engaged in the design and operation of wastewater-treatment systems. Messrs. McGillicuddy, Silverstein and McVoy, directors of the Company, are directors and sole stockholders of Environmental Engineering Inc. (EEI) which is the general partner of EEA. The Company has made an investment in EEA of $1,360,000 through March 1996 in the form of a note with interest accruing at 2% over prime and compounded annually and is currently investing at the rate of $15,000 per month contingent on EEI matching such investment and subject to termination at the discretion of management. The note, secured by a first lien on the partnership assets, matures on January 8, 1998. The Company also receives, in connection with its investment, warrants to acquire limited partnership units proportionate to all debt and equity investments made by other investors in EEA" From http://www.secinfo.com/d26n8.96.htm

[123] (Lord 1989)

[124] (Todd 1989)

[125] *Ibid.*

[126] *Solar Aquatic Apparatus for Treating Waste*, US. Patent 5,087, 353, granted February 11 1992.

[127] *Method for Treating Water*, US Patent 5,389,257, granted February 14 1995

[128](Spencer 1990)

by a marsh and then four more solar tanks and a final polishing marsh.[129] The original design called for the entire septage stream to be treated in the system, but in the first year of operation the high solids of the unsettled septage was not adequately removed by the 10 solar aquatics tanks and solids build up in the marsh was a problem. In 1991, the primary treatment tank was retrofitted with some baffling to allow for settling of solids, and the subsequent supernatant was then run through the solar tanks.[130] After this design retrofit, the system was run at a steady state for over a year and in June of 1992 the Solar Aquatics System pilot was certified by the Massachusetts Department of Environmental Protection as meeting Class 1 drinking-water standards.[131] The attainment of this certification was considered a major validation of the conceptual idea of using complex ecosystems to treat waste, especially the highly concentrated waste that is septage.[132]

At the same time that the Harwich system was undergoing validation, other SAS projects were being conducted by EEA. A key design element of these systems was the use of transparent materials for the construction of the individual treatment units. Light transmission to the water column was considered important for support of the high primary productivity in the treatment cells. These systems include a system that replaced a septic system for a small business in rural Indiana,[133] as well as sewage treatment

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[129] "The system consists of a headworks structure with a bar screen, a flow-through grit chamber, and a basket strainer to remove dirt and inorganic material. The septage then flows by gravity to two 10,000 gallon underground, insulated storage tanks where mixing and aeration keep solids from settling. A submersible grinder pump sends the septage into three parallel lines of ten solar tanks each. A constructed marsh follows, then four more solar tanks, and finally a polishing marsh before the water is disinfected with ultraviolet light" (Spencer, 1992 p.64)
[130] (Spencer 1992 p.64-65, Teal and Peterson 1993 p.36)
[131] (Teal and Peterson 1993) See also Peterson and Teal (1996) for detailed description of the process chain and the treatment outcomes of the various system components
[132] (Todd 2005 p.156, Todd and Todd 1994 p.xix)
[133] The SAS for Jim Davis' design studio, PAWAS, in Muncie, Indiana has been one of the longest continuously operating system, running since 1990 and still in operation in 2010. The design is credited to OAI and EEA (Logsdon 1992)

systems for a couple of communities in Canada.[134] A later project advanced by EEA was a system for Ashfield Village in Massachusets.[135] Other early projects that deployed the SAS technology include the treatment of sewage at Field's Point Wastewater Treatment Facility in Providence, R.I, a system in Marion Massachusetts to treat boat pump out waste[136], and a system built in the Intervale of Burlington, Vermont to test the capabilities of the SAS to treat dairy wastewater for Ben and Jerry's, Inc.[137]

Some of the above systems were developed in conjunction with OAI as well as with another new company called Advanced Greenhouse Systems (AGS). Provenance of these various trial projects in the early 1990's is difficult to establish because of the overlapping membership and actions of the various organizations.[138] AGS had been established in 1989 as a subsidiary of Gardener's Supply Company of Burlington, Vermont to market greenhouses.[139] The principle engineer of AGS was Michael Shaw, who became a close friend of John Todd and was subsequently involved in the

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[134] These projects in Canada were for Bear River and Beaverbank Villa, both coming on line in 1995 (Farrell 1996). The early adoption of SASs in Canada was attributed by EEA president Susan Peterson to the fact that the municipal process of application and permitting moves much quicker in Canadathan in the U.S.(*Ibid.* p32).

[135] The community opted for the system in 1993, and in 1998 the system became operational. http://www.purplepanthers.com/solaraquatics.htm

[136] (Todd 2005 p.160).

[137] A 27 month pilot treating dairy wastewater for Ben & Jerry's Ice Cream, Inc. (Farrell 1996)

[138] Confusion is added when companies are referred to by their current names in articles rather than the name under which they were operating at the time. For example, in regards the Providence Rhode Island system, it is referred to as 'flagship' of the technology in 1994 by virtue of "being to date the largest and longest running system" (Todd and Todd 1994 p.xix); and it is credited to the joint work of John Todd and OAI and Michael Shaw (Todd 2005 p.157). Shaw himself designates AGS as having been involved in this system, but in a later article, it is stated that the system had "construction and engineering by Living Technologies Inc (Todd and Josephson 1996 p.126). As the system was reported operational as of July 1989 (*Ibid*), and Living Technologies was not incorporated until 1993, wherein it was formed out of a buyout of AGS, it seems more correct to state that AGS was involved in the construction and engineering of the Providence system.

[139] Advanced Greenhouse Systems was established in 1989 as subsidiary of Gardener's Supply Company of Burlington Vermont by William Rapp (Crawford, 1999) and http://www.ias.unu.edu/proceedings/icibs/todd). The President and founder of Gardener's Supply Company, William Rapp established the greenhouse company with Michael Shaw, whom he had met through the Findhorn Foundation in Briton (Kelley 1995).

establishment of Living Technologies, Inc and also executive director of OAI.[140] AGS was involved in the production of the Harwich, Providence, Marion and Intervale systems,[141] after which AGS and EEA ceased to work together.[142] Advanced Greenhouse Systems underwent a reformulation in 1993 and became Living Technologies, Inc (LTI).[143] Though characterized as a buyout and reformulation of AGS, there is also acknowledgement of continuity, by the tendency to state that Living Technologies, Inc began operations in 1989.[144] Though formal incorporation of Living Technologies, Inc is also stated as having occurred in 1993,[145] an online listing of the official registration of incorporation states it occurred in 1994.[146] Michael Shaw was president of Living Technologies for many years, and in 1998 Ramin Abrishamian became CEO of LTI.[147]

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140 (Todd 2005 p.159). Shaw became executive director of OAI http://www.oceanarks.org/abo40_The_Next_Transition_at_OAI.php

141 http://www.ias.unu.edu/proceedings/icibs/todd

142 "AGS parted company with EEA after the completion of the technically successful pilot at Ben & Jerry's" http://www.ias.unu.edu/proceedings/icibs/todd

143 "In 1993 there was a management buyout of AGS and a new company called Living Technologies Inc. was formed." (*Ibid* and Crawford 1995). Though Kelley (1995) reports that "Living Technologies was spun-off as an independent firm in 1989 with Gardener's Supply becoming a minority shareholder."

144 (Kelley 1995)

145 (Crawford 1999)

146 From: Public Record data from Florida Department of State - Division of Corporations, accessed through CorporationWiki http://www.corporationwiki.com/ "Incorporated by Will Raap, Lynne Stuart, J Michael. Shaw, John Todd, Ramin Abrishamian, Charles F. Kireker, Living Technologies, Inc. is located at 431 Pine St Burlington, VT 05401. Living Technologies, Inc. was incorporated on Wednesday, October 26, 1994 in the State of FL and is currently not active. United Corporate Services, Inc. represents Living Technologies, Inc. as their registered agent." Lynne Stuart was an engineering and became Vice-President of Engineering for LTI and in 1998 was "the longest-serving employee" (Crawford 1999). In this same article Ramin Abrishamian is characterized as being a 'relatively new arrival at LTI,' becaming CEO of the company in 1998, coming to the company from having been a CEO of a Boston based biotech firm. This late arrival to direct involvement in the company make it seem likely his initial inclusion in the incorporation of the company was as an investor (speculative). Also, Charles F. Kireker was likely an investor, as his biography highlights his role as a venture capitalist for Vermont small businesses. http://www.kld.com/about/BoardOfDirectors.html. In describing the creation of LTI it is reported in Feinbaum (2002) "Todd's next venture into the business world was with a company called Living Technologies, which he founded with two close associates. Although they decided to build the company on a project by project basis, an infusion of capital soon became necessary. Todd raised the money through local investors and was able to bring experienced managers into the company. To fuel continued growth, the company needed to reach out for a second round of financing, with the eventual aim of becoming publicly traded. However, the company was eventually acquired by an outside investor and it was moved out of Vermont."

147 Shaw was listed as President as of 1995 (Kelley 1995) and 1998 (Geary 1999).

Meanwhile, at some point in the 1990's, Ecological Engineering Associates underwent a restructuring of relations, and John Todd became disassociated from that company. This is a difficult transition to ascertain from the public records. In private communication, one individual stated that differences of opinion between John Todd and other EEA members as to management decisions at the Harwich facility led to John Todd being "forced out" of the company. Another individual[148] stated that they had heard that the management of EEA wanted to scale up the process and do larger contracts and were less interested in the smaller idiosyncratic projects that John Todd was pursuing. In an article discussing the business of ecological design, John Todd was asked about the two companies he started. In discussing these companies he describes the experiences with both as "I lost the companies but couldn't have gotten a better education in business with an MBA."[149] In describing the history of EEA it was explained thus:

> Back then (1990), natural systems were new and as John Todd notes, launching the company took many millions of dollars. "To raise the money, I lost control of the company. The interests of capital were driving the agenda." The company brought in business experts, who didn't realize that projects required a "unique relationship with each client." That experience taught John "that money and information are not equal in an early business"[150]

In short, it seems that combinations of vision and capital contributed to the breach between the company partners. EEA continued to operate as an entity through 1998. Now the Solar Aquatic patents are licensed to the Ecological Engineering Group (EEG). EEG was incorporated in 2002 and is run by David Del Porto another leader in the ecological design field.[151]

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[148] A technology adopter, reporting on things they heard while investigating adopting a designed ecosystem treatment process.
[149] (Feinbaum 2002)
[150] (Ibid p.20-21).
[151] EEG company holds the patents to Solar Aquatics but also has in their design repertoire constructed wetlands, including the "Washwater Garden", and have recently added a new patent for the EcocycLET technology which is a constructed ecosystem designed to have no discharge. Prior to becoming EEG, David Del Porto's company was known as Sustainable Strategies.

Living Machines: The Terminology and Conceptual Underpinnings

Out of the formalization of Living Technologies, Inc. new impetus was created to market designed ecosystems, now being called Living Machines. In the early 90's John Todd had increasingly begun to use the terminology "living machines" to denote a range of designed ecosystems. Originally used as a vary broad concept, it referred more to a conceptual idea of how technologies should be designed, rather than referring to a singular technological object. In a 1990's interview, John Todd explained the living machines idea:

> **Robert**: *What's your next project? What's hot for you right now?*
> **John**: I'm thinking increasingly about a concept to which I've given the name "living machines." The idea of the living machine is going to be disturbing to some people. But basically what it's about is taking bits and pieces from nature, using the whole planet as a contributory, and reassembling them inside what I call "gossamer engineered structures" to do the work of society - produce food and fuel, treat waste, provide heating and cooling, etc. All of the basic work of society could be done by living machines.[152]

In general explanations of the living machine concept, Todd often stressed the ways in which they were different from conventional machines stating that "Living machines are fundamentally different from conventional machines. They represent, in essence, the intelligence of the forest or the lake, reapplied to the human ends."[153] Living machines were compared to conventional technologies and argued to be different on the basis of energy, materials, biotic design, control, pollution, management & repair and cost.[154] Often in these general descriptions, their uniqueness and aesthetic, emotional appeal is stressed:

> Compared to conventional technologies, living machines have a number of unique qualities. It is their aggregate characteristic, however, that most distinguishes them. People are accustomed to the mechanical moving parts, the noise or exhaust of internal combustion engines, or the silent geometry of electronic devices often have difficulty imagining living machines. Complex life forms inside strange, light receptive structures can seem at once familiar and bizarre. They are

[152] (Gilman 1990)
[153] (Todd 1991 p.111)
[154] (Todd 1991, Todd and Todd 1994)

> both garden and machine. They are alive yet contained and framed in vessels built of novel materials, some of which are still in the developmental stages. Living technologies bring people and nature together in fundamentally radical and transformative ways.[155]

Another early expression used in John Todd's descriptions of living machines, was the phrase 'gossamer engineering', stating that the structures and physical components of the systems should be based on "lightweight and light-transmitting components."[156]

In the 1990's, Ocean Arks International and Living Technologies, Inc. began developing and implementing technologies that they formally labeled "Living Machines". Demonstrating the variability in what was originally encompassed under the rubric living machines are the EPA "Advanced Ecologically Engineered Systems" (AEES) demonstration projects. OAI, through a EPA grant developed four different "Advanced Ecologically Engineered Systems," three of which were also called living machines in the write-ups.[157] These systems included two tank based wastewater treatment systems in greenhouses,[158] a collection of tanks on a mobile flatbed,[159] and a floating system, called a Lake Restorer, on a pond.[160] However, LTI as a business began largely focusing on deploying living machines as a wastewater treatment strategy, whether for municipal waste or food processing waste. With a spate of publicity over these wastewater treatment technologies, the Living Machines concept became to be more closely tied to the image of sequential tank based water treatment housed in greenhouses with verdant caps of

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155 (Todd and Todd 1994 p.170)

156 For example: A living machine is a device made up of living organisms housed within a casing or structure of "gossamer" materials (Todd 1991 p.109). See also Crane and Todd (1992). This use of 'gossamer' as a descriptor was dropped in later descriptions: A living machine is a device made up of living organisms of all types and usually housed within a casing or structure, made of extremely light-weight materials (Todd and Todd 1994 p.167)

157 (EPA 1996, 1997, 2002)

158 One system at Fredrick Maryland, and the other in South Burlington.

159 Set up in San Francisco at the Oceanside Water Pollution Control Plant to provide tertiary polishing of effluent

160 Located at Flax Pond, near Harwich Massachusetts

tropical plants.[161] Along with treating the waste, the secondary functions of the systems were also widely remarked on – the ability of the systems to be used to grow food, or horticultural plants for resale, the use of what sludge was generated as a compost, the educational possibilities, and the aesthetic appeal of the tropical greenhouse system.

A number of these defining elements of living machines had both material and conceptual antecedents in the earlier work of John Todd. The use of the greenhouse component of these living machines was in part a function of the material process being advocated.[162] This use of enclosures to augment primary productivity has its roots in the material bioshelter practices of NAI. However, the interest in using enclosures can also be seen as an outcome of John Todd's reoccurring visionary ideas in regards built human structures. Part of the vision behind the NAI bioshelters was the perceived need to rethink the way in which buildings are designed to have merely one function.[163] As such, a major design feature of the NAI projects had been to aim for systems with multiple modes of productivity and function. The idea of living machines performing multiple tasks, such as cleaning water and producing plants and fish is a continuation of these design ideas. That these multiple goals for the technologies existed was acknowledged not only in John Todd's own writings but was also observed by others evaluating the technologies. For example, in the EPA review of the four 'AEES' demonstrations, the multiplicity of goals for the systems is highlighted.

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[161] See for example Anonymous 1996, 1997a, 1997b, Chen 1995, Chin 1997, Crawford 1999, Farrell 1996, Kelley 1995 and Riggle 1999

[162] That of the tropical plants, and their abundant root masses, being important in the treatment process as well as being an income source through horticulture production and an aesthetic resource.

[163] In discussing the work of NAI in 1978 John Todd stated "If you look at buildings, sure they've put on solar collectors or insulated them more, but basically, the name of the game is not to change the underlying assumptions about buildings – namely that we'll go to school in one, do commerce in another, manufacture in another and grow foods in another. Instead of seeing them as ecologies, we see them as single function entities" (Greene 1978).

> Dr. Todd approaches the design and operation of his facilities from an ecological systems point-of-view and attempts to incorporate objectives well beyond just achieving the desired wastewater treatment goals into his projects. For example, Todd emphasizes the importance of snails, freshwater clams and other invertebrates in his "ecological fluid beds," as well as utilizing a variety of aquatic and wetland plants throughout his systems. He also stresses the value of his systems as a potential opportunity to produce fish as well as aquatic and wetland horticultural plants to be marketed locally, and for educating the public about the importance of natural biological systems in purifying and recycling wastewater.[164]

But beyond the material benefits that such ecosystemically designed systems could contribute, there was an even more conceptual, or idealistic element, that has run through the discussions of bioshelters, Arks, solar ponds and living machines. For John and Nancy Todd, these integrated biological and structural designs represented more than just physical and aesthetic solutions to production problems but rather were means toward reembedding humanity in an ecological consciousness. Using less resources and living more lightly on the land through the use of new and appropriate technologies were some of the main goals of NAI. As such, the bioshelters were seen as means to reintegrate human and natural systems in less damaging relations. But alongside the material benefits from this reorientation of production it was stated:

> Even if the healing of the breach between the human and natural worlds will take time, there are more immediate rewards in being involved with a bioshelter. One outcome of caring for living things is often a slow integration of faculties that have long been treated as separate. In contrast to the fragmentation, meaninglessness, monotony, and alienation that characterize so much of modern work, divisions between mind and body, between thinking and doing, become much less apparent, as do the dichotomies of the left and right hemispheres of the brain and those of reason and intuition and of stereotyped sex roles. It is not an unfitting place for mulling over the haunting question posed by Julian Jaynes: "How do these ephemeral existences of our lonely experience fit into an ordered array of nature that somehow surrounds and engulfs this core of knowing." [165]

This use of technological innovation as a tool for aiding in the restructuring of thought is a theme that runs through their work. In John and Nancy Todd's 1985 text *Bioshelters, Ocean Arks, City Farms,* they highlighted many different forms of design that rethought the nature of buildings and the intersection of built spaces and the biological world. This

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[164] (EPA 1996 p. v-vi)
[165] (Todd and Todd 1980 p.150-51)

book, and the later *From Eco-Cities to Living Machines,* advanced ideas for various structures or food production strategies that integrated solar aquacultures and hydroponics into the city streetscapes, along sidewalks or as bus stop backdrops.[166] These conjoinings of built spaces with lush biological components were not only advocated as being materially advantageous (i.e. space saving, or increasing the productivity of food production strategies) but they were also represented as providing important lessons for reinvigorating senses of community and belonging, and as such, reconnecting people with nature and the biological world. The concept was that integrating such structures into a community was in itself a means of social and ideological transformation:

> The community itself is the school; because it is designed after the larger workings of nature using biological precepts of design, it is like a world in miniature. Living in such a place young people may take an integral part in all that is going on and want to participate in the peaceful transition of the planet from one based on the production of goods, to one dedicated to a fulfilling life-base for all its living creatures."[167]

Thus, the estrangement of people from nature, and the necessity of overcoming it is a prevailing theme of the Todd's writing and material practices. Larger social change goals underpin the ideas and technologies he espoused. Through the use of new technical practices the hope is that "as the concept of living technology takes root, 'the old division between nature 'out there' and ourselves 'in here' will be broken down."[168] Thus the general concept of living machines can be seen as a continuation of both the ideas and technical practices that were first explored at NAI and that were part of a broader social change or ecological consciousness raising project. Technologies like living machines

[166] The 1994 book *From Eco-Cities to Living Machines: Principles of Ecological Design*, is in fact largely a reprinting of the 1984 book *Bioshelters, Ocean Arks, City Farming: Ecology as the Basis for Design*. The 1994 text has an added preface and epilogue that give recent history of OAI and advance the idea of living machines. It is interesting to note that in the core chapters of the 1994 book (which are the 1984 text) the terminology used to describe the overall thinking is Biological design and the designed ecosystems are called solar aquaculture systems. In the preference and epilogue Living Machines and ecological design are used.
[167] (Todd and Todd 1994 p.134)
[168] (Geary 1999)

both integrate systems and then act as reminders of the larger integration that exists between humans and the environment. Thus at one level living machines are intended not just as a means of technical engineering, but also as social engineering.

> It is our hope that studying human waste recycling in a beautiful, ecologically diverse and dynamic Living Machine…(humans) will begin to comprehend the meaning of natural systems in their lives. Equally important, it may allow them to engage with the natural world in sustaining the communities of tomorrow.[169]

As living machines began to be deployed, many writers made note of the aesthetic quality of the systems. People who worked with the systems report that many people have an “oh wow” moment when they enter the system. In terms of the larger and longer term goals of John Todd, these aesthetic qualities and emotional responses cannot simply be classified as ‘ancillary benefits.’ Rather, for Todd the visual and visceral pleasure that people receive when entering a living machine was a part of the primary function. In the designed ecosystems of bioshelters, arks, solar ponds and living machines the particular material functions of growing food or treating waste are but a part of the larger social goal of reformulating the relationship between humans and nature.

> The biggest blockade to the emergence of living technologies could be the very phenomenon living machines are intended to solve, namely, the estrangement of modern cultures from the natural world. Nature is “invisible” to many people in our culture. It is my hope that the aesthetic and emotional feeling that living machines can generate in us will yet carry the day. These machines can be made beautiful and evocative of a deep harmony that is nature. New economies wrapped in the wisdom of the natural world are capable of creating the future we desire.[170]

A final conceptual frame in the history of living machines is the larger project living machines were seen to be part of – whether part of ecological engineering, or ecological design. In an early description of living machines John Todd characterized it as “taking bits and pieces from nature, using the whole planet as a contributory, and reassembling them inside what I call ‘gossamer engineered structures’ to do the work

[169] (Crawford 1999) ellipses and parenthesis from original
[170] (Todd 1991 p.120)

of society." [171] This conception of taking 'bits and pieces' and reassembling them harkens back to H.T. Odum's idea of ecological engineers designing with all of the parts of nature at their disposal. Just as H.T. Odum's ideas were acknowledged influences on the early *design* ideas at NAI, these designs and subsequent iterations were also conceptualized in terms of ecological engineering. In the early articles on solar aquatics and living machines, John Todd utilized the term "ecologically engineered" and positioned the development of these designed ecosytems as part of a rising ecological engineering practice.[172] In an early chapter describing the idea of treating sewage with living machines, John Todd credits his business partner Barry Silverstein as having "suggested the term 'Living Machines' as being an appropriate description of the products of ecological engineering"[173] and then proceeds to describe the various systems he had designed explicitly as examples of ecological engineering.[174]

However, later descriptors of the ideas and technologies began to favor 'ecological design', such that in the 1994 text *From Eco-Cities to Living Machines*, the subtitle was *Principles of Ecological Design*.[175] In a highly synthetic overview of all of OAI's work, published in the Ecological Engineering Journal in 2003, all of the descriptors are to ecological design practice, and none to ecological engineering.[176] This change in conceptualization from "ecological engineering" to "ecological design" may not signify anything more than the growing strength of the term 'ecological design' in

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[171] (Gilman 1990)
[172] See for example Crane and Todd 1992 and Todd 1991
[173] (Todd 1991 p.109)
[174] In support of the idea of living machines being a very broad and general term, in this chapter John Todd recursively describes projects that had occurred at NAI as living machines (*Ibid.*)
[175] As is the subtitle of the overview history written by Nancy Jack Todd in 2005, of which the subtitle is *The Promise of Ecological Design.*
[176] (Todd et al 2003)

general.[177] However, it is also possible that this shift in framing and positionality was an outcome of negative experiences with engineers in the development and subsequent loss of Living Machines® as will be explored below.

Developing Living Machines®: Institutions, Trademarks and Patents

As OAI and LTI staff worked to advance the idea of living machines in the 1990's, the promotion and implementation of the systems began to solidify the meaning of living machine to a more particular definition and a more singular technical practice. By the early 2000's, the generic living machines term gave way to the use of the trademarked term Living Machine®, which could be tersely summarized as a singular technology.

> The Living Machine® is an emerging wastewater treatment technology that utilizes a series of tanks, which supports vegetation and a variety of other organisms.[178]

This transformation of living machines into the Living Machines® that became the basis of legal contention occurred through many intersecting variables which will be demonstrated in the following section.

At the same time that John Todd was writing about living machines as a general concept,[179] the term Living Machine had already been registered with the U.S. Patent and Trademark Office. 'Living Machines' was filed for registered as a wordmark in 1991, and was registered to Ocean Arks International in 1993.[180] Establishment of the trademark on Living Machine, set the stage for it to be considered a particular item of intellectual property, rather than a generalized concept. Another formalization of

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[177] What with the 1996 publication of the powerful *Ecological Design* by Sim Van der Ryn and Stuart Cowan.
[178] (EPA 2002)
[179] As in Todd 1991, Todd and Todd 1994 and Todd and Josephson 1996
[180] The description of Living Machine as a trademark was given as "waste water and water purification units for domestic, industrial, educational and ecological system uses."

technological practice came with the filing of two patents by John Todd and Michael Shaw for the Ecological Fluidized Bed (EFB) which were filed in 1993 and 1995 and assigned to Ocean Arks when granted in 1996 and 1997.[181] The EFBs were tank-based final water polishing systems that were to be a component part in various living machine constructions. Designed with an outer free water tank and inner tank filled with a media[182] water flowed downward through the inner tank media and then upwards in the outer ring. The patent specs stress the multiple trophic levels that the EFB could support, with benthic organisms in the outer ring and plants being supported in the media.[183] EFBs were included in the designs of the Living Machines implemented by LTI for many years, and LTI paid a licensing fee to OAI for the use of the EFBs.[184] Other non-patented components of Living Machines in the 1990s included primary settling tanks, closed aerobic reactors, open aerobic reactors, clarifiers and wetland cells. The open aerobic reactors functioned largely as activated sludge systems,[185] but they were capped with hydroponically grown plant materials. The plant growth on the EFBs and open aerobic reactors were largely responsible for the iconic lushness of the Living Machine Systems. The process chain of the living machines were each tailored to the waste stream of the client. Climatic conditions determined the type of enclosure the systems included. Just as

[181] Patent Number 5,486,291: *Ecological fluidized bed method for the treatment of polluted water*. And Patent Number 5,618,413: *Ecological fluidized bed system*.

[182] Original design specs were for pumice, latter systems experimented with plastic media pieces, called bioballs.

[183] A technical critique of the EFBs was that contrary to normal device naming parlance, these systems were only fluidized in their reverse flow phase, or backwash capacity, wherein the flow rises up through the media to dislodge the accumulated sludge to flow it to the outer ring from whence it would have to be collected (EPA 1996 p. 2.4-2.5)

[184] Pers comm..

[185] Disagreement exists in the literature as to the characterization of these early Living Machine systems. Some classify the systems as examples of fixed film systems due to the fixed microbial sites on the plant roots. Other writers characterize the systems as functioning primarily as activated sludge systems, wherein the majority of the biological activity is occurring in suspension in the tanks. See for example Norström 2005 and EPA 1996.

with the earlier SAS, stand alone greenhouses became an iconic image of the Living Machines, though other formats existed. For the system built for Ethel M. Chocolates in Nevada (1995), the entire facility was sunk into the ground and designed with a retractable cover. The system for The Adam Joseph Lewis Center for Environmental Studies at Oberlin College, (1998) had the Living Machine enclosure nestled into the corner of the main building. And even more daringly, for the Discovery Center in Kansas City, Missouri (2002) the Living Machine was centralized in the building in a central atrium enclosure.[186]

LTI and OAI worked together on projects in the early part of the 90's, including the showcase facility at South Burlington (1995) which was one of the four EPA funded demonstration projects. Other early projects include wastewater treatment for the National Audubon Society at Corkscrew Swamp Sancturary (1994); treating candy processing wastes for Ethel M. Chocolates in Nevada (1995); and community wastewater treatment for The Findhorn Foundation (1995). Early development of LTI was characterized as having occurred by "word of mouth and public relations rather than any overt sales effort"[187], but even that had allowed the company to put in six systems in 1998: The Adam Joseph Lewis Center for Environmental Studies at Oberlin College; The Darrow School in New York State; Cheddar Grove Cheese in Wisconsin; Magic Hat Brewery in Vermont; and Earth Centre in the U.K; and EFFEM Productos Alimenticios in Brazil.

[186] This system it must be noted has been chronically light limited and the Living Machine enclosure had to be retrofitted with grow lights. The design placement of the Living Machine in the building was done prior to consultation with LTI (pers com).
[187] (Crawford 1999)

But at some point in these developments, LTI needed a further round of investment beyond what had occurred from the initial local investors. This second round of investment ended up bringing about many changes in the company. This change is tersely summarized in one article as "To fuel continued growth, the company needed to reach out for a second round of financing, with the eventual aim of becoming publicly traded. However, the company was eventually acquired by an outside investor and it was moved out of Vermont."[188]

The outside investor was Tom Worrell, an ex-newspaper and media magnate, and who had originally met John Todd through their shared interest in boats and boat design in the 1980's. Worrell himself characterized John Todd as a friend and when initially approached in the 80's, to invest in wastewater technologies, he declined.

> In the mid-80's at his Charlottesville-area farm, Worrell was entertaining ecologist and inventor John Todd, a man trying to develop "living machines," systems to purify contaminated water by replicating processes found in nature. "John was a good friend, he thought of these wonderful things, but could never make them work," says Worrell. "He said to me, 'How would you like to invest in a sewage treatment facility made of plants? At that time," Worrell laughs, "I told him, ' I think I'll pass."[189]

However, at some point in the middle to late 1990's, when the technologies were more established, John Todd and Tom Worrell established an investment agreement. In 1998, there was a reformulation of the LTI board of directors and the management of LTI. At this point Michael Shaw ceased to be president of LTI and became instead Executive Director of Ocean Arks. Ramin Abrishamian was brought in as CEO,[190] and a new emphasis on marketing and sales was established.[191] The new investment money from

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[188] (Feinbaum 2002)
[189] (McNair 2009)
[190] Abrishamian was possibly one of the original investors as well.
[191] "According to Abrishamian, the company hasn't been marketed at all, so his initial marketing plans are quite simple: 'Just do it' the company's sales – more than 25 systems worldwide, including six countries and 10 states – has come from word of mouth and public relations rather than any over sales efforts. He is hiring a marketing manager" (Crawford 1999).

Worrell likely contributed to this reinvigoration of marketing and company growth.[192] However, by the end of the decade the company was close to bankruptcy[193] and due to failure to meet some of the loan conditions established in the investment contract with Worrell, company ownership devolved to him in 1999.[194] With the company floundering and more tensions existing between the Board of Directors, John Todd and Tom Worrell, Living Technologies Inc. was dissolved, and a new entity, Iasis Limited was established in Taos, New Mexico.[195] The new company included a number of the design staff from LTI, both engineers and others[196], as well as initially employing John Todd as a consultant.[197]

At this point, Living Machines® were not being actively marketed by the new company, but rather a phase of intense research and design was undertaken. It is in this era, that tensions became strained between Iasis Limited and Ocean Arks International. At the heart of the contention was the issue of Living Machines® as a trademark brand and proprietary technology, and subsequently who had the right to design, construct and name their systems Living Machines. As explained by individuals who were employed at Iasis at the time, the concern was that they were investing in research and design and

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[192] Speculation from interview comments which though not identifying precisely when the new investments flowed into the firm, acknowledged the impact of the investments on marketing.
[193] From personal communication.
[194] The 1999 date comes McNair (2009). In personal communications one informant described this process as "Worrell is a very astute business man and understands how business acquire each other. If you can loan a lot, and if they default and you are the biggest investor, you've just acquired the company. Tom carefully inserted clauses in the loan, nitpicky requirements, a lot having to do with reports. This is the suave business practice of people who are used to acquiring businesses. So the trap is sprung." Though the tone of this comment itself can be interpreted as a fairly negative projection of Worrell's intentions, e.g. "the trap is sprung," this informant was in fact overall positive about Worrell and his acquisition of LTI.
[195] Iasis Limited was incorporated in May 1999
[196] Including John Todd's son, Jonathan Todd (McNair 2009). Jonathan Todd had previously worked on projects through OAI and the still extant John Todd Ecological Design (John Todd Research and Design) Information taken from Johnathan Todd's resume, accessed through published report at www.mass.gov/Eoeea/docs/eea/nrd/jted-eco-station.pdf
[197] Information from an interview, unconfirmed in any written document.

attempting to improve the design basis of Living Machines, but that OAI was continuing to market an older style of living machine and the low functionality of these designs was damaging to the reputability of the technology.[198]

A number of the people who had interactions with extant Living Machines characterized the systems from the mid 1990's as "problematic", "under-designed" and one individual characterized LTI in general as "lacking a coherent technology."[199] As one ex-LTI worker stated about the mid 1990's period of the company

> We had a pretty high powered CEO who was raising money and really trying to commercialize the technology, a vice-president of engineering, so we spent a lot of money on marketing. There wasn't a lot of revenue coming in, but there was a lot of professional development going on. But there wasn't the R&D to back up the marketing though, we just didn't really have… there was some great ideas, but there weren't great products (pers. comm..)

Others less generously described the technical situation of LTI at the time of its acquisition by Tom Worrell as being "an empty bag."[200]

As OAI was continuing to deploy living machines, and Iasis was investing in research and development to improve the design basis, legal action was taken by Worrell OAI, claiming that as Living Machines® was a proprietary term referring to specific technologies, and that since these technologies had been the explicit provenance of the LTI firm, the trademark was one of the assets that was acquired along with the company. This case was settled out of court in December of 2000. One of outcomes of this settlement was that the trademark registration of Living Machines that had originally been filed by OAI, was terminated, and OAI would subsequently scrub all reference to living machines from its websites and cease to call any technologies it produced 'Living Machines.' Whether or not this settlement *officially* included the more general

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[198] (pers comm.)
[199] (pers comm. with technology adopters and practioners)
[200] (pers comm.)

requirement for John Todd to stop using the term living machines as a general descriptor for designed ecosystems is unclear.[201] However, in his subsequent writings John Todd has mainly switched to referring to the products of ecological design as 'Eco-machines'[202]

Coming out of the research phase, Iasis Limited was to became Living Machines, Inc[203], or more fully titled Dharma Living Machines, and was joined with an architecture firm as the consolidated firm Dharma Living Systems. A major project constructed by Dharma Living Systems was the luxury resort El Monte Sagardo in Taos, wherein a newer generation of Living Machines was deployed along with many other green design and water recycling technologies. In 2005, Dharma Living Systems would undergo a restructuring, with the architecture firm becoming Living Designs Group, and the water and wastewater portion, Dharma Living Machines became a stand alone company which in turn became Worrell Water in 2006. In 2007, Worrell Water would move its operational base from Taos, New Mexico to Charlottesville, Virginia where it operates from today.

In the research and development phase of 1999 and 2000, the ex-LTI designers began to move away from the hydroponic activated sludge based systems, and the research efforts were focused on a number of fixed film and wetlands based technologies. Out of these researches a number of new patents were filed starting in 2002. In total, 13

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[201] I was a volunteer at OAI in the summer of 2001, and at one point when Dr. Todd was visiting the South Burlington living machine he spoke with a group of us workers and stated how he was having to stop using the term living machine as that was owned by someone else and that he was working on a new generalized term.

[202] Eco-machines is used generally, but is also used specifically in regards to the new generation of tank-based enclosed designed ecosystems that his firm John Todd Ecological Design constructs, and as such he has trademarked the term Eco-Machine. In regards to designed ecosystems that are floating rafts that are placed directly in contaminated waters, these are called Restorers and have been deployed by OAI and John Todd Ecological Design in a number of situations.

[203] Incorporated May 2000.

patents have been granted, initially to Dharma Living Systems and then to Worrell Water, 6 of which are unique patents and the other 7 are continuations. It is worth noting that the listed inventors on all of these patents had been LTI staff originally. The first two patents are for process chains that include hydroponic reactors that include suspended plants above the system coupled with wetlands or fixed film reaction chambers.[204] Unlike the earlier EFB patents, which had remained the property of Ocean Arks, these new patents are for an entire process chain, not singular design elements. The later patents filed by the Dharma engineers mostly focused on wetland systems that achieve high treatment rates through combinations of vertical and horizontal flow, coupled with rapid pulsing.[205] These newer living machines are referred generally in Worrell Water's marketing campaigns as Next Generation Living Machines® and the company has focused on promoting its Tidal Flow Living Machine® which has been deployed at schools (Gilford, North Carolina; Furman University, South Carolina) and at a major environmental retreat center (Esalen Estates, California) among others. The tidal systems lack free surface water and can be deployed outdoors without an enclosure, though the company has also done some systems still in greenhouses.

Contested Connections

The overall transformation of living machines throughout the 90's in general, and the transition of Living Technologies to Worrell Water in specific, was not without contention and discord. In interviews informants stressed the role of technical and

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[204] Patent 6,811,700, *Integrated hydroponic and fixed-film wastewater treatment systems and associated methods*; Patent 6,830,688, *Integrated hydroponic and wetland wastewater treatment systems and associated methods*

[205] One patent deals with lagoon systems and nitrogen removal: Patent 7,347,940. The rest are variations on wetland systems: Patent 6,863,816; Patent 6,881,338; Patent 6,896,805; Patent 7,029,586; Patent 7,056,438; Patent 7,087,169; Patent 7,214,317; Patent 7,378,021; Patent 7,378,021; and Patent 7,320,752

business practices in the development of the tensions and problems. Some in talking circumspectly of this time period suggested that personality and egos also played a role in the final outcomes of the living machine to Living Machine transformation.

One of the major tensions was characterized as a growing estrangement between John Todd and "the engineers." In interviews with ex-LTI members, three different individuals explained this growing tension as being between the engineers and their engineering mindset and John Todd's visionary ideas. Over the course of a number of Living Machines installations the LTI engineers had done such modifications as changing some of the general process flows,[206] modifying the form of the EFBs, adding clarifiers and increasing aeration. Many of these changes were not seen as fulfilling the idealized goal of "gossamer engineering." Similarly, there was pressure from the engineering staff to streamline the production process, making each project less idiosyncratic so that costs could be brought down. Such technologicalization of the systems was reported as having been opposed by John Todd. Others stated in interviews that there had also existed differences of opinion in the Board of Directors over the general company direction and over which types of projects the company should pursue. As one engineer who worked for LTI put it:

> I think that it is important to straighten this out, it wasn't just that Worrell [went after Todd's company] At first he was trying to do what John wanted which was save the company from the engineers.*[Save it from the engineers?]* Well, he thought it was getting too technological. And we were going after big wastewater projects because that really was where the money was and maybe losing some of the vision. Which is, which is not necessarily… That is not false, because we were losing some of the vision, but the problem was it was either move in that direction or just fall apart. *[Small wastewater is a hard field to be in]*Yeah small wastewater is, but especially if your constrained to make beautiful expensive systems, especially when you don't really have a coherent technology. The original living machine, or the living machine that came to be kind of standardized in 1997 – 1999 was basically activated sludge with a green beanie on top.

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[206] Adding recycle

After the financial acquisition and the subsequent legal wrangling, the institutions and actants went their separate ways. In the ecological design community the rift between the institutions was known and John Todd's loss of control of the various technologies he had inspired was strongly felt by some[207]. Iasis/Dharma Living Machines found itself receiving some negativity as the company of the "billionaire who stole John Todd's patents."[208] Institutionally there was distancing, as each organization elided the old connectivity. In the case of Dharma Living Machines, for a number of years the website of the company did not have any information about John Todd's involvement in Living Machines on their page. However, now the newly refurbished page for Worrell Water does cite John Todd's inspirational role in developing the living machines idea, while at the same time distancing themselves from the early versions of the technology:

> Todd's versions of the Living Machine® were an innovative effort, but they didn't get consistent treatment, and could not be made to be simple and cost effective. In 1999, Tom Worrell, an investor and partner of Dr. Todd's, acquired the Living Machine concept, the company, and all of its intellectual property from Dr. Todd. He then put his engineers to work making the technology practical, reliable, and cost efficient.[209]

But this institutional distancing has gone both ways. In the history written by Nancy Jack Todd, *A Safe and Sustainable World*, no reference is made to the company Living Technologies, Inc in the story of the various institutions and people associated with the designing of ecosystems. Moreover, even in explaining why they no longer use the term living machines, prior connectivity between the with the current holders of the names is elided.

> In the late 1980s, the contained ecosystems that John had first contemplated in large jars on our front lawn, and which had been the workhorses of New Alchemy's solar aquaculture and Ocean Ark's ecological restoration, acquired a new name. One of John's business colleagues, who had been greatly impressed with their performance at Harwich, suggested we call them Living

[207] See for example comments in (Picard, 2008): "But according to Sellers, Todd later got 'screwed' out of his idea by some rich, eccentric 'Dr. No' character who forced Todd to buy back his own technology."
[208] One interviewee stated that this idea is what was making the rounds of the environmental community.
[209] http://www.livingmachines.com/about/history/

> Machines. That is still the most popular, almost generic name, but it is now the corporate property of a water remediation company based in the West. We no longer use it but now refer to the name Eco-machine.[210]

That the long and complicated history that connects this 'water remediation company' to OAI and John Todd is not included in the otherwise rich history of *A Safe and Sustainable World* makes it clear that the institutional wrangling around the design, deployment and ownership of Living Machines® has left some bad feelings, and perhaps justifiably so.

Conclusion

This history of the living machines technology seems to fit with Hess's notion of complementarization. Originating as part of a social movement and under the auspices of a visionary entrepreneur, the ideas of designing with ecosystems first became codified into particular technologies and then as the technologies were moved into more mainstream practice, elements of the technology were changed to make the technologies more effective and economic. Just as Hess postulated should happen after complementarization, disenchantment with the new technological deployments lead to division between those doing the complementarized technology and the original social movement elements. Following upon this division, comes a reframing of the social movement element and subsequent reinvention of eco-machines and ecological design. However, because of its focus on the social movement components of alternative technologies, the use of the complementarization frame has its limitations in explaining the processes of change that occurred with these ecotechnologies. Through out the history of these ecotechnologies, a range of constraints has influenced their development. and the nature of some of these

[210] (Todd 2005 p.167)

constraints challenges the simplistic narrative of moving from radical alternative to complementarized technology. These constraints will be discussed in the second section of this work, in particular in Chapter 9, and a further analysis of the complementarization of designing with ecosystems will be undertaken in Chapter 10.

CHAPTER 5

DEVELOPING ECOLOGICAL ENGINEERING –

SCIENCE MOVEMENTS AND BOUNDARY WORK

> Ecological engineering is emerging as a field from the actions of a lot of different individuals who come at it from different perspectives. (pers. comm.)

> Different people have different definitions and there are some people that have no definition for it. It's one of those hard things; you're a student and you're looking to the people who are teaching the field to say -- you're looking at them saying, "Well, what do I become whenever I become an ecological engineer? What do I become?" and what we hear is "Well, we don't really know yet." (pers. comm.)

Introduction

The concept of utilizing ecosystems as a basis for design practice has not only been deployed as part of the 70's environmental and alternative technology movement, as explored in the previous chapter, but it has also been the underlying principle in the development of the disciplinary practice of Ecological Engineering. The goal of this chapter is to outline the framing and objectives for this new field as experienced by its members and in so doing lay the ground work for the evaluation of ecological engineering as a potential example of a "science movement." Following the first section's brief institutional history, the second section of this chapter discusses the definitions and defining features of this field. The third section describes the major realms of disciplinary boundary work that the ecological engineering community is engaged in. The fourth section outlines the goals ascribed to the field and the relationship of those goals to sustainability and to environmentalism. The chapter then concludes with a brief evaluation of ecological engineering in relation to the theoretical perspectives of ecological modernization and science movements.

History

The history of ecological engineering (EE) in the United States is a mélange of scientific advancements,[211] technology applications, academic collaborations, institutional formalizations and individual personal commitments. Though H.T. Odum is credited with coining the term ecological engineering in the 1960's,[212] it was not until 1989 that the formative edited volume *Ecological Engineering: An Introduction to Ecotechnology* was published. This text laid out the realm and possibilities of ecological engineering (Mitsch and Jørgensen 1989). Following on this book, a number of international meetings, workshops and dialogs were held to explore the concepts and define the field (See Mitsch 1998 for a overview of these various national and international meetings and Etnier and Guterstam 1991, and Schulz 1996 for proceedings). Formalization of the field at an international level was advanced through the 1992 establishment of the journal *Ecological Engineering: The Journal of Ecotechnology*[213] and the 1993 establishment of the International Ecological Engineering Society (IEES). After a planning workshop in 2000, in 2001 the American Ecological Engineering Society (AEES) was formalized and its first annual meeting held at the University of Georgia. In 2004 two separate key resource textbooks on ecological engineering were published (Kangas 2004; Mitsch and Jørgensen 2004).

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[211] See both (Mitsch & Jørgensen 2004) and (Kangas 2004) for overviews of antecedent research that fed the development of ecological engineering.

[212] Development of ecological engineering in Europe and China has its own historical precedents. Debate exists as to the true primacy of Odum's 'ecological engineering' as Chinese researchers have a history of an 'ecological engineering' type practice (see for example Ma, Shijun 1985) that dates as far back or further than Odum's work. See Mitsch 2004, Chapter 13 for a history and analysis of Ee in China.

[213] The editor in chief of the journal at inception through the present has been William Mitsch, who was a student with H.T. Odum. The journal was renamed in 2005 to *Ecological Engineering: The journal of ecosystem restoration.*

In the United States further formalization of ecological engineering has been being pursued through the establishment of trainings and practices of ecological engineering inside of academic institutions. These initiatives, and their outcomes, are less easy to narrate then the history of societies founded, or key books published, as these educational initiatives are ongoing and are progressing with variable success. EE in the US academic setting arose partly out of the general growth in ecological sciences and the trend towards systems thinking in the later half of the twentieth century. While both H. T. Odum and his brother Eugene Odum are key figures in the development and promotion of ecology and ecosystem studies, jointly publishing the first text on ecology *The Fundamentals of Ecology* in 1953, it was H.T. Odum's systems work that feed into the development of the ecological engineering concept.[214] H.T Odum's development of the concept of ecological engineering arose out of his extensive studies in the energetics and structures of ecosystems and it was through his influential systems ecology program at the University of Florida that the early groundwork for the development of EE was laid (Mitsch 2003). Odum's legacy can be seen through his students and their efforts to establish EE as foci or programs of study in different academic departments in the United States.[215] The two earliest such developments were those at Ohio State University, initiated by William J. Mitsch, and at University of Maryland initiated by Patrick C. Kangas. Similarly, the foci on ecological engineering at Florida has been furthered by Mark Brown, another Odum graduate student. Interestingly, though these three schools are often identified in the EE community as the leaders in the development of the EE

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[214] For more detailed analysis of the development of ecosystems science in general see Golley, 1993 and Hagen 1992. Interestingly, it is this same rise in ecology and systems thinking in the 60s that influenced the development of Ecological Anthropology.

[215] Odum's legacy also includes Ecological Economics, as another of his systems ecology graduate students, Robert Costanza, is considered a key founder of that field.

discipline, even at these schools the programs are still in various stages of formation and formalization.[216]

Though Odum's systems ecology work is considered a key underpinning in the field, events in other fields also fed into the development of ecological engineering. Restoration ecologists working with pollution effected lands and environmental engineers seeking to treat wastewater began investigating the water purifying capabilities of wetlands. This work lead to some of the first design guidelines for constructed wetlands for wastewater treatment (EPA 1993a; EPA 1993b; Hammer 1989; Kadlec and Knight 1996). The use of constructed wetlands as wastewater treatment came to be an acceptable component of the 'Natural Treatment' panoply of environmental engineering practice (Kruzic 1994; Liehr, et al. 2004). Thus overlap in training and practice exists between environmental engineering and the developing ecological engineering community through this shared wetlands work. Concomitantly, some of the early EE programs developed inside of environmental engineering departments, for example, the program developed by Alex J. Horne[217] at the University of California, Berkeley[218] and the aforementioned foci at University of Florida. Another early burgeoning of EE in an environmental engineering department occurred at the University of Vermont but this program has not formally progressed. Other currently strong programs have developed inside of Agricultural and Biological engineering programs such as the program at the University of Arkansas and the University of Georgia.

[216] Note also that William Mitsch was the first president of the AEES, Mark Brown was the second, and Patrick Kangas was the fifth.
[217] Third president of the AEES
[218] He initial called his program 'applied ecology'

Faculty interest, development of research foci, and attempts to establish programs in EE occur at other Universities than those mentioned above. These include Kansas State University, Virginia Tech, Oregon State University, Oklahoma State University, University of Illinois, Clemson University, SUNY-ESF, Texas A &M-Kingsville. Some of these programs are older in the sense that key senior faculty, like Dan Storm, at Oklahoma State University, have had been involved with ecological systems principles and practice for a long time and have themselves turned out students that have gone on to be key developers of EE programs. For example, in the case of Dan Storm, his Ph.D. students Marty Matlock and Cully Hession have been the leads in the development of EE foci at the University of Arkansas (Matlock) and University of Vermont and Virginia Tech (Hession). The struggles to develop these programs and the various constraints of such development are discussed in Chapter 6.

Practitioners of ecological engineering are even less clearly identifiable than academic programs. Few engineering or design firms explicitly link their work to the concept of ecological engineering.[219] Some who consider their work to be part of ecological engineering, or to be examples of ecological engineering may not explicitly label themselves, or their work, as such, as the meaning of the term is not completely known in the general public. More familiar terms like ecological restoration or wetlands construction might be used. As one practicing engineer put it "We need to be braver about calling ourselves ecological engineers."

[219]The Ecological Engineering Group webpage states, "Ecological engineers and designers specializing in advanced and ecological water solutions and septic-sewer alternatives"; North American Wetland Engineering (NAWE) has as their promotional text "Hands-on, ecological engineering providing practical, innovative solutions."

How Ecological Engineers Define Ecological Engineering

> So one of the biggest hurdles is going to be that definition, making sure we can fully define what an ecological engineer does. (pers. comm.)

> If you show me a project, I may say, "Yes, that is [ecological engineering]," or, "No, that isn't." But someone else may see it differently. So I think each ecological engineer might think of it a little bit differently, because it's kind of fuzzy. And I don't know if it necessarily needs to be less fuzzy or more fuzzy. (pers. comm.)

Application of ecological engineering can occur in different realms, such as treatment of wastes, pollution removal, soil remediation, restoration of rivers, lakes or whole watersheds, mine land restoration, erosion control, and wetland creation. But just as many applications for ecological engineering exist, so to do many different constructions of a *definition* of ecological engineering. A key early formulation was framed by William Mitsch and Sven Jørgensen in the now classic *Ecological Engineering: An Introduction to Ecotechnology* (Mitsch and Jørgensen 1989). This definition has undergone revisions,[220] but in their 2004 textbook it was stated as :

> *Ecological engineering* is "the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both." (Mitsch and Jørgensen 2004)

Though this is not the *definitive* definition of ecological engineering, it has high referencing in the ecological engineering literature and online EE information as well as being frequently paraphrased (especially by students) in interviews.[221] In variations of this definition, Bergen (2001) adds the clause "consistent with ecological principles", and Gattie et al. (2003) further adds the concept of self design –so that the definition reads

> the design of sustainable systems, consistent with self design and other ecological principles, which integrate human society with the natural environment for the benefit of both (Bergen, et al. 2001; Gattie, et al. 2003 p. 410).

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[220] See the section on Sustainability below for an example of an early and major reframing.

[221] For example "I'm trying to go through Dr. Mitch's stuff in my head, but of course I can't remember it word for word. I think it's the use of ecosystems to benefit man and nature."

Two major elements of this definition, “ecosystems” and “for the benefit of both”, are important framing elements that are strategically used to help explain how this field of practice is distinct from other engineering fields. These disciplinary boundary shaping terms are discussed in the second section below.

But first, in the following section the definition of ecological engineering will be further explored by delimiting some of the major themes that are used by members of the EE community. Outside of a singular concrete definition of the field, a number of key elements or principles are also utilized to frame the field of ecological engineering. A number of formalized principles for defining the field have been proposed in the literature (See Appendix B for four different published sets of ecological engineering principles demonstrating the subtle variations in conceptualization and definition that are occurring in the literature). In the following I will focus on definitions and principles drawn from interviews and social interactions.

Conjoining Engineering and Ecology

In discussing ecological engineering with academics and practitioners a major first framing is the stress placed on the fact that it is “ecology AND engineering.” Embedded in this desire to *join* these two different fields is the conceptualization that these two fields *are* distinctly different. This is explained as the classic difference between engineering and science

> And it's a practice, ergo, it's engineering. It's not science if you're doing -- science is just the study. Scientists are very good at studying systems, studying the depth and blah, blah, blah. But that's not what we're talking about here. We're talking about what I want to do, saving the world, a proactive thing. And that's what engineers do. (pers. comm.)

That engineering is an applied, or solutions oriented practice which stands in distinction to science as study is an accepted trope in the EE community and the importance of engineering for the design and 'doing' of projects becomes a key distinction that is used to separate EE from ecological restoration (see Boundary Work section below).

But besides drawing on the general distinction of engineering and science, explanations of ecological engineering highlight the difficulty inherent in joining the specific science of *ecology* to engineering.

> Well, I think the main thing with ecological engineering is that it really needs to combine two very different kinds of activities and the people that are associated with those activities, ecologists and engineers. There is a big gap between those two communities. (pers. comm.)

The difficulties, yet necessity of this conjoining of ecology and engineering was a large subtext in various discussions at AEES conferences and was a frequent topic of discussion in interviews when we talked about barriers to the development of the field. These barriers develop from institutional structures, epistemological differences and just plain ideological stereotypes and prejudices held in the two communities.

> And that's unfortunate because engineering is the design of solutions for problems essentially. And the whole concept of bringing ecological and marrying those two words, I think, should make it okay with people, but instead -- they go, "Huh? How can they do that? … there's no way to bring those two together." (pers. comm.)

Thus in the very framing of ecological engineering the field incorporates a major barrier to its own institutional advancement. These aspects are further discussed in Chapter 6.

Rigorous Design Practice

Discussions of the necessity of conjoining ecology and engineering are coupled to explications of why each of these fields is necessary. That EE needs to be a prescriptive, rather than a descriptive field, is a highly shared construct. For some this means that the field by necessity must be an engineering practice.[222] Engineering is necessary in short

[222] But this is not universally felt, see Chapter 6 for a discussion on the professional nature of the term 'engineering' and the implications this has for the development of the field of Ecological Engineering. In short, not all agree that the field must be an 'engineering' due to the constraints to training and practice that come with the professionally regulated term 'engineering'

because "engineers do things." As one student succinctly put it "I wanted to do something tangible, not just research, hence the engineering degree." One of the major things that engineers 'do' is design.[223] For those who see the field developing as an engineering practice the stress is placed on the need for EE to be based in rigorous design principles and an analytical depth like any other engineering

> When we talk about designing and building and operating these constructed ecosystems, we're thinking about that with a quantitative rigor that other engineering disciplines have. (pers. comm.)

At the AEES open forums, conversations often range around how to teach ecological engineering, what people are doing and how things are progressing. But the larger focus of these talks is on the concern of how to get the students prepared for 'practice' and how to get 'ecological engineering' to be known amongst potential employers. A series of exchanges at the 2005 workshop is enlightening. "Our students feel they are taking a risk" was stated by a professor speaking of the students who were choosing to focus in EE, referencing the newness and unknowness of the field. At the same workshop, others expressed that EE would be "selected for" as the need for lower-energy systems became more apparent under rising energy costs. Another workshop participant expressed how EE was poised to offer practical solutions for interfacing human systems and natural systems through the designed ecosystems. Another professor stated that "We need more marketing. We need to be selling ecological engineers as designers of ecological services. We need to be selling a service, selling what we do."

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[223] A rich literature exists investigating the nature and role of design in engineering. Scholars discuss the epistemological differences between science and engineering (which may not be as stark as is commonly maintained. See Lelas, 1993), and also investigate the ways in which engineering is a producer of knowledge, not just using or applying knowledge generated through 'science' (Channell, 1982; Layton 1971 & 1974; Hannson, 2007). At the heart of this knowledge generating engineering practice is the product, the design. The ways and means of 'designing' then become sites of scholarly investigation as well (Bucciarelli, 1994; Vincenti, 1990; Vinck, 2003). Design is more than a mere application of received science knowledge, and encompasses its own methodologies and practices. The iterative, tactile and tacit knowledge aspects of doing design make it an art (Ferguson, 1978; Florman, 1994).

All of these conversations highlight the way in which the field is constructed as a proactive, problem solving, design oriented field. For some this means that the field must by necessity be an engineering practice

> Much of our experience in wetland design is not ecological engineering, because it is not so much design for ecological processes as it is for aesthetics. Design for aesthetics is not ecological engineering, that is gardening, fancy gardening. And that is what a lot of folks call ecological engineering – fancy gardening. That is what we have to avoid. If we are not going to be fancy gardening we had better be rigorous engineers, we had better design with a purpose. (pers. comm.)

But for others, maintenance of the field as an 'engineering' was less the goal than simply creating a field based on good a technical and quantified design work. (See both the Boundary Work Section below and Chapter 6 for further development of this idea).

Grounded in Ecological Science

For those who define EE as an engineering practice, comparisons are often made to other engineering fields and those field's reliance on a unique scientific practice. As chemical engineering relies upon chemistry so too should ecological engineering be grounded in its own science – that of ecology.

> I think the elements that make a project an ecologically engineered project is the explicit consideration of ecological science within the design. (pers. comm.)

> I think an ecological engineer, to me, is doing a new type of engineering, and they need a strong foundation in the sciences of ecology and environment, and they need to understand soils and microbial ecology and community ecology; understand systems to understand what they're dealing with and what they're having an impact on. Or if they're inventive-type people, they need to know the basic systems in order to be able to invent. (pers. comm.)

The primacy of ecological knowledge as a foundation for doing EE is thus a major distinguisher of the field from other engineerings (see Boundary Work section below) and a contributing difficulty to the establishment of EE programs (See Chapter 6). However, the interrelation of EE with a deep knowledge of ecology is not merely discussed as a passive application of ecological knowledge. Instead, the applications of EE are seen as avenues to fundamentally test the soundness of various ecology concepts.[224] In fact, Mitsch (2004) states that one of the key principles of ecological engineering is that it is an "acid test of ecological knowledge."

This drawing upon and adding to the scientific knowledge of ecological sciences is a component of doing ecological engineering, and for some, it is the *rigor* of this science that is the key element in doing ecological engineering. Just as the 'engineering' component is used by some to emphasize that the field must be a rigorous design practice, others point to the 'ecological' and stress how that must mean *science* and not just "green hand waving." An expressed concern was that ecology in the general populace is becoming to be more equated with general environmental or green ideas, and does not necessarily connote the idea of 'Science.' Even in academia, some fear that ecology is too broadly used:

> The problem with ecology in general is that "ecology" is a term that's been taken by everyone. So you have industrial ecologists, you have, human ecology…it's used by everybody. (pers. comm.)

Thus an important part of developing ecological engineering for some is the maintenance of proper boundaries on its scope with the realm of ecological science.

> And the reason I'm being just ornery about that is that I think the field needs to have some strong fundamentals to it. And the fundamentals need to be from the science of ecology, and if we just venture too far from that, it will become like your environmentalism term…just so broad as to mean nothing. (pers. comm.)

And along with maintaining the proper scope of the field within the realm of practice that can be based on fundamental ecological principles comes the need to develop and improve upon those ecological principles. Thus, part of the necessary development of the

[224] Ecology itself is a 'young' science, and as such is still establishing overarching theories and many describe the field as still being too descriptive. In particular the concept of ecosystems is still developing theoretical constructs (Golley, 1993). Within systems ecology many different theories and modes of analyzing ecosystems exist, such as Pahl-Wostl's self-organization, Ulanowicz's ascendency, Allen and Star's hierarchy theory and emergent properties and Pattens environs theories and indirect effects and H.T Odum's systems modeling and emergy analysis. That ecological systems theories still need to be 'tested' is expressed in the restoration community as well as in the Ee community (see Mitsch 2004, p.32).

field of ecological engineering is the further development of the science of its practice (Gattie and Foutz 2007). This use of systems ecology as the scientific basis of EE adds an extra constraint to the development of the field as the methodologies of systems level analysis challenge the boundaries of conventional scientific reductionism (Gattie, et al. 2007).

Systems Level Work and Larger Scales

In talking about ecological engineering individuals discuss the systems level thinking that is necessary for the field. For some this is expressed as an interest in multiple scale use in biological systems:

> Processes that deal with one trophic level are not ecological engineering. Just because there is a living thing in them does not make them ecological. I define the difference between an ecological design and another design in the existence of multiple trophic levels. (pers. comm.)

But the systemic level of thinking is also expressed as including the relations of human cultural systems and natural systems in one rubric. As one student put it, "I can't deal with thinking about systems without people in them, but ecologists don't think that way. Ecologists talk about natural systems, and I feel natural." Integrating human systems with natural systems and working with ecosystems to do this was a common defining feature of EE as mentioned by students. The most commonly mentioned ecological engineering application was the use of designed ecosystems to treat wastewater.

> [Ecological engineering is] engineering principles applied to more ecosystem processes. Environmental engineers work with waste treatment and water treatment for human systems. Ecological engineers work with the same principals but at ecosystem level.

Amongst faculty, there was less focus on particular applications as indicative of ecological engineering, and more focus on explaining what ecological engineering is striving to encompass. Some stated that ecological engineering as currently practiced has not yet reached its true potential, but rather it needs to expand beyond focusing on individual projects and think and work at larger systemic levels. For some the continued perceptual tie of ecological engineering to wetlands work is problematic.

> In order to avoid the narrowness that has infected ecological engineering-the perception that ecological engineering is swamp engineering - that is the derisive term that is used by the civil engineers to describe us - the way we overcome the tendency towards that bias, is that we must define ecological services broadly. (pers. comm.)

In defining the application of ecological engineering more broadly some reference the need for the field to encompass larger scales of thinking and planning. The need to think and plan ecosystem projects at the landscape level was mentioned. Others used the scale of watersheds to indicate the scope of ecological engineering activities. At the other extreme two informants also stated that ecological engineering can occur in lab settings, as ecosystems are scale free.

Utilizes Self-design / Self-Organization

Another element in the defining of ecological engineering is the concept of self-organization in ecosystems. Self-organization refers to the emergent properties of ecosystems, and the propensity of the component biological components to change composition in the face of changing forcing functions (i.e. sunlight, nutrients, wind). Understanding the dynamic nature of ecosystems and allowing this dynamism to occur, to in fact plan systematically for this ecological dynamism within the design phase, is a crucial, and defining element of doing ecological engineering.

> I guess you have to define the fundamental difference between ecological engineering and engineering in general; And that's ecological systems are self-designing. So as far as I know, unless you're talking about really evolved AI, there's no other engineering that's dealing with something that designs itself. It's all your own design. So there's always that sort of inherent contradiction there, and that's at the heart of what ecological engineering is. (pers. comm.)

However, in discussing self-design in interviews, informants are careful to denote that this does not mean just a “hands off, anything goes” construction of ecosystems. Of importance (and this returns to engineering rigor and the application of ecological science) is that the human designer lays out the parameters and space with the ecosystem properties and inputs in mind such that self-design occurs within that controlled realm. Thus, within ecological engineering "utilizing self-design does not mean designing without rigor." Some individuals were painstaking in their definitions of "self-design" as a principled and scientific concept related to systems ecology because of their concern that it is misunderstood by some folks who hear the term.

> I had difficulty with self-organization at first. I thought it was too much like Lovelock's Gaia ideas. But grounding it in systems theory approaches, systems optimization, holonic organization, takes it away from the tie-dye attitude. (pers. comm.)

However, allowing self-design can require a degree of flexibility in the management of a designed ecosystem. To some, this allowance of change and adaptation is crucial to what ecological engineering should be. This element of EE is strongly advocated by some of the early academic developers of ecological engineering. (Brown 2004; Kangas 2004; Mitsch and Jørgensen 2004). However, the use of "self-organization" or "self-design" can be problematic. For engineering practitioners, in designing ecosystems for projects that are under some sort of regulatory oversight (for example wastewater treatment or pollution remediation) allowing too much self-design could move the systemic functions outside of the permit requirements.[225] As one practitioner explained, he is personally liable under stringent performance standards for his constructed wetland treatment designs, so he needs to more actively design the

[225] And even in ecosystems constructed for mainly research purposes, too much 'self-organization' can impact research goals. At one wetland research site, the difficult decision had to be made as to how to deal with carp that entered the wetland during a riverine flooding period. Though stochastic events can be part of self-organization, the entree of the carp changed the sedimentation dynamics of the wetland. As some of the major research goals of the wetland revolved around the carbon cycle and sedimentation, it was decided that the carp needed to be removed as they stirred up the wetland bottom and impeded the studies on sedimentation and settling.

ecosystem (perhaps planting it completely) and more actively maintain it (weeding it). He explained:

> The trees that want to self-design themselves into the wetland, might serve good ecological functions, but there is too much risk that their roots might damage the influent distribution and cause treatment failure. (pers. comm.)

At the 2005 AEES workshop, during an interchange of ideas on self-organization and self-design, one practitioner stated "Perhaps I am thinking about self-organization in too broad a way. I don't want my wetland self-organizing into a forest." To which another practitioner replied, "Yes, when we design these systems, we need to fence them in a little. We don't want chaos."

Boundary Work in Ecological Engineering

> *[So what then are the boundaries of ecological engineering?]*
> There are none right now. Just like anybody can call themselves an ecological engineer or nobody can call themselves an ecological engineer, depending on how you look at it. Right now we really don't have any boundaries. (pers. comm.)

Boundary from other engineerings

Throughout interviews and conference meetings, ecological engineering is distinguished from other engineering practices in general and from environmental engineering in specific. In interviews, individuals talk of ecological engineering as being a "new type of engineering" or of it being "distinct." That ecological engineering is thought of as distinct from other engineerings is evidenced by the outcomes of the pilesort task.[226] During the process of the pilesorts many different sorting criteria were

[226] Data presented are from the 40 pilesorts conducted. The one data manipulation that was preformed was that any pile that had been labeled "unknowns" was disaggregated, and each card made into a singleton pile. This is done to avoid the problem of "false groupings" as suggested in Gatewood (1999a & 1999b). This transform was necessary on only 6 cases. It is worth noting that when I compared HC diagrams with the 'unknowns' aggregated and disaggregated no appreciable differences emerge. This is likely due to the fact that the most common cards in a pile marked 'unknowns' were cards that had high proximities anyway. These were green engineering, and green chemistry and sustainability science (each labeled unknown 6 times, thus making up 18 of the 24 unknown labels. The others were Industrial Ecology, Sustainability Science and Landscape Architecture, each labeled unknown twice). 1.

used. People sorted out "applications" from "pure science," they separated out "ecological fields" from others that "don't necessarily contain ecology". Another common sorting theme was the use of ideas of "traditional" versus "newer applications." Though many different sorting criteria were used, the interpretation that ecological engineering is conceptualized differently than other engineering fields is supported by the hierarchical cluster analysis and multidimensional scaling run on the aggregate proximity matrix of the 40 individual pilessorts.[227] In both the MDS and cluster analysis, all of the formal engineering fields are joined into a single strong cluster and ecological engineering is not included in that grouping (See Figure 1 & 2 on p. 146).[228] Though individuals talk about the 'engineering' nature of ecological engineering this does not equate to the field being seen as strongly associated with other engineering practices.

It should be noted that the separation of ecological engineering from the other engineerings in the pilesorts could have also been an outcome of individuals sorting on a criteria of newness versus 'establishment.' In interviews, the young and tentative nature of ecological engineering was often part of individuals descriptions of the field. Individuals saw it as an "underdog" fighting for position. The non-grouping with the other engineerings could be a reflection of this dimension of new field vs. old field. However, 'green engineering' is also 'new' and not a formal discipline, but ecological

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[227] The individual pile sorts were run through the Anthropac 4.0 software package. The individual pilesorts are transformed into individual proximity matrixes. From these an aggregated proximity matrix is compiled (See Appendix C). The output aggregate proximity matrix was analyzed and plotted with a multidimensional scaling (MDS) algorithm in SPSS and hierarchical clustering (HC) algorithm in Anthropac. In SPSS the MDS analysis is based on the PROXSCAL method (Version 1.0 by the Data Theory Scaling System Group at Leiden University, Netherlands). The Anthropac hierarchical clustering method used is Johnsons HC and the clusters were generated through the Anthropac Average protocol, which is an unweighted pair- group average method.

[228] It is important to note that a MDS representation is scale free and that interpretation of meaning based on proximity is limited by the level of stress associated with producing the two dimensional representation. However, in the context of pilesorts it is considered that while a stress below 0.10 is considered excellent, below 0.15 is considered to be an acceptable level of distortion. (Borgatti,1996)

engineering had low proximity to that, or to the other fields often described as new or emerging, such as sustainability science, industrial ecology and green chemistry, so the dimensionality of the sort is likely not just an outcome of new fields vs. old fields but does represent a underlying categorization of ecological engineering being distinct from other engineering practices.

The Boundary with Environmental Engineering

> Ecological engineering has this allure to it that environmental engineering does not. Environmental engineering has all of the pipes, tanks and pumps. (pers. comm.)

The boundary of ecological engineering with environmental engineering is blurry and contested due to shared overlaps of realms of work, in particular wetland work, and some shared institutional roots (see Chapter 6). In interviews, individuals spoke of interchanges with environmental engineers who did not see a difference in the fields, or who merely saw ecological engineering as a subcomponent of environmental engineering. However ecological engineers work to highlight the differences between the fields in order to further the delimitation of the ecological engineering as a new practice. As a young discipline, their interest lies in highlighting the differences between the two, not in pointing out the similarities.

> Then there are tensions with environmental engineers who say 'that is not so different from what we do.' Um, yeah it is. Environmental engineers can practice ecological engineering with additional training. With additional knowledge and a modified approach. Draw the box bigger. Defining the problems larger, in a larger ecological context. (pers. comm.)

The difference between the two practices is characterized by ecological engineers as being differences in 1)knowledge sets, 2)scales of analysis and 3) goals of the practice. By claiming a grounding in ecosystem sciences, ecological engineers distinguish their work from environmental engineering, which they characterize as being involved with the "unit process" mode of analysis with reliance on technological "brute force" instead of ecological processes.

> Most of the environmental engineers I know do -- I call it-- waste management. Okay, they're interested in what comes out of a pipe or what comes off the landscape, and monitoring it, and modeling, and, in some cases, mitigating that. But they're not thinking from the point of view of providing habitat or improving species connectivity or things like that. (pers. comm.)

> They [ecological and environmental engineering] are dramatically different, the core knowledge base between the two are different. I have had civil-environmental engineers in my ecological engineering classes and they are lost. They are fundamentally lost. They don't understand watershed processes, they aren't very good at broad watershed level hydrology; they are very good at hydraulics, but not at hydrology. They don't understand geochemical cycling, they don't understand terrestrial or ecosystem processes very well. They don't understand weather, metrology very well. Maybe stochastic hydrology and that is it. The fundamental knowledge base you have to have to even understand ecology, are generally lacking. They are very good at what they are trained to do, at pumps pipes, tanks and microbial processes. (pers. comm.)

Ecological engineering as a new field is not well known in some institutional settings and the perceived similarity with environmental engineering leads to confusion amongst potential students. Adding to this confusion is the fact that people do not necessarily even have a clear idea about the realm and practice of environmental engineering[229].

> I would say that, if I were to poll the entire undergraduate program in environmental engineering and said that, "Did you know what you were getting into when you signed up for this?" They would say, "I thought I was getting into environment and ecology. I haven't had one ecology course in the entire time that I've been here. They want to do something with environment, and they're taught pipes and pumps and air pollution, and the stuff that's -- it's a great education. Don't get me wrong, but it's not environment as they think of environment. (pers. comm.)

As a practice environmental engineering encompasses a wide range of realms and applications. The characterization given of it in interviews with ecological engineers is that it focuses on the 'end of pipe' treatment of potential pollutants. As one student characterized the difference "[environmental engineering] is more concerned about public health implications" and less looks to make solutions "that benefit nature itself."

[229] This is likely tied to a the way in which both 'environmental' and 'ecological' have taken on generalized and vague meanings in popular parlance. Both are used in reference to the general non-human realm and all things 'green,' 'natural' and other terms related to a general feel good environmentalism.

Boundary with Applied Ecology

Just as ecological engineering attempts to distinguish itself from other engineering on the basis of the uniqueness of the inclusion of a real and deep use of ecology; concomitantly it distinguishes itself from ecological sciences that do design work on the basis of 'engineering.' The difference in being an 'engineering' versus an applied science is strongly felt by the ecological engineering community in two different ways. In the first case, the distinction is used self-referentially to describe how their practice has qualities lacking in other fields working with complex ecosystems, like ecological restoration.

> I think restoration is a major part of ecological engineering, obviously, because I do a lot of that, and in fact, I think that it should be a bigger part than the waste water wetlands, which seems to dominate, for whatever reason, the literature and imaginations of most folks. Because there is a crying need, a huge need for restoration, and the people who are often involved in restoration don't have the training, the engineering and design training. They have training as ecologists. (pers. comm.)

Thus the design training of engineering and the rigor of the engineering approach of EE is considered to be a strength that can add to restoration work. In fact, some characterize restoration ecology conceptually as a subcategory of what ecological engineering is.

> Ecosystem restoration is a subset, because in ecosystem restoration, you're trying to manipulate an environment – trying to restore it to what it used to be or change it to a more functional system. That's part of what ecological engineering does. But [ecological engineers] don't necessarily just restore things. They can actually start from new and build things. A wetland wasn't there before, but we built one. These creeks, maybe, weren't there before, but we've added them. Now we're starting to get into -- I'm really interested in sustainable designs and sustainable building. This building wasn't here before, but we built it and it's sustainable. It's got ecological principles and engineering principles that go hand in hand together, and it's on a landscape that's been ecologically designed by an ecological engineer. (pers. comm.)

Ecological engineering may be considered to be a potentially broader practice, but individuals acknowledge that currently ecological restoration is the more dominant nomenclature. Ecological restoration is more established as a realm of study and practice, and the term ecological restoration is free of the negative associations that go with the term engineering.

> I think, I agree with X that ecological restoration is ecological engineering and I think there is a bit of a sort turf thing, people think of themselves in terms of ecological restoration and why would they call themselves ecological engineers, especially since there is a cultural divide. A lot of the ecological restoration people are biology types and they think engineers are pretty bloody stupid. To a certain extent they have good reason to have that opinion. (from an engineer) (pers. comm.)

This leads to the second way in which the distinction between being an engineering practice versus an applied science is acknowledged as important by ecological engineers. Being a formalized 'engineering' field is recognized as leading to stereotyped assumptions of the field and difficulties with recruitment. The overall trope expressed at society meetings or in interviews is that for ecologists (and other environmental scientists):

> The word engineering just scares the crap out of them. They're afraid of it. They got beat up by an engineer or something… There's the negative image that the word engineer brings up. (pers. comm.)

The distinction of being an 'engineering' practice thus drives people away on the shear basis of the name. One active AEES member was brainstorming at the 2005 conference and was discussing the need for the society to reach out to non-engineering folks. She stated

> We need to be doing out reach to biology, to botany. I try to do this, I tell my wetlands colleagues about this conference and say 'you ought to go,' but they see 'engineering' and they flip out. (pers. comm.)

An expressed concern at AEES meetings is that there has been a dwindling in the number of "ecologists" who are active participants in the society. Other active AEES members, many of whom are actually ecologists, characterize this loss or dearth as stemming from different normative stances on the relation of humans and nature. The EE approach is characterized as being more willing to "tinker," and less reifying of a pure nature. For example, one ecological engineer was discussing laws that allow only the regulatory classifications of species as exotic or invasive. He called such simple classificatory schemes "ecological bigotry" as they wholesale eliminate possible useful and appropriate design choices. Another ecological engineer then stated "I agree with you completely, but we will drive the last three ecologists out of the organization" with ideas like this.

Though the ecological engineers joke about scientists being 'scared' of engineering, at the same time, they often acknowledge that "engineering" and the "engineering mentality" has caused problems, and that ecologists might be slightly justified in their initial skepticism.

> Ecological restoration is ecological engineering and I think there is a bit of a sort turf thing…there is a cultural divide. A lot of the ecological restoration people are biology types and they think engineers are pretty bloody stupid. To a certain extent they have good reason to have that opinion, so what I think, I think they need to see the biological sophistication of ecological engineering in order for them to become convinced that they are in fact part of the same field, albeit practicing in some what different ways. (pers. comm.)

The denigration of engineering is not practiced by just non-engineers. As one ecological engineer put it "I'm inspired by BAD engineering; we will fix what other engineers screwed up." The acknowledgement that some forms of engineering have been insensitive to larger systemic and ecological concerns is likely one of the reasons that ecological engineering is so starkly dived from the 'traditional engineerings' in the pilesort.

The Boundaries and Overlap with Ecological Design

> I think [ecological design] gives you a lot more flexibility in terms of what I involve myself in, whereas if I'm an engineer, people define engineering pretty narrowly. To saying, "He should be designing stuff, shouldn't he?" Whereas ecological design, it would be like, "Well, what is that?"[230] (from a engineer) (pers. comm.)

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[230] Interestingly, this was spoken by an engineer. Later they also spoke about the negative baggage that the term 'engineer' brings up.

Alongside of the rise in sustainability and appropriate technology, there has also been the development of a set of ideas called 'Ecological Design (McHarg 1971; Orr 2006; Todd and Todd 1994; Van der Ryn and Cowan 1996). This set of ideas and practices sweeps across many fields and scales and is similar to ecological engineering in the conceptualization of a necessary redesign of the human-nature interface inspired by ideas from ecology. In fact, examples of what constitutes 'Ecological Design' include elements that are also incorporated into the Ecological Engineering rubric. For example, one key Ecological Design book references H.T. Odum's work and discusses the concepts of designing ecosystems, and gives the examples of constructed wetlands and living machines for treating wastewater and even mentions the development of the field of ecological engineering (Van der Ryn and Cowan 1996). However, despite overlapping elements, the practice of ecological engineering is not simply synonymous with the concept of 'ecological design.' Ecological design as a concept is problematic as it is conceived of as being both as a realm broader than ecological engineering, and simultaneously, as being what ecological engineers *do*. In the following, the lexical format 'Ecological Design' will be used to denote the idea of a broad field of practice, and the format 'ecological design' will be used to distinguish the more generalized concept of form of design work.

In the first case, 'Ecological Design' is characterized as:

> …basically a way of thinking. So it's not a practice per se. It's a way of thinking. So an ecological designer could look at a building, a farm, a restoration project, an engineering project or a combination of all of these with a set of intellectual tools which are really based on how nature works and in reading the instructions in nature. And there aren't really -- it's not formalized. It's not formally coded. It is a way of thinking which is based on a number of assumptions, not the least that the energy and materials and form are all connected in some way or another. It's the most holistic, I think, of all, and it allows itself to go anywhere, and it can get reflected in many. (pers. comm.)

These framings of 'Ecological Design' depict it as a broader and more encompassing realm of thought then ecological engineering. As stated in the quote above Ecological Design exists more as a realm of conceptual thought, rather than as a set of particular practices.[231] Thus in discussing 'Ecological Design' in interviews, some individuals associated it with the work of landscape architects or green architects, gardening, composting, and alternative housing structures. Some characterized the practices of ecological engineering as being more narrowly focused than, or being "almost a sub-category of," ecological design." Others described the relationship between the two concepts not as being nested sets but as being similar in thought but separated on scale related to the degree of rigor and quantification of the design practice.

> I think ecological design and ecological engineering are very closely related and they are really more or less a continuum. I guess ecological design would be a little bit softer, where maybe the engineering skills required to do the design are not as exacting. So for instance, a good gardener with an intuitive sense of how water moves in the landscape could probably do some really good landscaping design, ecological design. (pers. comm.)

As discussed above, a key component in the definitions of ecological engineering for some is that, as an engineering field, it is a rigorous design practice. It is this rigor and scientific grounding that became a key difference in how the ideas of 'Ecological Design' was distinguished from 'Ecological Engineering.'

> And then of course, there's the difference in quantitative rigor. I think that in ecological design, it can be there, but it doesn't *have* to be there, whereas in engineering it *has* to be there. There's no doubt about it. There isn't anything else other than the quantitative side, so it's much more narrow, much more focused, whereas ecological design overlaps with it, but it covers many other kinds of problems. I think ecological design has been around for a lot longer than ecological engineering, but it's much more amorphous than ecological engineering. There's a lot of people that do that kind of stuff. And they have less unity than I think we do, and we don't have all that much unity. (pers. comm.)

[231] In the few instances where Ecological Design is being formalized through education or certification, it is largely through interdisciplinary programs, and are largely associated with building or landscape architecture programs. A number of certifications are offered not through degree granting universities but through stand alone design institutes. One highly salient Ecological Design masters level certificate is offered at the University of Vermont

The more diffuse and broad range of ‘Ecological Design’ was coupled by some informants to its relationship with the environmental and appropriate technology movements of the 1970s. In particular, the work of John Todd, both his designs and his writings, were cited as examples of this broader and more inclusive idea of ‘Ecological Design’. For some, the lack of quantification in the ‘Ecological Design’ realm was seen as its greatest limitation in comparison to ecological engineering.

> [They are] pretty much the same, but [ecological design] is lacking the rigor of engineering. So it’s more conceptual, less based on numbers. Often not based on the first or second law of thermodynamics, which is kind of a big problem. (pers. comm.)

However, the relationship between ‘Ecological Engineering’ and ‘Ecological Design’ is problematized by complexities created from the term ‘design.’ Some informants linked the phrase ecological design not to a broader realm of thought, but rather saw it as a descriptor of the type of work that ecological engineers *do*. Thus rather than being a term for a wide ranging practice (‘Ecological Design’), this construction of the idea focuses on the importance of *design* as a central element in engineering practice (‘ecological design’).

In studies of knowledge production, science and engineering are construed as having fundamentally different epistemologies and praxis, and often engineering is denigrated as being merely the application of scientific knowledge. However, another school of thought exists. The distinction of engineering is that it is a practice based in design, and that the generative and creative process of *design* makes engineering more than a mere application of science, it is also a creative production, more like an art (Ferguson 1978; Florman 1994). Thus design practice is considered crucial to how engineering is done (Bucciarelli 1994; Vincenti 1990; Vinck 2003), and simultaneously, it is through design and application that engineering becomes a producer of fundamental scientific knowledge, not just an applier of knowledge generated through ‘science’ (Channell 1982; Hannson 2007; Layton 1971; Layton 1974).

Developing a skill set in design was referenced by ecological engineers as a key element in any engineering education, and as such ecological engineering was not seen as really altering the basic premises of being an engineer

> We are calling ourselves ecological engineers, and we aren’t changing the definition of engineering, there is still the focus on making a design and taking it to the client. (pers. comm.)

What is new about ecological engineering is that the *design* basis of the practice is based in ecological systems.

> Design does not have to be technology, you see? Design is the creative process that happens when you try to solve a problem with what you have at hand, the knowledge that you have at hand. And so if the components that you're using to solve it are ecological, then it is, quote, “a soft solution" instead of a hard one. If the components that you use to solve it are all plastic, concrete and heavy metals, then it's going to be high-energy technological solution. (pers. comm.)

Thus, in interviews, when some individuals talked about the activities of ecological engineers, they would equate ecological design with the *doing* of ecological engineering.

> They are very compatible, ecological design is what ecological engineers do. If you are designing an ecosystem for a specific purpose you are using engineering principles to do that-thermodynamics, conservation of mass, conservation of energy, principles, quantification of processes. That is ecological engineering, if they call it ecological design, so be it. (pers. comm.)

In one interview, a student reacted to the term ‘ecological design’ with a description of the design basis of engineering and stated poignantly “To me design is still that shining light in the distance that I hope to arrive at some day.”

The difference between ‘ecological design’ and the various conceptualizations of the scope and rigor of ‘Ecological Design’ are not merely interesting definitional debates. Recognizing that they are a small professional society in relationship to other fields, there is an awareness in the AEES that they need to be strategic in their institutional practices and affiliations. Whole systems thinking, sustainability, green and ‘ecological’ are starting to have a more general cache and the niche carved out by the AEES society is seen as a potentially valuable institutional space.[232] Knowing that formalized and accredited engineering programs are far in the future (or undesirable[233]), other forms of professional establishment are sought. Thus as part of the formalization and professionalization of ecological engineering the AEES has been considering establishing a method of certification for practitioners. One of the major points of discussion was whether the certificate was going to be for 'ecological engineering' or for 'ecological design.' The discussions of the relative merits of establishing a certificate in 'design' rather than 'engineering' range around two axes, one related to the need for inclusiveness and the other to the need for speed. If the certificate was to be 'ecological engineering,' then only engineers would be able to achieve it (see Chapter 6 for discussion of the professional and controlled terminology 'engineer'). Similarly, as engineering is a more institutionally controlled term, making an formalized certification program in ecological engineering would be a more laborious process. The broader frame of 'ecological design' was advocated as being more inclusive, and thus would not alienate some of the existing membership of AEES, and would allow the society to draw in a larger pool of interested parties.

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[232] It is important to note, that it is not mere hubris that was leading the AEES to see their realm of practice as being of interest to other societies. A major component of the AEES business meeting in 2007 was to discuss the wide number of offers of professional affiliation that were being discussed with AEES leaders by other much larger professional societies in agricultural engineering, environmental engineering, landscape architecture and even ecology. Other fields in their strategic restructuring or positionings were seeking to incorporate ecological engineering within their oeuvre

[233] Engineering accreditation is considered undesirable by multiple individuals for substantially different reasons. One group of thought exists that ecological engineering should not be administered, and judged, as an engineering. See Chapter 6 for this debate. The other reason that people see an accredited engineering program as undesirable is that ABET accreditation is done at the undergraduate level, and many involved in AEES feel that ecological engineering is too broad to be achieved through an undergraduate training. As such they feel the society should not be pursuing the establishment of undergraduate programs in ecological engineering.

Having decided to pursue an Ecological Design certification, at the 2007 AEES meeting a panel discussion was held on developing the specific criteria for the certification. The discussion delved very deeply into what is meant by '*design*', and if the design training of people in fields like landscape architecture would fit into the proposed rubric. The key contentions in the conversation, which continued at the 2008 meeting, was how to balance between the need to be open to individuals with non-engineering backgrounds and the desire to include design fundamentals that drew on engineering precepts. A major subtheme in this conversation was the awareness that the idea of 'Ecological Design' may have rising cache, but that the term also comes with the burden of being a little too broad, too nebulous, and in some cases being enacted with too little depth in ecological sciences.

> Will there be a need for a certificate of Ecological Design? As a society we are saying there is. We are going to get in before someone else does. There is a group at [X] from landscape architecture that are taking it up. It burns me, they don't really know what they are doing. I am worried. (pers. comm.)

<u>Ecological Engineering, a Science Movement?</u>

Why Do Ecological Engineering?

> A bright possibility is *ecological engineering*. Adequate knowledge about the natural solar-energy-based system may allow a small concentrated loopback of energy to guide the systems of fields, forests, and seas to stabilize and produce for man. Although there is yet excess energy, it might be better to put crash efforts into ecological engineering rather than into space. A knowledge of natural system control will be of vastly greater survival value to man than a memory of space exploration. (H.T. Odum, *Environment, Power and Society*, 1971 p. 309)

H.T Odum's *Environment, Power and Society* was a very influential ecosystems science text and also an introduction for many to the idea of ecological engineering. It is poignant that his explanation of ecological engineering includes the idea that it is a "bright possibility" in aiding the survival of man. Thus from the earliest constructions of the field it has been tied to ideas of low energy use and sustainability. How these ideas are expressed varies among individuals and has undergone some modification over time, but the theme of sustainability remains strong within the ecological engineering community.

As mentioned above, a commonly cited definition of ecological engineering is "the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both." (Mitsch and Jørgensen 2004). This definition is the outcome of a number of modifications and changes that occurred over the years to the initial definition of the field offered by Mitsch and Jørgensen in the influential *Ecological Engineering: An Introduction to Ecotechnology*. In this they stated:

> Ecological engineering, in contrast [to environmental engineering], is involved in identifying those ecosystems that are most adaptable to human needs and in recognizing the multiple values of these systems. As do other forms of engineering and technology, ecological engineering and ecotechnology use the basic principles of science (in this case it is mainly the multifaceted science of ecology) to design a better living for human society. However, unlike other forms of engineering and technology, ecological engineering has as its *raison d' être* the design of human society with its natural environment, instead of trying to conquer it. And unlike conventional engineering, ecological engineering has in its toolbox all of the ecosystems, communities, organisms, that the world has to offer (Mitsch and Jørgensen 1989).

This earlier framing placed the scope of ecological engineering as encompassing the "design of human society with its natural environment". This bold statement toward changing human society was later reconsidered and retracted.

> We now believe, with hindsight, that "the design of human society" was perhaps too ambitious a goal for a fledgling field and would be much more than engineers and scientists can or should do. In fact, it would be social engineering. But "the design of sustainable ecosystems" is clearly a sustainable goal that can be achieved for individual projects, watersheds, and even landscape scales (Mitsch and Jørgensen 2003).

In this text, the authors are trying to more narrowly delimit the realm of ecological engineering, seeing the design of society as too ambitious. So now the scope of the formal definition covers only "the design of sustainable ecosystems". But individuals still consider the scope of ecological engineering to cover a broader set of sustainability goals, that in fact mirror the earlier call of for the "design of human society"

> I think that in ecological engineering, one of the main focuses should be preparing society or helping society become more sustainable, which means less reliant on non-renewables. Because I think in the next 30, 40, 50 years, there's going to be a major change in society, because of peak oil. We've already passed it, or we're getting ready to, and there's just going to be less and less oil around. There's going to be more of a demand, and our whole world right now is dependent on oil. And something that ecological engineering could do to help the world is design systems that are more sustainable and that would lead us into what Odum called "a prosperous way down", instead of a disastrous fall. It might be too late, but the more we're aware of it and the more we as ecological engineers can help design sustainable systems and design ecosystems that can help society, but also protect the natural environment and protect the clean air and clean water we have, then the easier that slope's going to be to go down. (pers. comm.)

The concept of "sustainability" has a prominent place in how individuals define ecological engineering, and their personal motivations for getting involved in the field. In interviews an identified defining feature of an ecologically engineered system is the low energy inputs that go into making it, or into running it.[234] For example, one informant contrasts the ecological engineering approach to a river restoration with an ecological restoration approach, saying "ecological restoration relies heavily on energy to create and maintain their designs". Similarly at AEES meetings, many discussions of the overall goals of ecological engineering have focused on elements of providing design solutions to current unsustainable practices. These discussions of sustainability are also used to contrast their group to other disciplines. The unsustainability of current systems, largely due to their heavy oil dependence, is a commonly cited concern. Informants speak of "designing for the prosperous way down" or "preparing for the low energy future". But within all of this discussion they make clear they are talking about a sustainability that can be quantified.

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[234] The necessity of ecologically engineered systems to be "passive" in relation to energy inputs (besides sun or wind) is not largely advocated, but the overall energy signature of designs is considered as an important component to consider in how ecological engineering is pursued. Both Kangas (2004 p. 17) and Mitsch (2004 p.41) present graphical representations of the realms of ecological engineering spread across scales that include the relative contributions of human agency and energy vs the inputs of the living systems. It has also been suggested that ecological engineered systems should have at least 50% of the energy from non fossil fuel in

> I think sustainability now has gotten a very analytical approach to it. Engineers are starting to do sustainability…So, I don't think it's far out anymore. I think it's really grounded in basic science, because we're trying to figure out how to be sustainable, not just plant flowers and trees, and that's it. We're really figuring it out, not having just the philosophy. I think maybe the philosophy is important, but if you have the philosophy but you don't have the technical background to apply it, then it's all just fluff. And that's been the problem in the past. It hasn't been quantified. (pers. comm.)

When asked to give a life history of how they ended up involved in their research or practice, many individuals stated a personal desire to "do something". Of course, all of engineering is "solution oriented", but within ecological engineering, this desire is often related to making solutions that are in some ways geared to the natural world. The fact that this field draws individuals motivated by their perception of environmental problems is an acknowledged situation. Speaking to his peers at the AEES meeting, one professor introduced a poster section by pointing out that the society was gifted with a "different group of students". He was comparing the ecological students to the general environmental engineering students at his university. He told the story of asking his classes "Why they got into their field, was it to save the world? All of my environmental students look confused at this question, but all of the eco-eng. students stick their hands in the air". As the professor recounted this tale, the hall filled with knowing laughs and head nods from the other participants.

Faculty report that students are drawn to the ecological programs from a desire to learn about ecosystems, not just the "pipes and pumps and air pollution" they get in environmental engineering programs. Similarly, as put by another professor

> [Students] are attracted to this concept of ecological engineering, they are not attracted to biological engineering. Why? Some opportunism, and excitement about being involved in something new at the ground level. But not just something new, but something new that matters. And it doesn't just matter to me, for optimization of my well being. But something new that will make the world better.[235] (pers. comm.)

[235] Though 'doing something' about sustainability, or human beings' use of natural resources was the most dominant thread in why students got involved in ecological engineering, there are a couple of other

A final component of the goals of ecological engineering is that though individuals might make a point of stressing that ecological engineering is for the "benefit of both", individuals usually have one of the two as a primary reason they got involved. For some, it is aspects of human health and social justice that were main drivers for becoming involved. More than one student was inspired to pursue research in constructed wetlands for wastewater treatment after experiencing poor sanitary conditions in the developing world. For others, it was their own experiences with land development near their childhood home that inspired them to get involved with a design field where they "could help do development right." In the life histories the interviewed ecological engineers spoke of critical experiences or teachers that set them on a course toward pursuing ecological engineering. Important in this, is that many of these narratives contain elements that could be from how 'environmentalists' would speak about how they became engaged. For example, when asked "What is the story that brought you to this kind of work?" one senior figure in the field unequivocally stated

> The environment part was because it was the first Earth Day. That was clear-cut in my career. I had already got my bachelors' degree [in engineering] and I was working for one of the largest polluters in Chicago, and I started seeing these things about the environment and stuff, and I said, "That's pretty cool." And I went to the first Earth Day, a big celebration in downtown Chicago, and from then on I was hooked. First of all, I wanted to solve the problem within the company. (pers. comm.)

This senior ecological engineer is very open about the significance of Earth Day on his career trajectory. He is unabashed in admitting that he was influenced by the 'environmental movement' However, don't make the mistake of calling this scientist an environmentalist.

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differing rationales. For a couple of students, the initial drive to getting involved with studying and designing ecosystem was from an interest in space exploration. For a manned mission to Mars, or in a colonization attempt of the moon, the ability to create healthy ecosystems that will provide waste recycling services and food will be critical. Another student reported that she got involved in her masters research project simply because that was where there was a funding line.

Are Ecological Engineers Environmentalists?

I dredge forth another chunk of decaying tuber from the large tub of cold water in front of me and drop it into the bucket at my feet with a stinky, squelchy splat. It is spring, but it doesn't feel like it inside the small, green, half-dome house. A distinct chill is still in the air, and the bioreactors from which April and I are dredging last year's plant growth testify to the freezing winter weather that had frozen these tubs and plants. The hunks of elephant ear tuber are fetid, and April and I hurriedly clean through each of the tanks. We are prepping this ecological treatment system (ETS) for a new round of experiments that April will be running through the coming year. Once we have removed the remains of last year's growth, we will be able to place out in the racks the very small and delicate looking starter plants now waiting in their boxes. These plants are dwarfed by the mechanical surroundings. Designed as an experimental set up, the system has a redundancy of tubs and pipes which are actually multiple systems that can be configured in several different ways. This is better for experimentation, but gives the small greenhouse the overall impression of being filled with PVC spaghetti. I am told that when the system is growing, the impression is quite different, but for now the ecological features of this system are not so visually apparent. As we place out the baby plants, April explains some of the various experiments she will be running throughout the summer as part of her PhD project in Environmental Sciences.

As I talked with April, she stressed the need for the research she was doing. Her interest was two-fold. First, she wanted to do good science to contribute to the growing knowledge set about how designed ecosystems function, but she was also motivated by her interest in solving environmental problems. Speaking of her first exposure to the ETS system, she said

> I just thought it was great, really interesting, a great application of how you can actually go out and solve some of the environmental problems that we're studying. And that was what I was wanting to get into, the actual application of the tools to solve the problem. (pers. comm.)

April went on to explain that she had started as an environmental scientist as an undergrad after having witnessed the development of the land around her parents' Oregon home. In conversing she referred to herself as a tree hugger. When asked if she felt constrained about calling herself an environmentalist, she replied

> For myself, I consider myself a real scientist, but I have no problem with being called an environmentalist. So for me, I don't know why people wouldn't want that. But I can see in other people that, yeah, they don't want to be labeled a tree hugger. (pers. comm.)

Many ecological engineers acknowledge that they attract individuals who want to "save the planet". There is a tendency, however, to qualify this statement with some reference to a pragmatic, hard-science, non-advocacy approach that they as scientists and engineers take. One of the past presidents of the AEES will say "We're using wetlands to save the world, but we need to have our coefficients right."[236] The need to do, and be seen to be doing, good engineering is strongly felt. For example, a couple of American ecological engineers stated that they were leery of being to closely institutionally linked with the International Ecological Engineering Society (IEES). The expressed concern had to do with the different constructions of the boundaries of the field as pursued by the two societies. A few AEES members stated that they feel that IEES has a more relaxed framing of the field and does not draw the disciplinary boundaries of what constitutes ecological engineering practice as tightly as they would like to draw the boundary. As one individual explained it, the frame of ecological engineering that the IEES uses is

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[236] Referring to the mathematical basis upon which the wetlands are designed and the need for more systematic development and testing of wetland design.

more similar to the idea of 'Ecological Design.' This individual pointed out that a number of years ago (2003) a conference was held in the US entitled *Ecological Engineering for Integrated Water Management: Designing Urban and Industrial Watersheds*. This conference was jointly sponsored by the IEES and the Harvard University Graduate School of Design. The range of presenters included a number of key "Ecological Design" leaders, including representatives of Living Machines, and the keynote speaker was Michael Braungart of Cradle-to-Cradle design. The AEES was not officially involved in this conference. At the core of the issue is image and reputation. In the interviews with the American ecological engineers who were hesitant about institutional linkages between AEES and IEES, these individuals did not denigrate the work of IEES, seeing in the broader 'Ecological Design' perspectives important and useful ecological strategies. However, what was expressed as a concern was the way in which *other* U.S. engineering societies would perceive the work and scope of the IEES. These individuals were concerned about the way in which other engineering societies view the engineering rigor of ecological engineering. Thus they see the need to more narrowly define the boundaries of the ecological engineering field away from the more inclusive frame of Ecological Design and to be careful about the methods by which "saving the planet" will occur.

As discussed above, within the American Ecological Engineering Society, there is fairly strong agreement that the practice of ecological engineering is to be strongly grounded in an ecosystem science that is free of value judgments. Throughout the literature, and at meetings, an overall pragmatic approach is evident within the ecological engineering community. This is not a group that reifies pristine nature.

> The big difference is the perspective that ecological engineers have that there is no such thing as pristine, there is no such thing as natural. It just doesn't exist. This notion of natural, of pristine, is

> a Victorian Christian ethic. It is a garden of Eden ethic that is completely contrary to the state of ecosystems, and to ecosystem science. (pers. comm.)

At the same time, many in the community of ecological engineers acknowledge that 'saving the world' is a convenient shorthand to discuss motivation for why many of them got involved in their technical and scientific practices. Such notions of 'saving' are not only couched in terms of environmental health, or ecological functioning, but these ideological reasons for participating also include concerns for social and economic justice. As one ecological engineer put it "recall that the definition of the field stresses 'for the benefit of both' not 'for the environment.' At times at AEES meetings a tension would arise between individuals who stress more the environmental health and nature restoration component over human health and welfare.

That individuals have value-based rationalities in joining the field is often playfully and jokingly acknowledged. For example, there is also a lot of play with the idea of 'the hippy'. They know that other engineers think "Oh, he's the hippie engineer." Some embrace this term, and don't contest it. Others use it themselves in an illustratory way– "I'm not a hippie, but I do ecological engineering". At one meeting, they had fun with their identity and embraced the idea of saving the planet and their image as hippies and produced a conference t-shirt that was tie-died with the phrase "Saving the World is Groovy."

But for all of this light-hearted exchange, some serious concern about identity and positionality exists.

> We're not a granola munching bunch of hippies. These are engineers, they have their own – they want – we all are going to make money. We attract people who are civic minded. I differentiate because there is a certain altruism that lacks discipline. I've experienced that in the church, I experience that in my social work, with the world hunger organization -A sort of undisciplined altruism for altruism sake. These are not the folks who stick it out. I would put most environmentalists in this package. They want to save the forest but they don't want to learn forestry. They want to save the rivers but they don't want to learn limnology or stream ecology.

> They want to save the planet but they don't want to understand the processes they are trying to save. That is the sort of emotionally motivated process that I don't trust at all. And I eschew that in ecological engineering practice. (pers. comm.)

In interviews I asked directly about what being an environmentalist means and if there is a linkage between being an environmentalist and being in ecological engineering. For some, identification as an environmentalist was core to their self-identity and construction of their life goals, and subsequent pursuit of ecological engineering. In some interviews, the idea that ecological engineering could be linked with environmental issues was non problematic.

> Yeah, because I would consider myself an environmentalist because I want to protect the environment and respect the environment and recognize that we need the environment to survive. Just -- it's kind of like a practice, I guess, is what I would say where you try to be sustainable and you are aware that you impact the environment around you whether or not you choose to conserve or waste or whatever. (pers. comm.)

For some students, identification as an environmentalist did not carry any dangerous or negative connotation to their status as scientists or engineers. For these researchers, environmentalism was a relatively non-problematic category, and simply meant concern over environmental problems.

> Environmentalism or environmentalist, I see a person or persons as somebody that is concerned about the environment and the issues, global warming, pollution, recycling, yada, yada, yada. (pers. comm.)

However, for some of the older ecological engineers there was a stronger concern over being seen as associated with 'environmentalism.'

> Unfortunately, environmentalism has gotten a bad name, because it's usually not quantitative and there's some very flaky ideas floating around a lot of times. Nobody wants to be associated with that. (pers. comm.)

And environmentalism was seen as problematic not merely because it was 'unquantified' but because of a concern about the slippery slope of engaging in environmental advocacy.

> Environmentalism, unfortunately, that's taken on sort of a – I won't say negative, - but there are strong advocates for the environment to be sure; it's taken on sort of an us-versus-them kind of concept. I don't mind the people, but it just tends to be confrontational sometimes. I would call it a political term… people who are trying to influence our environmental policy politically. As

> opposed to what we try to do, which is we want to influence it, but we want to have good science telling us what's right and wrong. (pers. comm.)

Another set of interviewees addressed the question of what constitutes an environmentalist as a two part issue. They say that their own definition is simply concern for environmental issues, and defined as such, they do see this as linked to ecological engineering. But then they would explain that for them, being an environmentalist is about more radical action or advocacy and under that definition, "Then no, ecological engineers wouldn't be environmentalists".

What is striking in these different formulations, is that while being an environmentalist is not problematic, it is being *labeled* an environmentalist that is dangerous because the label is seen as having a negative connotation of advocacy, confrontation and non-objectivity.

> It's really hard – in the minds of the public, it's very difficult for them to separate environmentalists – in fact, I've been introduced any number of times as an environmentalist – and I usually, the first thing I do is to correct the person that has introduced me to say an environmentalist to me is an advocate. It's someone who practices advocacy, and it's not science. You could be an environmental scientist, and I see a very big difference between an environmental scientist or ecological engineer and someone who practices advocacy or someone who is an environmentalist. (pers. comm.)

Despite these objections, this same individual has no problem with the practice of ecological engineering being linked with concepts and technologies that have their roots and their *raison d' être* in the environmental social movement of the 70's.

> I think that it is appropriate to be linked with the concept of appropriate technology and "Small is Beautiful". There is something I talk about a lot with students in the course on ecological engineering and theoretical, conceptual interface. It's what I call time, energy and space trade-off, and it's very simple. If you try to do something in a smaller space, it takes more energy. If you try to do it in a shorter period of time, it takes more energy. So appropriate technology is going the other way from that. It's trying to minimize the amount of energy coming from non-renewable sources, and that means larger areas usually and longer periods of time. And so I don't have any problem with that.. (pers. comm.)

An interesting problematic thus exists in the ecological engineering community. The personal motivations and life pathways that have brought some to the field and practice have ties to value systems and judgments that are related to ideas that some would label under the rubric 'environmentalism.' Moreover, sustainability is a cornerstone precept of the field. Similarly, overlap in practice and technologies exists between ecological engineering and what has been called 'appropriate technology.' This overlap especially exists through aspects of constructed wetland work and through the aforementioned living machine family of technologies. Though the ecological engineering field has significantly broadened its scope of practice beyond its initial work in wetlands, this wetlands work (and the subsequent tie to water and wastewater treatment) remains a strong identifier of the field.[237] And similarly, the designed ecosystem technologies like living machines are utilized as teaching examples for ecological engineering instruction and their iconic status and presence in the popular media has lead individuals to the field of ecological engineering.

Conclusion

Overall, the development of an ecological engineering discipline has been undergoing many of the normal activities identified as disciplinary forming boundary work. Such boundary work is manifest in the attempts to define the field of practice and delimit those actions which make the field unique, the desire to designate certification criteria, and the concerns over policing the boundary between sound practice versus activism. For disciplines, though boundary work is always an ongoing project (especially

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[237] The persistence of this perceptual linkage is cited by the editor-in-chief of the Ecological Engineering journal. The dominance of wetlands and wastewater work in the early years of the journal, has lead the journal to actively attempt to break that association through the combination of special issues focused on other forms of ecological engineering application and a strategic semantic shift. Relabeling the subtitle of the journal from *The journal of ecotechnology* to *The journal of ecosystem restoration* was explicitly a strategic move to highlight the appropriateness of the journal as a publication venue for a wider range of applied ecology and restoration work. Perhaps it is also important to note that the journal is an independent journal and is not a publication *of* the AEES or the IEES, though, through partnership agreements, membership in either organization includes a subscription to the journal

in relation to edges and overlaps with other fields) internal cohesion of a shared identity is usually strengthened through these very boundary struggles. However, in the case of interdisciplinary fields boundary work does not work in the same way (Frickel 2004) and the inability to generate internal cohesion on a shared disciplinary perspectives requires a more constant and active reflection on what are the shared practices and goals of the interdiscipline (MacMynowski 2007). The continued debate over the role and prioritization of engineering training within the ecological engineering community is an expected outcome of the current interdisciplinary nature of the field. What is interesting in this is the tension within the community between those who envision the further development of the field as an engineering practice versus those who would have the field remain as an interdiscipline not explicitly tied to engineering. Between these two frames different enactments of boundary work occur. Those envisioning a formalized and recognized engineering discipline are more concerned with the boundaries of the field from non rigorous, non-quantitative practices. Others who envision ecological engineering as an interdisciplinary field that melds multiple expertise, from engineering science, to landscape architecture design sensibilities, to ecological knowledges, do not advocate for the same boundary development on the issues of engineering science.

Though lacking an internal coherent disciplinary identity on the basis of technical practice or educational status, the developing field of ecological engineering has as high degree of cohesion on the idea that there is *need* for ecological engineering principles and ecologically engineered systems in the world. The shared sense that current techno-industrial practices have a negative impact on people and the environment is evidenced through the core ecological engineering goal of generating positive change for both humans and the environment through designed ecosystems. The fact that ecological engineering is geared to fixing or ameliorating these impacts makes the labeling of it as a science movement a non-problematic categorization (at least for the external social scientist). Internally, the acknowledged closeness of the field to other forms of practice that are deemed as popular environmentalist “hand waving” or “fancy gardening” has added to the perceived need to develop a strong and narrower boundary around the ecological engineering field. Those within the field would likely not characterize it as a science movement, but rather would likely characterize it as the logical and necessary advancement of science and technology in the face of rising ecological needs, or in other words a necessary incorporation of “environmental consideration from the design stage onward” (Mol 2009) to generate more sustainable technologies for the benefit of both humans and nature.

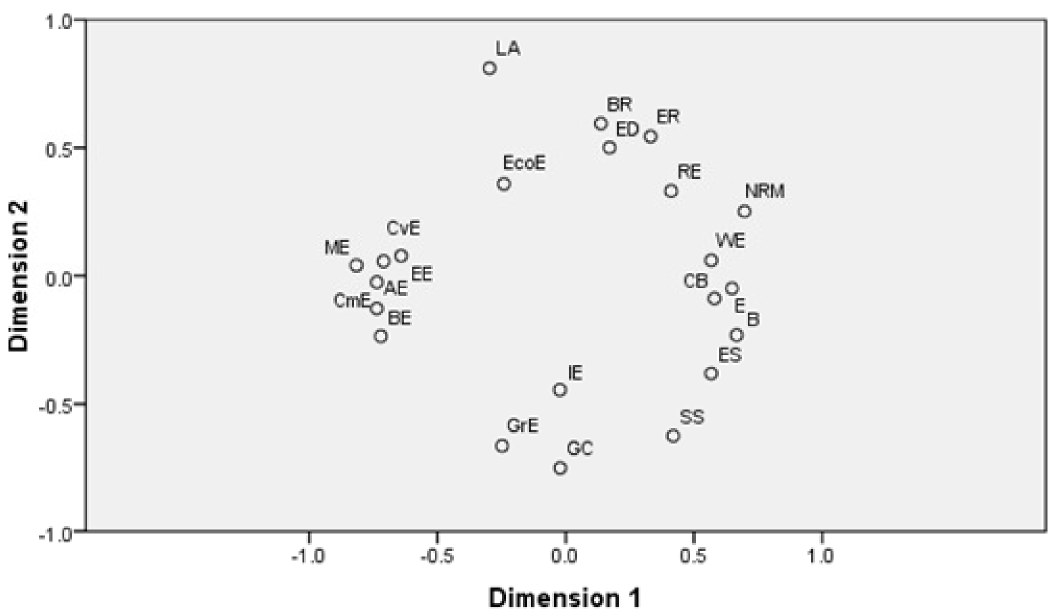

Figure 1. Multidimensional scaling from pilesort data.

N=40. PROXSCAL random start in SPSS 16. MDS in 2 dimensions, minimized normalized raw stress 0.0493 after 60 iterations.

Level	Landscape Architecture		Industrial Ecology		Green Chemistry		Green Engineering		Ecological Engineering		Bioremediation		Ecological Design		Ecological Restoration		Restoration Ecology		Natural Resource Mangagment		Sustainability Science		Environmental Science		Conservation Biology		Biology		Ecology		Wetlands Ecology		Agricultural Engineering		Biological Engineering		Civil Engineering		Environmental Engineering		Chemical Engineering		Mechanical Engineering
0.8250																																	x	x	x								
0.8000																																	x	x	x		x	x	x		x	x	x
0.7750																													x	x	x		x	x	x		x	x	x		x	x	x
0.7250															x	x	x												x	x	x		x	x	x		x	x	x		x	x	x
0.6611															x	x	x												x	x	x		x	x	x		x	x	x	x	x	x	x
0.6500															x	x	x										x	x	x	x	x		x	x	x		x	x	x	x	x	x	x
0.6500											x	x	x		x	x	x										x	x	x	x	x		x	x	x		x	x	x	x	x	x	x
0.6000											x	x	x		x	x	x								x	x	x	x	x	x	x		x	x	x		x	x	x	x	x	x	x
0.5759											x	x	x		x	x	x								x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
0.5694											x	x	x	x	x	x	x								x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
0.5250					x	x	x				x	x	x	x	x	x	x								x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
0.4700					x	x	x				x	x	x	x	x	x	x						x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
0.4583			x	x	x	x	x				x	x	x	x	x	x	x						x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
0.4500			x	x	x	x	x				x	x	x	x	x	x	x		x	x	x		x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
0.4000			x	x	x	x	x		x	x	x	x	x	x	x	x	x		x	x	x		x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
0.3319			x	x	x	x	x		x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
0.3111			x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
0.1977			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
0.1618	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
0.1063	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Figure 2. **Hierarchical clustering of pilesort data**

N=40 Average-linkage protocol in AnthroPac 4.0, 1996. (Anthropac output converted to Excel table)

SECTION 2

THE CONSTRAINTS TO DESIGNING WITH ECOSYSTEMS - INSTITUTIONS, REGULATIONS, CAPITAL, MATERIALITY

The next 4 chapters discuss the institutional, regulatory, capital and material constraints in the development and adoption of the field of ecological engineering and ecotechnologies based on ecosystem design. It is important to note that though these four things are divided into discrete chapters, this is an outcome of striving for narrative clarity, rather than a function of these structures being truly distinct. For example, to discuss regulations as a constraint is not merely a discussion of the role of laws and standards upon actions, but also encompasses issues of institutions – as laws themselves are outcomes of institutional actors, and also subsequently generate institutions of enforcement. Simultaneously, regulations as a constraint are not discrete from capital, as economic concerns and rationalities can affect the very generation of regulations; and the development of regulations sets the realm in which capital decisions operate. Nor are the constraints of regulations fully separated from a realm of materiality. The production of regulatory standards is very explicitly about the control of material practices. For example, regulatory standards premised on 'best practices' inherently rely upon material realms for their instantiation. Similarly, regulations are enacted by regulators who themselves represent forms of embodied knowledges and codified norms that impact how they interpret and enforce regulations. Thus, discussions of the role of regulations in innovation and adoption of ecologically based technologies can be as much about the social institutions of law as about the very material reality of a particular regulator.

Chapter 6 focuses on the development of ecological engineering as an academic and professional practice, and as such, focuses on the institutional constraints brought to bear by the structures of universities and professional societies. Chapter 7 focuses on the role of regulation in framing opportunities and constraints to deployment of new technologies and ecosystem based designs. Chapter 8 highlights the way in which limitations of funding impede both the social movement development of alternative technologies as well as the academic development of ecological engineering. It goes on to discuss the role of capital investment in both driving innovation and potentially influencing distribution of those innovations. Chapter 9 introduces the idea of materiality as a cross-cutting constraint. After first exploring the ways in which I, as a researcher, initially ignored the salience of materiality as a driver in the formation and deployment of ecotechnologies and ecological engineering, the chapter continues with discussions of the three material realms of places, bodies and things.

CHAPTER 6

INSTITUTIONS

> There is a "catch 22" that sometimes causes the engineering profession to follow rather than lead. "If something is not yet accredited, then it is not recognized engineering. If it is not recognized engineering then it may not be taught, researched or supported by engineers." (Odum 1994, p.116)

Introduction

The conference room at the Olentangy River Wetland Heffner building was as full of bodies as it could be. All of the chairs around the large rectangular conference table were full and a second row of chairs had been crammed around the outside of the table. Chairs had been wedged into all available floor space and still graduate students were draped across the cabinetry and utility sink on the side of the room. For all of this crowding, the room still had a spacious feeling due to the visual expansiveness provided by the two glass walls. Though the blinds were partially down to limit the glare of the bright morning, the sweep of the ORW grounds out to the wetlands was clearly visible. This backdrop of the world famous ecologically engineered wetland system was a fitting frame to the lively and serious discussion of ecological engineering that was taking place inside the room.

Officially, the 5th annual meeting of the American Ecological Engineering Society (AEES) had finished the day before, but still there were 40 individuals present for that long, early morning workshop titled "Advancing the Field of Ecological Engineering and Education." Individuals from various schools and programs, as well as practitioners from companies, were presenting overviews of their implementation of ecological engineering and laying out their perspectives on the core elements, principles and practices that need to underlay the practice and education of ecological engineering.

As densely packed as we were, the atmosphere in the room was light and ebullient. As one of the presenters flashed his first slide on the screen, every part of it covered with a model and bullet points, a good natured ribbing came from the crowd "could you have packed more on there?" "Hey, we were limited to four slides and you know I have a lot to cover" came the reply. The camaraderie of many in the room was obvious and set the tone of the meeting as a convivial community forum. This was a crowd of individuals who knew each other and the respect and friendship with each other came through in forms of attentive interest and light banter. But all of the good-hearted jocularity did not detract from the seriousness with which the group approached the questions that were guiding the workshop. Each presenter talked about what types of course work, research or applications their group had been pursuing in establishing ecological engineering. Out of each presentation wide ranging discussions followed that often reflected less the specific content of the presentation, than a forum for reflecting on the larger epistemological problems facing the development of ecological engineering.

Discussion ranged over the estrangement of practicing ecological engineers from the academic milieu, the role of regulation in driving or stymieing innovation, and role that institutional support – through regulation or funding lines – could play in stimulating the development of ecological engineering. The overall tone of these discussions was of a group of people who recognized the various barriers to what they were attempting and who were highly reflexive on the process in which they were involved. In fact a major theme of the discussion was the fundamental struggle of conjoining ecological thinking, based in systems thought, holism, and open systems with the practice of engineering, with its constraining institutional structures, inherent conservatism, and the dominant unit processes and linear problem solving approaches. At times the conversation felt like it could have been taking place at a philosophy conference, not an engineering one. However, even with all the awareness of the barriers working against the development of a new field of engineering, the ‘can-do’ attitude of the engineers also was evident. After a discussion on the difficulty of linking ecological engineering practice with research projects in academia, and a lament over the slowness of the development of the formalized field of ecological engineering, one individual stated “Are we being too hard on ourselves? Did mechanical and electrical engineering have these discussions, or did they just evolve over time?”, and then later another engineer stated “This work just has to be done”.

The drive to do the work of ecological engineering, to dig deeply into ecological sciences and apply that knowledge to the production of technologies or landscapes, and to produce knowledge and systems that have positive outcomes on human and environmental systems is certainly strong for many of the individuals who have been slogging through the process of developing the formal institutions of ecological engineering. To be sure, many people are ‘just doing it’. There are spaces and realms wherein people are working in institutions and projects applying the ideas and concepts of ecological engineering without overtly working to distinguish these technologies as practices of ecological engineering. The ‘doing it’ is in the application of the ideas, not in the deployment of labels. However, in regards to the development of educational programs that aid in the guidance of individuals into skill sets for being able to do ecological engineering, therein ‘just doing it’ is less easy. The ‘doing’ of ecological engineering education comes up against many institutional barriers.

Having looked at of the definitions and ideological boundary work being done by ecological engineers (Chapter 5), it is necessary to also look at how the idea of ecological engineering is actually being able to manifest inside of academia. Individual academic institutions are interesting examples of local phenomena enmeshed in a network of national and international communities with reputations, standards of practice and professional accreditation oversight that impinge upon educational agendas. Along with these inter-institutional relations, a particular school will have its own personnel and staff, from the individual department to the university administrative level each with their own goals, quirks and prejudices which can bear upon attempts to introduce new concepts, new courses and new programmatic elements. The existence of such disciplining institutional structures and gatekeeper personnel are likely universal constraints for academic institutional change. However the endeavor to generate new forms of engineering practice will experience added constraints that arise out of the nature of engineering as a professional practice. The disciplining that accompanies education in a ‘professional’ practice adds both structural and ideological barriers to the development of ecological engineering; and the perceived identity and reputation of engineering addsABE yet other constraints. In the following sections, I will first show how engineering as a profession and the subsequent concerns of accreditation have an impact on ecological engineering education. I will discuss how engineering is not just a practice but an *identity,* which has subsequent impacts on the development of ecological engineering. These professional practices themselves are under influences from larger socio-political conditions, and shifting national market and regulatory trends can influence university funding and departmental developments. In the second section I will show how such processes have had both a *general* role in formulating the disciplinary homes of Ecological Engineering initiatives, as well as having had very specific impact on some ecological engineering programs. In the final section, the institutional constraints discussed is less specifically tied to the institution of engineering, but rather arises out of the institutions of academia itself wherein institutional funding and evaluative procedures and institutional gatekeepers can stymie new and innovative programs and how such have affected the development of ecological engineering as an academic discipline.

Engineering: A Profession and an Identity

As discussed in Chapter 5, the concept of ecological engineering incorporates both a range of applications and a number of goals that have overlaps with practices that have been designated by other names or are the provenance of other fields. On one hand, these overlaps are not problematic when considered from the ultimate goal of improving both human and environmental conditions through practices of ecosystems management, manipulation or design. However, in achieving the goals of 'doing' these applications, it is necessary that these practices be known as available possibilities. Individuals, business and government agencies need to know that the practices of 'designing ecosystems' exist. Hence, there is a necessity for systems of promotion of the ideas and production of individuals able to do the practices. In a sense, these practices need to be branded and advertised. As discussed in Chapter 5, one possible 'branding' is 'ecological design', the other 'ecological engineering'. Though an individual could construct the exact same technology or interact with the *material* realm in the same way under either name, the use of the brand ‘engineering’ brings with it very different *social* interactions, and brings to bear very different social institutions on the development of the field of practice. Engineering may be about the manipulation of the physical realm, but it is also a legally constructed realm of action and a socially constructed identity (Downey and Lucena 1997, 2004; Tonso 2006). As discussed below, the development of the practice or field of ‘ecological engineering’ is both invigorated and constrained by these social institutions of engineering.

The profession of Engineering and the Engineering Curriculum

> You can’t call yourself an ecological engineer if you’re not an engineer. In fact I can’t call myself an ecological engineer even though I am a certified ecologist and a licensed engineer, because there is no professional certification. I am a hydrologic engineer. I am an engineer and ecologist. I am associate professor in ecological engineering; I am not an ecological engineer, because there is no such thing. For just anyone to call themselves anything engineer would be a violation of most states’ laws. Because they protect the profession of engineering, because of the credibility and licensure process. (pers comm.)

In the United States, engineering is a legally recognized profession, and as such the use of the term “engineering”, the production of engineered structures, and the production of engineers through the educational system are controlled through laws and institutional organizations (Reynolds 1991). These formalized structures have had substantial impact on the nascent ecological engineering practice, especially in regards to generating educational opportunities .

When asked in interviews about constraints to the development of ecological engineering practices, university faculty frequently discussed the difficulties arising out of the professional nature of the engineering degree and the subsequent institutional oversight of curriculum. Many had had, or were in the processes of having, their attempts to promote ecological engineering courses or programs blocked or thwarted by the confluence of the professional nature of the engineering degree and the subsequent attitude of their colleagues to curricular change and student enrollment.

In brief, engineering is a professional degree like medicine or law, but it varies in the significant fact that the first level of professional certification comes with the attainment of the undergraduate degree. Whereas future doctors or lawyers study pre-med or pre-law at the bachelor's level, engineers study *engineering,* thus attaining with their bachelor's degree a professional level degree and can legally practice as engineers after passing the Fundamentals of Engineering Exam (F.E.).[238] Since professional licensure is achieved with this undergraduate degree,[239] engineering curricula are both tightly packed with courses and are overseen by regulating institutions. The primary institution that accredits U.S. engineering programs is ABET, Inc. This not-for profit federation of professional societies was formally the Engineers Council for Professional Development which was established in the 30's. In 1980 it became the Accreditation Board for Engineering and Technology and subsequently it was simply referred to by its acronym ABET(Henry et al 2000).[240] ABET is an oversight board that is supported by the

[238] As one student said "It's like the lawyers' BAR exam, just less well known".

[239] There are also subsequent levels of licensure– after a number years of practice and continued education, an individual with an F.E can apply, and test, to become a Professional Engineer, or PE. The PE (Principles and Practice in Engineering) is the final professional exam that engineers must take if they are to become licensed Professional Engineers. All designs that are to be constructed have to be signed by a P.E. who is thus certifying the design and as the signatory can be held liable for failures in the engineered systems. P.E exams are developed and administered by the engineering professional societies, and are largely specific not only to each engineering field, but also vary state to state. The process of creating a P.E. for a particular branch of engineering is a long process and itself is controlled and contested. For example, the development of the field of Environmental Engineering inside of the older Civil Engineering departments, has meant that the P.E. certification for a environmental engineer initially was through the Civil Engineering P.E. Overtime, some states have developed stand alone P.E.s in Environmental Engineering, but others have not and thus an individual after years of environmental engineering work can find themselves having to restudy such things as road building and bridges for the more inclusive Civil Engineering P.E. exam. from state to state.

[240] It was so universally know as ABET that, in 2005 the organization officially became ABET, Inc.

professional societies of various engineering and technical fields. The board certifies individual *undergraduate* programs of training every six years.

The fact that the undergraduate degree is a professional degree both tightly constrains curriculum change and often causes undergraduate programs in engineering to have more requirements then any other major. These curricula are mainly based in mathematics and sciences, and have left little room for any humanities or social science course work. These technocentric curricula came under heavy scrutiny in the 60's with the rising social critiques of technology and modernity. A major call for reformulation of engineering education was developed in the 1968 report from the American Society for Engineering Education entitled "Liberal Learning for the Engineer" which "shared with many other statements of its time a concern for helping engineers take a broader view of the special responsibility for results of the professional skills and roles in society" (ASEE 1975 p. 305). The long term outcomes of these critiques can be seen in the overhaul of the ABET system in 2000. Acknowledging that the old criteria for necessary skills and courses were "inflexible" and "stifled" innovation, the new criteria (now referred to as EC2000) changed the accreditation process from a focus on programmatic elements and curriculum oversight, to a set of standards aimed at judging learning outcomes of the programs (Besterfield-Sacre, et al. 2000).[241] With the designation of 11 student learning outcomes stipulated, engineering programs now have more freedom in structuring their curriculum.

[241] The ABET website itself acknowledges this new freedom "Lacking the inflexibility of earlier accreditation criteria, EC2000 meant that ABET could enable program innovation rather than stifling it, as well as encourage new assessment processes and subsequent program improvement." http://www.abet.org/history.shtml

Altogether these elements – undergraduate professional degree, accreditation oversight, and the new EC2000 standards – have had impacts on the ways and means of developing ecological engineering inside of academia. In particular, the undergraduate professional degree of engineering is a major element in conversations on how to achieve ecological engineering education. At one level, this is an ongoing academic discussion at AEES meetings with the question of whether a long term goal of the AEES should be the establishment of master's level programs. The arguments around this issue have to do with the breadth of knowledge needed in ecological engineering practice and whether it would ever be feasible in an undergraduate program to cover the necessary topics adequately. Some think it is a goal that can be worked toward, where as others feel it would be too focused, too early. "I have been adamantly opposed to bachelors degrees in ecological engineering. I don't think it is wise. Masters degree, yes. Bachelors no."

One element that enters the discussion of generating an undergraduate program is the constraint brought to bear by the need to attain "professional level skills" by the end of the four year degree. As such, some in the ecological engineering community have discussed the possibility of a five year undergraduate degree. It must be noted that this five year plan is not a discussion that is limited to ecological engineering. Other practices, like Civil Engineering, have proposed a move toward a five year degree. Another conversation in engineering community is the wholesale move to a general pre-engineering degree at the undergraduate level, with the first professional degree becoming the masters.[242]

Barring such sweeping changes to the entire undergraduate engineering education milieu, ecological engineers point to the difficulties of modifying undergraduate

[242] See Edward Wenk,1988.

education as a reason to avoid even trying to make undergraduate programs. Currently, barring an interdisciplinary attempt at OSU, instantiation of ecological engineering as programmatic foci in universities has either been through environmental engineering departments or agricultural engineering departments. As such, the set curriculums of those departments have major constraining impacts on adding courses to generating trainings in ecological engineering. In speaking of why he would not even try to make any *undergraduate* course in systems ecology, one engineer stated

> You have to come back to the ABET, the Accreditation Board for Engineering and Technology. The way that's set up is that there are societies associated with each discipline. So chemical engineering has the American Chemical Engineering Society or whatever it's called, and same with electrical engineering. It's usually one or two societies associated with each degree. Then you get to environmental engineering, and it's like this laundry list of societies associated with it. It has like ten, and now it's chemical engineering, electrical engineering, mechanical, and the civil engineering, obviously. So they all get in there, and they all -- I think when they do the degree, they're like, "Well, you need to have this. You need to have this." [mimes throwing things into a pile]. And of course, with everybody's coming at it, and saying "you need, you need," before you know it, it's this huge, gargantuan degree. (pers comm.)

And as another put it:

> I think that there are progressive environmental engineers that are doing a lot of stuff that we would think of as ecological engineering, but as far as academics go, they don't have the room to squeeze in more -- they can't take ecology. They can't -- they got so many requirements, there's no way. (pers comm.)

With an already packed set of requirements, the inclusion of new courses is difficult to achieve. The addition of new subjects for engineering undergraduate students often raises the need (or perceived need) to remove other elements of study. However, which courses to remove from the curricula are never easy to agree upon. Some faculty perceive such requirements as two years of calculus as unnecessary rote work, while others perceive it as a necessary hallmark of a strong engineering education, as well a point of passage for the retention of the students who truly "have what it takes to be engineers." Thus changes in curricula can entail not just switching one course content for another, but can represent larger changes in department perspectives and ideologies about education. One faculty member who had been working on establishing integrative systems courses for sophomores in their environmental engineering program remarked on the resistance to the programmatic change from colleagues. Rather than seeing value in courses that catch and retain students through hands-on, integrative classes,

> I was presented with the rhetoric of 'weeding out' students that 'can't hack it in engineering.' They didn't seem to appreciate that we were losing enrollment to the lab sciences where junior students actually get to 'do something.' (pers comm.)

Even when attempting to establish master's program, where there is a bit more flexibility in the curriculum, faculty interested in ecological engineering are affected by colleagues' perceptions of science students and fears about ABET. At one university, a faculty member told of his difficulty in getting his department to accept an ecology trained student into the environmental engineering master's program. Though the student was amenable to taking a number of undergraduate engineering courses to get an equivalency,[243] key faculty resisted the admission of the student citing concerns based on reputation and ABET accreditation. Though ABET *does not* accredit graduate programs, the argument was made that by allowing students who themselves have not gone through an ABET accredited engineering program into their master's program, the department was basically giving those students "an end run around the accreditation process." Those students gain the value of attending (for their masters) a department with accreditation without themselves having gone through an accredited curriculum themselves (for their undergraduate).

> My department's been fairly supportive in terms of the curriculum [for a master's track], but they've been less supportive in terms of the kinds of students. They only want me to teach engineering students,…and really, that's only certain people, but they're the most powerful

[243] This type of accommodation was cited at other engineering departments – accept a person with a science degree, but have them take a year, or two years worth of undergraduate engineering courses prior to getting their master's from that engineering school.

> people. They're the ones who are in charge of these committees, and they're the ones that admit students to the program. That's been a big frustration. (pers comm.)

Profession and Identity

The professional nature of engineering does come with the perks of status and higher earning potential. The value added of a being a recognized formalized engineering practice has been shown to have had an impact on the formation of engineering professions in the past (for example the development of Chemical Engineering, see Reynolds 1986). In regards to the development of ecological engineering, an individual trained as an ecologist, and then doing restoration work will have a different marketability and pay rate, than an individual trained in an engineering field doing the exact same restoration work. The recognition of this differential influenced a number of young ecological engineering enthusiasts. One young individual described his switch from a wildlife biology program to ecological engineering as an outcome of the realization of the limitation of local jobs in his home state for biologists. In looking for another field, one in which he could still work outdoors, and "do stuff" he was directed to talk to the dean of the Biological Engineering program that was starting a new foci in ecological engineering.

> It sounded exactly like what I was looking for. It was still working with the environment, it was still working with things that I had a passion for, but instead of waiting for the end of my career to be making a potential $60,000 a year that was the beginning of my career possibly making that, and to be able to work in a job where I felt I was making a difference, but also one where I felt I was not feeling like I was suffering for choosing that option. (pers comm.)

Similarly, another engineering student discussed their reasons for pursuing a PhD with an ecological engineering foci. Having done a master's in bioremediation, they thought they didn't want to stay in environmental engineering and bioremediation

> If I'd stuck with bioremediation, I would have started looking at one bacteria and its ability to degrade one chemical. I wanted to do something on the bigger scale and more with natural systems, and I didn't want to do the lab stuff anymore. And so I was like, 'Well, I can either take a

> step down and just do a normal science degree,' -- I don't want to say a step down, but obviously engineering, it comes with some clout. It's kind of bad to go and do all this work for a couple engineering degrees and then go do a PhD in marine science, for instance. You know what I mean? You're taking a pay cut eventually, I guess. So, I didn't want to lose the engineering side of things. So then I stumbled on ecological engineering on the internet, and here I am. (pers comm.)

That engineers can garner high salaries is an outcome of their professionalized practice, but the idea that it is 'a step down' to move from engineering PhD to a science PhD is an outcome of engineering identity construction. Engineers are *engineers* not just because of the practices they undertake, but because of an inculcated identity that is developed. The distinctiveness of engineering from science and the idea that there is a recognizable engineering identity are benchmark ideas for engineers. That engineering education creates 'engineers' perhaps seems a tautology, but it is a widely held idea amongst engineers that there is a distinct form and outcome of engineering education. Coupled to teaching 'design' as a crucial identity marker in engineering, are other less specific sets of ideas, values and forms of cultural praxis. The ways in which engineering education formulates engineers through both formal educational structures and through the inculcation of cultural norms, behaviors and ideas has been a rising area of science and technology studies. Scholars in engineering studies have looked at the ways in which the environment of classrooms, construction of gateway classes, styles of homework and projects, hierarchical structures, and gendered power structures all create engineering identities, and limit engineering enrollment. But it is not just science studies scholars who say that there is an engineering identity. Engineers say this about themselves quite volubly.

Not only does engineering education and culture generate a certain sense of identity among engineers, there has also been a subsequent generation of ideas about engineers by people in other professions. And engineers are very aware of this.

> It's unfortunate, but it's true. I think that word "engineer" garners a lot of disrespect, suspicion and everything else as being the problem instead of the solution (pers comm.)

This negative view of engineering has a serious implication for developing the field of ecological engineering. The very identity as an 'engineering' can impair enrollment in programs. As one student succinctly put it when talking about choosing a major for their undergraduate degree, when asked if they considered any engineering programs the response was strong

> Not at all! Never-ever thought about it, because I never equated helping the environment with engineering[244]

The engineering identity thus becomes a barrier to the enrollment of individuals who actually are interested in solutions-oriented eco-technology development. They want to do something; they just do not see engineering as the pathway to this goal. In this case, the nomenclature 'ecological design' has an advantage over 'ecological engineering'

> I feel like there are lots of people interested in renewable energy, and interested in constructed wetlands, and interested in green design, and saving the world with a design paradigm. Those people aren't intellectually depraved but for some reason they don't really see engineering as a pathway for using those technologies that they seem to like; and like to talk about, and go to lectures on and invite speakers to talk about. I don't know why there is a disconnect. But it does seem like there are an awful lot of people at this university that love those ideas, and want to be an ecological designer. They say that: "I Want to Be an Ecological Designer", and then yet don't really see engineering as a way of doing that. (pers comm.)

The engineering identity and ecology

The question that arises at the AEES meetings frequently is: How do you make an ecological engineer? Is the goal to have a new engineering discipline? Or to give ecology training at the masters level to engineers, or to give engineering training at the masters level to ecology students? At the society level, there is no consensus on this question, and thus in the universities, faculty interested in ecological engineering are forging ways ahead individually and in piecemeal fashion. As such, attempts to

[244] In their second year, this student transferred into a civil and environmental engineering department out of an environmental science program.

weld together forms of training that encompasses both ecological systems and engineering design come up against myriad constraints. The issue of engineering being a professional degree has affected the development of ecological engineering in academia not only through is limitation of curricular change inside of engineering departments, but also erects barriers to interdepartmental, or intercollegiate collaboration.[245] Establishing trainings that cross from engineering into the sciences creates problems of accountancy and control. One engineering faculty was describing the difficulty of getting their students exposed to ecological sciences, explaining that it was a two pronged problem. On the one hand, if the students could use their few electives to take an ecology course, finding ones that provided the right combination of depth and application was not possible: “The courses our students need don’t exist out there [in the biology or other science departments].” But the second prong of the problem was that even if great courses existed pressure existed to develop the courses in house: “My colleagues want our students in our seats”.

The institutional barriers to inter-collegiate collaboration would have impact on the development of any new discipline that explicitly attempted to work across disparate science and engineering colleges. But because the science is ecology, even more problems develop. On the one hand, the conceptualization of engineering, or ‘technology,’ as the source of environmental woes is not uncommon. Engineers acknowledge that they have “a bad reputation” among some people in general. But this bad reputation is believed to be significantly prevalent among biologists and ecologists and other environmentally based scientists. At one AEES meeting, this idea of having

[245] Though inter-college collaborations are in and of themselves difficult, crossing the engineering / science divide is argued to be an even harder position – both from institutional barriers as well as from ideological ones.

scared off all the ecologists from the organization was being discussed, and one biologist who was there piped up with "I'm not scared, but I have colleagues who are." In talking with this individual, they explained how at the environmental consulting firm where they worked there were colleagues who were very dismissive of the idea of going to an engineering conference. The attitude expressed was they would "sooner sleep with the devil."

Calls to develop ecological engineering explicitly state that "Ecologists and engineers need to work together and understand each others' language" (Mitsch 1998). The drive to join the practices of science and engineering is based on the different strengths of the fields, but there is difficulty in balancing between them:

> That's the problem with this field. You bring in people who are scientists and they're out there doing their statistics and their T tests and their XYZ tests and all the statistics, finding more, more, more. And it's like, they can't back off and fricking solve the Gulf of Mexico hypoxia. They can't do it. They're always going to find another way nitrogen is doing this or that. That's just the way science is. It's always probing for more and more. You don't know enough to solve a problem; we've got to have a $6 million grant before we can answer that question. That's the direction science goes, and that's okay.… Engineers on the other hand, are just the opposite. They'll solve a problem before the problem even exists. They will make a problem, and then solve it before there is a problem. So that's their problem. We've got little bit of a yin and yang here. We need the middle ground; maybe that's what we're trying to do. (pers comm.)

Incubating Ecological Engineering – Finding Departmental Homes

The following section details the history of development of a number of ecological engineering programs to demonstrate the ways in which these academic institutional structures, accreditation issues and the professional identity of engineering have influenced the form and formalization of ecological engineering programs. The three subsections look at constraints associated with 1) attempts to develop an interdisciplinary ecological engineering program; 2) the development of ecological engineering in engineering departments 3) the perceptions and power of colleges to affect the development of programs.

Interdisciplinary homes

All of the above issues – professional gate-keeping in engineering, interdepartmental accountancy, and identity conflicts – can be seen in the attempt at OSU to develop an interdisciplinary ecological engineering program. The Ohio State University is highly salient in the ecological engineering milieu (not to mention wetlands ecology). This is an outcome of the presence of Dr. William Mitsch, another of H.T. Odum's PhD students. Though H.T Odum is the father of ecological engineering, having coined the term and outlined some of its precepts, Dr. Mitsch is credited with vitalizing the formalization of ecological engineering as a field and having stimulated the academic growth of the discipline. The 1989 publication of *Ecological Engineering: An Introduction to Ecotechnology*, was just the first step in a series that aided in developing the field of ecological engineering in the US (See Chapter 5). Having already developed the world renowned Olentangy River Wetland Research Park, in the late 90's Dr. Mitsch garnered the support of the OSU dean for the development of an interdisciplinary initiative in ecological engineering. The goals of this initiative were stated thus:

> The Ohio State University is embarking on an ambitious plan to develop a comprehensive academic program in the new field of ecological engineering. This new discipline concerns itself with design, restoration and/or construction of self-regulating and self-sustaining terrestrial and aquatic ecosystems. While initially focusing on graduate and post-graduate education, the long term goal of the program is to develop a new undergraduate ecological engineering curriculum that can achieve ABET accreditation.[246]

In 1998, three new faculty lines were created, in three different departments. The job call for these positions were for an Ecological and Bioresource Engineer, to be housed in the Department of Food, Agricultural and Biological Engineering; an Aquatic Ecologist/ Ecotechnologist, to be housed in the School of Natural Resources; and an Aquatic Systems Restoration Engineer to be housed in Department of Civil and Environmental

[246] http://ces.iisc.ernet.in/hpg/envis/doc98html/jbfac99115.html

Engineering and Geodetic Science. Students in these three departments, as well as those participating in the interdisciplinary Environmental Sciences Graduate Program administered by the Graduate School, were all to be able to focus on Ecological Engineering. Though the initial job call stated "successful candidates are expected to collaborate with each other, current OSU faculty in ecological engineering, and colleagues in their primary appointment department," by the year 2005, institutional barriers to collaboration, coupled with science vs. engineering conflicts had all but estranged the Natural Resources faculty member from the Engineering faculty.

In attempting to develop this interdisciplinary program, a number of institutional barriers existed, one of which was the general 'accountancy' trend in universities. Interdisciplinary work, whether in course teaching, or advising, or shared program development, is not favorable to departmental budgets. Pressure was brought to bear on faculty to work inside of their own colleges and departments. More particularly, in attempting to design a standard ecological engineering program, the professional nature of engineering impeded programmatic design.

> The education system doesn't accommodate this very well at all. We're trying to have an ecological engineering program here. But every time I would say, "Let's put in an environmental science major because that bridges engineers and scientists," they say, "No, no, no, Bill, we can't do that. We have to put it in the engineering department. It's called engineering." We get that kind of stuff. So it's not been an easy to thing to put in a program at Ohio State University, or any university. Engineering is taken. (pers comm.)

Because of the inability to formulate a program that spans disciplines due to resistance on the part of the engineering departments, one solution that is being sought is to have a generalized specialization that is overseen by the Graduate School.

> It really isn't a program, because a program is within each department. We're trying to get this formalized over the university level, so it doesn't matter if you're in this department or if you're in X's department or if you're in environmental science graduate program. As long as you do the specialization and take the courses, then it will show up on your transcript as ecological

engineering. And that's something that the department can't regulate. It's done at the university level, and that's why we want to do it. (pers comm.)

Engineering Department Homes

Larger trends in engineering also have a background impact on the development of Ecological Engineering. Some see ecological engineering as being an offshoot of environmental engineering, but as discussed above, curriculum constraints in that field have had an impact on the ability to effectively develop ecological engineering inside of those departments. Another major institutional womb for ecological engineering programs has been in agricultural engineering programs. The relative success of these programs is an outcome of larger social institutional changes.

Trends in Agricultural Engineering

Agricultural engineering developed as a professional practice early in the 20th century. The American Society of Agricultural Engineers (ASAE) was formed in 1907. Initially focused on agricultural mechanization (Isaacs 2003), the field has been critiqued as having been slow to expand its range of application. With overall declines in agriculture as an occupation for US citizens the relevance and popularity of agricultural engineering was waning in the later half of the twentieth century (Loewer 2003), thus agricultural engineering programs suffered declining enrollments, with critically low enrollments being reached in the late 80's.[247] Agricultural engineering's heavy emphasis on mechanical processes had been contested early in its history. Even at the inception of the society in 1907, some advocated that programs should include a focus on biology (Verma 2003). Under the changing times of the mid-century, some departments began to attempt to reframe themselves by emphasizing biological sciences. Departments began

[247] All engineering programs were suffering declines through the 1990s (Davis and Gibbin, 2002 p.55).

implementing name changes, adopting the word "biological" into the program titles as early as 1965 (Verma 2003). Though a number of such expansions occurred, these programmatic name changes were not always accompanied by substantial curricular change. However, the drastically low enrollments in agricultural engineering programs in the 80's became the impetus to augment this trend towards the incorporation of term "biological" despite the reluctance of some faculty and the dragging heels of the ASAE.. A 1990 meeting of agricultural engineering department heads found that many departments were implementing biological sciences as a core component of the their programs. This change was found to be well supported "especially among the midsized to smaller departments, where survival supplanted tradition as the order of the day" (Loewer 2003). One outcome of this 1990 meeting was a report which recommended "that undergraduate programs in Biological Engineering (BiolE) should be offered and that a core curriculum be developed" (Loewer 2003).[248]

In the 1990's, the ASAE made the first step of officially acknowledging the broadening scope of the practice of members of the society by making it the formal policy to refer to the society as The Society for Engineering in Agricultural, Food and Biological Systems. This nomenclatural manoeuver was completed in 2005 when ASAE officially became ASABE (The American Society of Agricultural and Biological Engineers). An overview history article published by the society stated "Of all the changes in the Society's history, none was debated as long or had a more profound impact than changing the name of the Society" (Howard 2007).

[248] Areas of emphasis of these biological programs "were identified as Biotechnology Engineering (Biosystems Engineering), Bioenvironmental Controls, Machine Systems Engineering, Bioprocess Systems Engineering, Natural Resources Engineering and Food Engineering. BME [Biomedical Engineering] as an emphasis was not included." (Johnson 2005). BME already existed as distinct programs that had developed out of mechanical and electrical engineering.

These manoeuvres represent attempts to establish ASABE's authority and control in the realm of biological engineering which was seen as a subject area of growing importance. As stated in one opinion paper "If ASAE does not step up and demonstrate leadership, another organization will shortly assume leadership of biological science-based engineering, and eventually, responsibility for accreditation of biological engineering educational programs" (Dooley 2002).[249] This concern seems to have been shared throughout the ASAE, for in 2003 the society issued a formal position paper claiming its authority and priority in accrediting biological engineering programs (ASAE 2003). The claim made in this paper is that ASAE has already been accrediting biological programs for many years, thus their society has precedence in the field over newer biomedical societies. The ASAE had become part the ABET system in 1966, and subsequently had been the main society for the accreditation of "agricultural and similarly named engineering programs." The incorporation of biological engineering inside of agricultural engineering meant that by the time of this 2003 announcement, of forty-eight programs accredited by ASAE, 36 contained the phrase 'bio'(ASAE 2003). Of concern for the society was that forms of biological engineering programs were developing out of expansions of biomedical engineering (itself offshoots of mechanical and electrical engineering), as well as out of Chemical Engineering.[250] The further professionalization of biological engineering through the establishment of a PE exam is currently being pursued by the ASABE (Sukup and Moore 2007). But this too is under "delicate discussions" between ASABE, the American Institute of Chemical Engineers (AIChE), and Biomedical Engineering Society (BMES) (Johnson 2009).

[249] Currently (2009) the president of ASABE
[250] Currently the Biomedical Engineering Society (BMES) is the lead accreditor of Bioengineering programs.

That these negotiations would be called 'delicate' speaks to both current professionalization and boundary work being done around the developing field of biological engineering as well as hints at some larger issues that impact on Agricultural Engineering's historic relationships to other engineering disciplines. Agricultural engineering has been separated from the other engineerings, not just by subject matter, but also in more institutionalized manners in many universities. Individual universities have varied and often complex reasons for the structure and distributions of departments and programs. However, agricultural engineering departments were largely located at state land-grant universities. For some agricultural engineering programs, this meant that they developed in a separate university from the other state engineering programs.[251] In other cases, even if a university housed an Engineering Department, agricultural engineering programs often were housed in Agricultural colleges rather than in the College of Engineering. These institutional divisions have salience in the development of new forms of engineering, both biological engineering and subsequent developments of Ecological Engineering, as struggles over enrollments, funding and curriculum play out not just as departmental activities but as intra-collegial struggles over resources.

These general trends in agricultural engineering have salience to the development of Ecological Engineering through interplays of interests and power. With the general trend toward inclusion of 'biological' as a component of agricultural engineering to expand the scope of the field and thus to shore up enrollments and strengthen departments, academics with interest in developing ecological engineering often found agricultural engineering programs to be receptive and accommodating. The general

[251] As for example the existence of Agricultural Engineering at the University of Georgia even though Georgia Tech was the state 'Engineering' school.

receptiveness of agricultural engineering to the endogenous growth of ecological programs was frequently commented on in interviews. But the growth of ecological engineering within these departments has been occurring alongside the development of biological engineering, sometimes non-problematically, and other times with real effects on the ability to develop an ecological engineering

The Maryland Case

In listings of key or foundational schools for the study of ecological engineering, University of Maryland is always included. It is striking then that officially, ecological engineering is not currently offered as a program of study. What is offered is Ecological Technology Design. The history of the development of ecological engineering and its current manifestation as Technology Design highlights the ways in which larger institutional dynamics and funding can impact the development of a new field of practice, as well as demonstrating the salience and power of the term 'engineering'

Initial development of ecological engineering as a focus at Maryland is credited to Dr. Pat Kangas. Dr. Kangas is an ecologist coming out of a biology background, who did his PhD work with H.T. Odum in Florida. Kangas was initially hired into the Maryland system to coordinate the undergraduate program in Natural Resources Management, which was in the Department of Agricultural Extension Education.[252] In the 90's, due to general financial concerns at the university, Kangas's department was closed down by the university and he was asked where he would like to move the NRM program. At that point, he was the only full time faculty for the NRM program and he stated a preference for the Agricultural Engineering Department

[252] NRM was initially in this department "for some really weird historical reasons." (pers comm.)

> So the Dean asked me, and I said I wanted to come to the Ag Engineering Department and I did that because I wanted to really get something going with Ecological Engineering. So that's my story for how this all came about. That may be an illusion. It may be that the dean was going to put us over here no matter what, because at that time, we had a lot of undergraduate students in the Natural Resource Management Program, but the Ag Engineering Department had practically no undergraduates. So it was a good political move to sort of shore up that department, while at the same time, I had to go somewhere with this program. So it may be that the dean would have done that anyway, but that's what I requested and that's the way it worked out.

Thus, though Kangas had interest in the placement of the NRM program in the agricultural engineering department with the view toward developing ecological engineering, the placement could have also been an outcome of the general trends occurring to Agricultural Engineering departments.

Once housed in the Agricultural Engineering Department, Dr. Kangas found a receptive environment for the undergraduate NRM program and his goals for graduate work in ecological engineering. The supportive environment of the Maryland Agricultural Engineering Department meant that Kangas was able to enact his goal of getting a "a critical mass of three people who would work at this undergraduate program in Natural Resource Management, but at the graduate level be thinking and working and developing the ideas of ecological engineering."

At the same time as NRM was being moved into the Agricultural Engineering Department, the department itself was undergoing reformulation. The undergraduate Agricultural Engineering curriculum was reformatted into a Biological Resources Engineering curriculum in 1992. And following in the trends of Agricultural Engineering programs nation wide, the overall department changed its name and became the Department of Biological Resources Engineering (BRE). As one person put it, "This Maryland program, was pretty flexible because they got rid of the Ag. There's no Ag engineering at all here anymore. It's all biological, and they really were progressive in trying to change the curriculum." The programmatic elements of the BRE were broad, including biomedical engineering, bioengineering and bioenvironmental and ecosystem engineering. Agricultural engineering had ceased to exist, but there was still a remnant of faculty involved in agricultural extension.

Just as the Agricultural Engineering Department had been housed in the College of Agriculture and Natural Resources, so too was the reformulated Department of Biological Resources Engineering. At this time, all of the other engineering departments at the University of Maryland were housed in the A. James Clark School of Engineering. Over the 90's, the BioE program at Maryland grew, following the national trends. At some point in the early 2000's, a biomedical inventor approached the University with the offer of a $30 million endowment for a bioengineering department. With the money to develop a bioengineering department, pressure was brought to move the Biological Resources Engineering Department into the A. James Clark School of Engineering. The position was staked that "all engineering should be housed in the College of Engineering." The inner workings and timelines of the large monetary gift and the Provost's desire for all engineering to be housed in the Engineering College are not clear, but one former graduate student did express the sentiment that "We were never missed until this gift came along." Though some BRE faculty were amenable to moving colleges, a complete move of the BRE was not possible, as some of the BRE faculty lines were extension positions and "that federal Ag. extension money has to stay in the College of Agriculture."

The outcome of these inter-college negotiations was that 4 of the BRE faculty who were more involved in biomedical or bioengineering research moved to the new Fischell Department of Bioengineering housed in the A. James Clark School of

Engineering. The faculty who had been more involved with the undergraduate NRM program and graduate program in ecological engineering did not make the move as the new department was much more bio-medical. As one informant put it “I didn’t see myself fitting in with that.” The faculty that remained behind were to formulate a new department. One of the possible options they considered was doing something with the ecological engineering idea.

> We were pushing ecological engineering. We said, "Look, we’re one of the top ecological engineering programs around. Sure, maybe there are only five of them, but we’re one of the top five. We’re well-known. People know us. But basically, [the provost’s] words were, "That’s a non-starter…He was not necessarily against it, per se. But he was against having it outside the College of Engineering. He doesn’t want any engineering outside of the College of Engineering.

In the end the Department of Environmental Science and Technology was developed out of the dissolved Biological Resources Engineering Department to remain in the College of Agriculture and Natural Resources. Because of the new caveat on not having ‘engineering’ programs outside of the College of Engineering, the new department is now focused on using the terminology ‘ecological design’ rather than ecological engineering. The department offers a bachelors of science wherein the students can focus in the four different tracks of Ecological Technology Design, Environmental Health, Soil and Watershed Science, and Natural Resources Management. At the graduate level the specializations are Ecological Technology Design, Soil and Watershed Sciences, and Wetland Science.

The Maryland case brings to the fore the difference between calling the practice ecological design or ecological engineering. As discussed both above and in Chapter 5, the term engineering is seen to bring with it prestige and earning potential by some. However, in the academic realm it also can bring with it both disciplinary constraints, and negative baggage. So though having to give up the term ecological engineering, not all involved see this as a bad outcome. As one faculty noted, as a non-engineering program, there is more flexibility in the curriculum, and it is possible to make an integrated technology and ecology program for the undergraduates. As the programmatic overview on their webpage states

> The ENST concentration in Ecological Technology Design prepares students for integrating natural systems with the built environment to solve environmental problems while achieving economic, ecological and social sustainability. The science and applications of using natural systems, processes and organisms to address environmental issues has evolved during the last few decades to a mature level whereby there are strong employment opportunities for graduates that are cross-educated in ecology and technology.[253]

Though having lost the ability to have an 'ecological engineering' program in outcome of larger institutional trends and developments, the fundamental concepts and goals of integrating ecological processes and technological practices continues at Maryland uninterrupted. The main outcome is that though a number of the faculty are engineers the students who pursue to Ecological Technology Design program are not receiving engineering degrees. But this is not seen as a shortcoming to all involved in the program, as they feel that lacking the constraint of the "rigidness of engineering education" actually aids in the pursuit of the practice, and ideas of ecological engineering. In fact, in his text book *Ecological Engineering: Principles and Practice*, Dr. Kangas purposes that ecological engineering development could be aided by a similar attitude and creativity to that which underpinned the computer revolution and states that "providing an educational environment that facilitates this kind of spirited learning will accelerate the development of the discipline." In line with this, he purposes an "Ecological Engineering Ethic" inspired by the Hacker Code of Ethics, in which one element states "Ecological engineers should be judged by their ability to create ecosystems, not bogus criteria such as a degree

[253] http://www.enst.umd.edu/Undergraduate%20Program/ETD-BS/index.cfm

in engineering, passing the P.E. exam, or ABET certification" (Kangas 2004, p.338-339).

Home Denied – Gatekeepers and Recalcitrant Colleagues

Developing new practices in academia takes committed and driven individuals. However, no matter what the personal drive and interest on the part of a faculty member, some degree of openness or institutional space must exist to allow the development of new programmatic elements and actions. Coupled to the general curricular barriers discussed above can be added very direct and poignant obstruction by key personnel in a program or a department. Faculty in discussing their various attempts to establish ecological engineering programs often mention the necessity of 'support', whether in the form of funding lines (like the OSU case), or simply in collegiality

> The dean, and the department chair were real supportive of ecological engineering. And there was a lot of autonomy there, and they really let me try to build that up.

A case in point is the experiences of one faculty member who has tried in two different universities to establish ecological engineering foci; once it failed, and once it was successful. In both cases, he was hired into a department that was already planning a reformulation from an older Agricultural Engineering mode to some new formulation that would bring in forms of bioresource or biological engineering. In the first case, after working there for five years, it took that long to just get the general switch to Biological Engineering in place even though that had been previously agreed upon by the department. As the faculty member worked to generate the institutional space for an ecological engineering component within this newly emerging Biological Engineering "my department head said 'over my dead body'." At that point this faculty member left that position and entered another newly converted agricultural engineering program, but in this case the dean of the program was himself interested in ecological engineering, and thus developing the ecological engineering focus there was possible.[254]

Gate keeping by senior staff is not a new phenomenon. Even in the earliest iteration of ecological engineering under H.T. Odum, personality and the power of the engineering identity came in to play. In 1970, Odum was brought in as a systems ecologist into the Environmental Engineering Sciences Department. This department was the outcome of institutional interplay between the older Civil Engineering faculty and department and the then emerging 'environmental' field. One of the original five graduate programs in Sanitary Engineering in the United States developed in the Civil Department at University of Florida. With the increasing success of this program, there was the desire on the part of faculty to hire faculty trained in chemistry and biology to widen the breadth of the field. "Other Civil Engineering faculty resisted. They felt that all of the faculty should have terminal degrees in Civil Engineering" (Heaney 2007). The outcome of these different perspectives was that a separate Department of Bioenvironmental Engineering Science was created in 1966. This Department later changed its name to Environmental Engineering Sciences. Rapid growth of the department was fueled by student demand and federal funding. The hiring of science based faculty was an accepted part of the early ideology of this engineering – science department. As such, H.T. Odum was brought in to further the water resources and ecology sciences component. From his hire in 1970, Odum quickly establish a strong program with the creation of the Center for Wetlands in 1973.

The influential and leading nature of Odum's work and thought is currently a well recognized truth, with his work having influenced developments in ecological

[254] But still fraught with difficulties, but at least the department was supportive.

engineering, ecological economics, ecological modeling and emergy analysis. However, at the time of Odum's hire, tensions and animosity amongst the older Civil department and the new department still existed. This is where individual interests and action has an impact. In the 1960's the chairman of the department, who was very supportive of the integrative approach, was instrumental in getting Odum hired as well as other scientists. However, subsequent chairmen have been less supportive of the integrated science – engineering approach,

> That chairman was a real innovative thinker. But when he was replaced he was replaced by the idea that this is engineering, this is part of the College of Engineering, the Dean of Engineering wants it to be engineering, engineering, engineering, and the chairs followed that. (pers comm.)

Speaking of one of these new Chairman who was not supportive of the integrated approach, an Environmental Engineering Sciences faculty member recalled this incident

> The chairman who came in afterwards told me, his first day he came and said 'I want you to understand that I consider H.T. Odum peripheral to this department'; if I expect to survive here I had better change my field. That was the first thing he said to me. That was this department, I was not tenured. It really worried me at the time

Thus with the change in Chairman for department, support for integrated engineering-sciences approach of the department was lessened.

Relevance, Rank and Rewards

Perceptions of relevance, or perceived status of particular tracts of thought, have influences in subtle ways in the ability to develop new practices. Just as Odum's work was labeled 'irrelevant' in the 70's by one person in a position of power, perceptions of status have affected the growth of ecological engineering in some departments. At one environmental engineering program, the inability to strengthen the nascent ecological tract was indicated to be a subtle outcome of perceived rank in the engineering academic hierarchy.

> So, and then… I don't know how to talk about this with out it coming across in your dissertation that X is arrogant, but… um…there is definitely a concern here, about the… how do I say this…I mean there aren't any other highly ranked…there aren't any ecological engineering programs that are out there that are within a highly ranked environmental engineering or ecology program. I may be wrong on ecology, I can definitely say that within environmental engineering. So…there is a tension here between saying, we need to play a role in evolution of this field because we need leadership from a highly ranked school. And that is kind of important just for bringing the attention that is needed to evolve a new discipline. And also the challenge of feeling like…sort of how the field is defined so far isn't up to X's standards.

The concern over reputation and rank of various programs draws upon a deeper stereotype in engineering. As discussed above, Agricultural Engineering has had a different historical development than other engineering fields which has lead to both the institutional structural separations discussed above, as well as to a more ideological or cognitive separation. In short, Agricultural Engineering is overall perceived as different from, and to some degree lesser than, other engineerings.[255] This stereotype, while not generally overtly written about, can be seen through flashes in writing and conversations.

> Agricultural engineering continues to fight the stereotypes associated with it while biological engineering strives to communicate its true identity to the public and employers. Agricultural engineers make their presence known one by one as they enter the real world and prove they have the knowledge and background to be great and competent engineers who can compete with the best (Persyn 1997).

In this, agricultural engineers have to 'prove' that they can 'compete with the best.' Similarly, another author notes "Throughout ASABE's history, we have striven for full respect of our profession and struggled with our core identity" (Sukup and Moore 2007) That an engineering profession has to struggle for respect, is indicative of the fairly deep stereotyping that exists about what, and who constitutes agricultural engineers. As such, one young engineer stated

> I don't generally say agricultural [engineer] because people either don't know what this is, or they think it means farmer, and that often translates into hick for them. This is one of the things that really bugs me, because this is done by supposedly educated people, other engineers. They hear agricultural and they think hick. (pers comm.)

[255] This is the engineering equivalent of the general science to humanities hierarchy that 'jokingly' exists in academia. With the purest of science physics at the top of the pile, trailing down to ecology (a messy science), to the social sciences (are they really science?) and then to the humanities (what are these good for again?).

This subtle demeaning of the agricultural engineering in general played into the claim that no ‘high-ranking programs’ are currently involved in ecological engineering. Thus the ability of interested individuals to develop ecological engineering inside their home institutions can be effected by nothing more than hubris and fears of losing status in the perceived eyes of others.

Other elements of rank and recognition add to the structural impediments to the development of ecological engineering. As a new field, and as an interdisciplinary science-engineering field, issues of publication and subsequent rated relevance of that work affects the perceived value of faculty and their work, and thus subsequent institutional support for further development. As academic performance is evaluated on publications, and as where one publishes is perceived as a measure of the value or worth of ones work, the relevant rank of journals becomes a consideration to publication strategy

> I don’t know how exactly to quantify it…but it’s probably a challenge any new discipline faces. But you know you can look at like publications in peer reviewed journals and the quality of those journals. And like the Journal of Ecological Engineering is not viewed as a high rate journal, a top rate journal. So if I publish in that journal, I won’t get as much credit for it as if I publish in another.

But this is very similar to the Catch 22 that Odum spoke of in the quote which heads this section. A new field, and especially a new interdisciplinary practice will have difficulty publishing in the “high rank” journals as the work is deemed ‘outside’ or ‘not relevant’ by gatekeeper individuals. But, failure to be published in those “high rank” journals allows others to then be dismissive and say, ‘see, it’s not really well recognized.’

Along with this cycle, comes the added inner-institutional structures that not only stymie inter-college collaboration but also stymie creativity inside of individual departments. Initiatives to develop new whole new programs or to advance curricular change take large investment of time and energy on the part of faculty. In discussing the time and energy it took to develop a new sophomore design course for their departments Biological Engineering program,[256] a faculty was discussing the labor intensive nature of both developing the course and then administering the course. The faculty contact hours were significantly higher with the new courses, both in terms of face time and evaluative procedures. When asked about how the university administration perceived the reformulated courses, the faculty admitted the university had been pleased with the grant money that had enabled the new courses to be developed but in terms of how the professors were judged it was;

> So scholarship in the classroom, while there may be lots and lots of lip service to it at higher administration there is zero value to it, zero value, and I mean that at the highest sense. There is zero credit given to that academic service, that form of scholarship, in the tenure and promotion review process.

Because only certain types of work add well to a tenure review package, at the AEES business meetings senior faculty were fervent in stating that their junior colleague should avoid investing too much time in Society business or even in their own departments trying to develop programs. While deeply committed to developing the practice of ecological engineering, many of these senior individuals would warn about the dangers of investing time in such a young field for the junior, untenured faculty. Such time investments in trying to develop new programs can directly bear upon individual's tenure applications.

Conclusion

In the end, the development of ecological engineering in academia can be seen as an emergent event from the intersection of individuals with interest in the field and

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[256] Which was made possible because of the massive NSF funding push in the 90's of STEP, aimed at improving engineering education and subsequent engineering enrollments.

institutional structures. Institutional structures themselves are not always the constraint, but rather it can also be the action of key personal within those institutions that can impede or promote those who wish to develop ecological engineering initiatives. Overall the dynamics between local institutional structures, national professional organization and personal politics can all play either to the benefit or detriment of the new field. As one faculty member stated "It's all really serendipity, what you get interested in, how that happens, and then what you're actually able to do with that interest." The role of serendipity, of having individuals with interests end up in institutional spaces that allows that interest to be manifested is important. Part of what makes those 'institutional spaces' available is governmental policy initiatives and subsequent funding lines. Though direct support of ecological engineering has yet to occur, faculty interested in ecological engineering have been aided by funding initiatives aimed at increasing systems thinking such as the complex-systems IGERT funds, as well as the earlier STEP grants program for innovation in engineering education. Acknowledging this lack of support from national level funding institutions, one faculty stated

> Until NSF actually says ecological engineering is a big thing like nano, we are never going to have the momentum we need to really move forward. Even though there is enough grass roots momentum, enough students interested, and enough faculty, it is popping up everywhere. Even, in spite of the lack of institutional support from NSF at the highest level, it is emerging. That tells you how strong of a need there is, it is need driven, it is grass roots driven. As opposed to policy driven like nano technology.

The grassroots level emergence of ecological engineering despite the lack of major institutional support pays testament to the role of individual commitment. When blocked at one location, individuals move. When blocked by institutional structures, new structures are created. When blocked by gatekeepers, individuals work around them. In the end, it is the actions of individuals and their drive and commitment that moves the concept of designing with ecosystems from Odum's proposed process to practical applications and extant programs of study. After speaking of all of the institutional barriers they had experienced, and were experiencing, one ecological engineering faculty person banged his hand on the table and exclaimed.

> As you see there are people like X and myself and others, who do it be damned, administration be damned. That's what we got into this for, and were going to do it.

But he also pointed out, "I've already received tenure".

CHAPTER 7

REGULATIONS AND STANDARDS

Introduction

It had been a standard Monday morning at the engineering firm, the morning staff meeting had been followed by the engineering Work Load meetings, and now we were all gathered together over lunch to discuss the dreaded "Template." As the template discussion flowed, I madly scribbled into my official 'Field notes' book. As I scratched away, in the back of my mind, I mocked the naiveté I had had just that morning. As I contemplated the vast number of pages of my frantic chicken scratch handwriting that would need to be transcribed, I wondered how I could have been concerned that participating at an engineering firm would not be a good venue for field anthropology.

Like all Mondays, it had started with the 8:30 am meeting of all who were in town, sitting down together to schedule the week. I was in the conference room early, and got the chance to chat with Lily, the office manager. She acknowledged that they could do the scheduling tasks by Outlook, but stated that the face to face time was valuable for quickly dealing with a plethora of little office details as well as generally aiding in conviviality. Once we were all in the room, and the president and owner (and engineer) of the firm had finished gently admonishing the group to be careful about what they placed in the paper recycling bin, we went around the table with each person reporting what their weekly tasks were going to be, and when and where they might be traveling. Even I, the visiting anthropologist, was called on to relate my schedule. After hearing the litany of work that each person was going to be doing that week, I was feeling a little chagrined that my plans mainly entailed 'sitting around and watching you work.' I reported that I as yet had little specific planned, with nothing firm beyond traveling to Duluth with Ralph on Wednesday for the engineering analysis report to the city planning committee. Then Lily invited me to sit in on a conference call Tuesday morning that would be discussing some change orders and contract problems that had arisen with one of the community wetland design projects, and Sam suggested I go out with him that afternoon on the EcoCheck run. With the addition of either a municipal water district meeting or a soil sampling junket on Thursday, I now had a number of exciting out of office 'participation venues' lined up. But in reality, just 'sitting around and watching' the daily office work was also an informative venue.

Following on the 8:30 "scheduling meeting" the engineering staff broke into the two teams of "Industrial" and "Residential" for their "Work Load" meetings. In the Industrial Team meeting that day a discussion of a contract negotiation and potential IP infringement dominated, but other rapid fire topics included bench studies on treatment processes, CAD labor limitations, invoicing, survey mapping, permitting applications, and regulatory hold ups. With a final listing of the weeks top priorities, the team members dispersed, whilst the team leader remained for the follow up team leaders Coordinating Meeting. This meeting between company officers, office manager and project team leaders also covered an array of topics, though this time focused more on the machinations of the business including expanding the staff base, adding to the skill set of the young engineers so they can cover some of the CAD work or soils work, getting more of the engineers through the NCESS process[257] and overall invoicing issues for the company. With the wrap up of *this* meeting we then all gathered for the lunch meeting that would cover the Template design. The groans that had greeted the announcement of "we need to discuss the Template" at the 8:30 meeting had me primed for something really onerous. Luckily, the lunch meeting started with a slide presentation by one of the engineers who had recently done a two week vacation in Morocco. Following on the pleasant chatting about Ned's experiences, the serious business was brought up.

The "Template" turned out to be a very detailed set of spreadsheets that allowed the designers to tabulate the costs of various design options. John explained to me at the beginning of the meeting:

> The template is designed to be tailored as we go along. The items included on the template are driven by the developer market. It allows us to have small up front costs, and to quickly hone in on various collection and treatment alternatives for small residential home developments. This speeds up the 'bread & butter' design work. It's good for the individual projects like X & Y, which are unique problems and have to be innovative.

As the work had already mainly been done, this meeting was not so onerous. The groans I had heard were more an outcome of the past tediousness and time-consuming nature of the project, rather than an expectation that this particular meeting was going to be grueling.

During the discussion the following exchange occurred

> –With the new regulations [on minimum sizing of septic tanks] we might see a shift away from septic toward package or screens.
>
> – With package plants there will be more dealing with solids which needs to be included in the template. Even with vertical flow[258] we need to put more emphasis on solids handling.
>
> – I'm so astonished at the tank sizing that Minnesota requires.

[257] NCESS is a not-for-profit that is basically "a service for filing for licenses in each state. In centralizes the processes- you send them all of your info, and then they facilitate getting the correct info to the different state licensing boards."
[258] Vertical flow wetlands, which the company specialized in.

– In the last 5 years it has gone from a ¾ day retention time, to now 3-4 days retention is required. The old requirement probably was too low, and likely caused under-sizing. But with the larger tanks the price-point of technology is shifting, and alternatives to septic will become viable as septic costs are going much higher.

– Pumping out tanks costs $.08 - $.10 per gallon. The Ponds, have 30,000 gal tanks that have to be pumped once a year. These are costs we need to capture, that might drive the choice of the technology.

– We've got the cost of tanks in the spread sheet, but what about alternatives other than a septic? We don't have the expertise in some of these, like some of the European screens. This template is designed so that we can turn the crank, for a budget of 500,000 plus 50%. We don't have the budget to investigate all the alternatives.

- But I am concerned that the spreadsheet will cause lock in – here's what we cost out. We turn the crank and it works great, but there are options that don't show up. Right now, if you run it for a 300 home development, a full on greenhouse based living machine might be cost feasible, but not for a 100 home development which is more like what we are going to do. But with changes in the regulations, package plants and living machines become cost effective mechanisms. Especially when you included the MOM costs[259]

After a bit more discussion, the meeting was wrapped up with the following:

– It is going to be rough making the switch to the new template.

– It's the evolution of business. You can't rely on something old.

Throughout this morning, I had been continually struck by both differences and similarities to experiences I had had while participating in a wetland research facility at a university. An aside note in my fieldbook during the Industrial Team meeting reads "Note- how many projects were talked about, how fast the information is exchanged. The pacing of the work is very different then being at the university". I was struck by the fact that everyone was working on multiple parts of different projects, with many different individuals contributing bits and pieces. The goal was the production of the product, who did the production was less important. How different it felt than at the research center where the tonal emphasis was on the individual laborer- on their thesis or PhD research. To be sure at the research center joint work did occur, and time was spent on the overall research goals and projects of the whole facility, but the educational context of the center meant that the overall emphasis was on individual projects and individual achievements.

[259] MOM = Monitoring, operating and maintenance

The other striking difference was the general prevalence of concerns of regulation, licensure and permitting that pervaded the conversations at the company. In the realm of application of designed ecosystems the regulatory realm was definitely a salient constraint.

In the following section, I will discuss regulatory frameworks that have had a significant impact on the development of both ecological engineering practice as well as the general ability to pursue alternative wastewater treatment. I will then discuss the role that prescriptive standards have had on constraining innovation in the wastewater field. Finally, I will discuss the way in which regulation is also an issue of 'regulators' and subsequently regulatory constraints can be social issues as much as legal ones.

Role of Regulation in Developing Practices

> I would say that largely regulations drive the process and then the technology adopts to fill the market niches. (pers comm)
>
> Ecological engineering was developed in water systems and that is still where it is. That is largely because it is still the most regulated facet of ecosystems right now. That is where the regulations drive it, that is where the money is. There is no money in terrestrial ecosystem restoration (pers comm)

The major player in water regulation in the United States is the Clean Water Act (CWA). When it was passed in 1972, emphasis in the program was placed on large polluters and on point source pollution. Standards for effluent quality were set and any discharge to a surface water of the US needed a national pollutant discharge elimination permit (NPDES).[260] But the CWA did not merely set standards; it also established a means to address pollution through a well funded grants program. Title II of the CWA enabled major federal funding for wastewater treatment plant construction. For public works projects, up to 75% of the construction cost was available from the federal

[260] This system is officially overseen by the US EPA but is largely delegated through authorization to state environmental protection agencies.

government with the individual states expected to furnish the remainder. The CWAs emphasis on large point-source polluters coupled with the funding mechanism created a push toward a narrow range of large-scale wastewater treatment technologies and under the 1972 CWA there was a large flurry of wastewater treatment plants built for the large and mid-sized American cities. It is during this period that the concept and technological base of 'conventional treatment' truly solidified into a standardized set of technologies and professional practice.

In 1987, the Clean Water Act was renewed as the Water Quality Act, and in this rewrite a number of significant shifts occurred. No longer were there direct federal funds for wastewater treatment. Rather, states were required to maintain a State Revolving Fund (which would receive some federal support) to which industries and municipalities could apply for low rate loans to finance water quality projects. However, a second major funding shift occurred in the creation of the nonpoint source management program, called Section 319. Under Section 319, federal funding was made available to states to use on a range of innovations, demonstrations and training programs aimed at dealing with more diffuse pollution problems, such as from agricultural runoff, or from failing septic systems,[261] or from small municipalities that were not regulated under the NPDES due to too low discharge rates. Overall, the 1987 WQA switched the emphasis of regulation and subsequent technological solutions from a focus on large point sources to a myriad of potential small sources. Simultaneously with the advocating of innovation and demonstration projects, technology based standards were changed to more performance

[261] Though each individual septic system is technically a 'point' the overall impact of failing septic systems is diffuse, and thus a thus considered a non-point source problem.

based standards. It was under these regulatory and funding conditions that the burgeoning field of 'alternatives' in wastewater technologies started.

Thus, 'alternatives' arose to meet two different opportunities generated by the Water Quality Act and its funding program. First, conventional treatment plants were very costly for small cities and municipalities, as conventional technologies do not scale down well, and the per unit (house) cost can be as much as $60,000 per home to sewer a smaller community. With the 1987 switch to the State Revolving fund and the 'polluter-pays' model, cities were not as eager to adopt these large and costly conventional treatment systems. However, if they coupled their treatment systems with a demonstration project, like a tertiary treatment wetland, the municipality might be able to receive the lower rate loans through section 319.[262] Secondarily, as this same state revolving fund made funds available for addressing non-point source pollution sources, very small towns or suburban developments could now apply for funds to assist in small scale projects based on clustering rather than individual septic tanks. Thus the combination of regulation and funding opened the door for burgeoning innovation in neighborhood scale treatment systems. In this new regulatory environment, various ecosystem based treatment processes could gain traction. As put by one wetland engineer "if your wastewater is going to be treated near your home, you don't want something ugly."

The other realm of regulation that had a major impact on ecological engineerings early emphasis on wetlands also came out of the CWA. Section 404 of the act regulates

[262] As one goal of the Section 319 program was to reduce overall nitrogen and phosphorous loads in streams and river reaches, projects like constructed wetlands to polish waste water effluent to a high quality were supported. Similarly, constructed wetlands to abate storm water runoff and the repair of riparian ecosystems were all possible demonstration projects for lowering total daily pollution in a watercourse.

the filling or dredging of the waters of the United States. Because wetlands were included in the purview of this definition of waters of the United States, any construction or activity that damaged wetlands became a regulated activity. Rather than forbidding damage to wetland areas outright (which would have been economically and politically untenable), Section 404 established methods of trading, or mitigating impacts. Though still a debated practice, the concept of wetlands mitigation allows that a wetland in one area can be negatively effected, if in another area a wetland will be restored or even built. The outcome of this regulation was a market for individuals and companies capable of restoring or building wetlands which added to the overall design base for developing the practices of ecological engineering.

Prescriptive Standards and Performance Standards

> In the face of this regulations for onsite and decentralized systems are changing. In the past, most state codes for septic systems were of a prescriptive formula, in short recipes for how to make a system. Use this collection box and this drain field. If you followed the prescriptions you were granted approval. Which doesn't mean that it would work. Now more states are switching to performance based standards. Saying we don't care what type of technology you use, we just want you to reach these treatment goals. In the states that have gone to these performance standards, you are see enormous amounts of innovation. (pers comm.)

National standards for discharge limits of BOD, TSS, fecal coliform, nitrogen and phosphorus drive the adoption of wastewater technologies and the goals set for the treatment regimes. However, the cost of treatment factors into technology advancement as well. As one engineer pointed out "We could do all systems as zero-discharge, but who would be able to afford that?" Thus, technology choices are a balance between meeting regulatory mandates and costs. Though effluent standards for wastewater are set at the national level, state and local ordinance are also in place; and these can regulate more strictly than the national standard or regulate on a prescriptive standard rather than a performance standard. Prescriptive standards state specific technologies and or design guidelines for a pollution abatement solution. These prescriptive standards have the advantage for regulation in that they are a one time oversight of the design process rather than requiring a continued monitoring of a technologies performance. In local ordinances for onsite waste water treatment prescriptive standards have often been the norm. These standards can include the type, size, or placement of a technology. There are two outcomes to prescriptive standards that come to bear on the deployment of designed ecosystems as wastewater treatment options.

The most direct outcome of prescriptive standards is that it limits the ability to adopt innovative systems. Attempts to do something new require going through extra permitting steps. As one wetlands designer said of constructed wetland he worked on "It took only nine days to construct, but that was after nine months of permitting work." The existence of prescriptive standards for onsite treatments often conjoins with zoning regulations. Prescriptions for onsite treatment are for septic systems and subsequent lot size zoning is tied to minimum requirements for septic leach fields. Thus attempts to do clustered developments must overcome the dual regulatory institutions of Boards of Health[263] and county zoning commissions.

However, prescriptive standards can have a positive impact on the adoption of designed ecosystems as well. In the story in the introduction above, the engineers were discussing potential changes in Minnesota's state regulations on the size of septic tanks. Concern about performance failures in septic function was leading the MPCA to increase the required size of septic tanks for homes. Increasing the prescribed size has real implications for the construction costs of placing those tanks. At one point the engineers were talking about this issue and one commented "A tank that size is going to take a lot

[263] Which in most states over see the 'non-point source' pollution of septic systems.

more concrete and be a real bitch to place." Such regulatory changes thus will drive different conclusions on the cost-benefit analysis of pursuing different technical options. As mentioned in the Template discussion, if the costs of putting a development on individual septic is increased, cluster systems like wetlands and even living machines become more economically viable option for small developments.

A final element of regulatory standards setting that can be problematic for innovation and innovators is the fact that though the CWA sets national guidelines for water quality, it is up to each state to permit and regulate treatment systems. Thus, under the constraints of rules written toward design standards, new innovations like the solar aquatics or living machines might have to go through 'proof of concept' demonstration projects in multiple states. For both technologies, and technologists, licensure is done on a state by state basis.[264] As the process of gaining licensure can be costly for technologies this can have a limiting factor on the speed at which new ideas are implemented.

Regulations and Regulators

> Regulators are better with standards that say "thou shalt design it thusly" (pers comm.)

Regulatory standards can both foster or impede innovation through the establishment of practices and markets. However, these written regulations are overseen by real people, and thus regulatory impediments to innovation can be as much about the enactors of the laws as the laws themselves. The human element of regulation comes to bare on adopting eco-technologies or implementing constructed wetlands in a number of ways. Regulators, like engineers themselves, are stereotyped as being conservative and risk adverse. Regulators can be reticent to accept novel technologies as their own technical base for

[264] Though some states are adopting standardized procedures or are allowing equivalencies. Some states have notoriously hard licensure processes for particular fields, and a strategy for some engineers is to attain that state's licensure which then other states might take as an equivalency.

judging the proposal might be inadequate and their ability to judge the project on its individual merits might be limited by both overwork and under enthusiasm to take a risk.

> If you want a frictionless existence, just use the guidelines. But if you introduce something to a regulator who has never seen it before, and who might not be educated to evaluate it, they won't want to try it because it's also their butt on the line (pers comm)

Thus, just as within academia, the implementation of new forms of practice can be affected by gate keeping individuals. In discussing regulations and regulatory hurdles during interviews, there were many occasions when interviewees highlighted the "really it was just this one regulator" or "we all try to avoid having to work with that guy [a regulator]."

Similarly, regulatory hurdles can come out of confluences of regulator reluctance coupled with political expediency. Even if lacking direct prescriptions for technologies, local ordinances may contain "recommended" practices, or recommended design guidelines. These "recommendations" can be used by regulators as prescriptions out of their own uncertainty or truculence. In describing the long, twisted history of getting one of their systems permitted for a small municipality, an engineer showed me an old manual on lagoon construction

> These guidelines for lagoons were set 20 years ago, and they recommend an equation for a lagoon, which then the regulators want you to use, no matter what this guy says [pulling *High Performance Aerated Lagoons* off of the shelf]. And what's more, these guidelines [shaking the first booklet again] are geared toward conventional systems for municipalities, not for small residential systems. These are "recommendations" but then county ordinances will refer to this text, thus making these recommendations the de facto law. (pers comm.)

The engineer went on to describe how in this case the permit application was turned down, with one of the causes of concern being that the proposed design did not match the "recommended" design guidelines. The letter of rejection for the permit included a list of technical "problems" with the design that would need to be answered or addressed before a permit was granted. However, before drafting a technical response to the rejection, the engineer consulted with a number of the municipalities officials. It turned out that the letter of rejection was more of a political response relating more to who went over whose head, and who rattled whose cage to get the stalled permitting process going. In discussing the time period when they as design engineers didn't yet know about the political machinations, the engineer stated

> The Mayor of the town of this project went rabble rousing to the regulatory agency. In short, he said 'We've been working hard, and you've done nothing' [waving hands animatedly]. It's possible that the mayor was not very diplomatic. So this letter comes a few days later. It could be politically retaliatory. The minister that got leaned on by the Mayor tells the regulators get something out to them pronto. And the technicians turn around and write this letter asking for more info. So is their problem with our design *truly* technical or is it political? If it's politically motivated it will be death by a thousand lashes, but if it's technical we will be able to prove our design and convince them.

One of the striking things in this story is the awareness that in some cases technical proof of concept is not going to be enough. Larger institutional dynamics and plain personal foibles can also influence the ability to design and implement technologies.

Conclusion

It is important to note that not all discussion of regulations were negative. As mentioned above, the Clean Water Act and follow up Water Quality Act set the stage for investment and invigoration of the water technology field and this was an oft acknowledged baseline for practitioners of wastewater treatment technologies. Without regulation there would be, if not no demand, then a greatly diminished demand for any of these technologies.

Similarly, regulation, and thus subsequent abilities of governments to levy fines, is also seen as a spur to the development of sound technical practices. In speaking of wetlands construction in general,[265] one designer pointed out

[265] Wetlands constructed for stormwater abatement or mitigation are lacking in regulatory oversight. Putting them in might be overseen, but whether or not they meet their design goals is not evaluated. This is one of the major critiques of the wetlands mitigation program in general. Just because some one puts a wetland in somewhere, does that mean that it provides a wetland function then or in five or ten years?

> And the other thing of course, there is not yet a professional regulatory mechanism. Once you get some kind of regulation, the snake oil salesmen begin to fade away. There are all sorts of odd things that come in engineering design, in our field, and you say 'Why is this being done?', and of course I could be wrong, but assuming I am not wrong, then there are things that come out that make no scientific sense…

The need for oversight to protect against bad design and the role of licensure to mitigate against bad designers were acknowledged as social goods in a number of interviews. Even receiving fines was seen as not an unmitigated tragedy, but more a representation of the engineering process of learning through failure. As one senior wetland designer stated "I've been fined many times. It's what happens in this field." However, the form that that oversight takes, whether as prescriptive standards or as performance standards can effect the pursuit and deployment of new technologies. Similarly, the ways in which regulators understand, or interpret regulations can also impact the implementation of alternative technologies.

Though accepting at one level the necessity of regulatory oversight, on the day to day practice level, the most salient feature to many were their own recent hurdles with regulatory agencies to get their projects approved. "Permits, Permits my life is about permits" one joked. But for all of that, it might be true.

CHAPTER 8

CAPITAL

Introduction

Not-for-profit research centers, academic production centers, and for-profit engineering firms have all been involved in aspects of developing the specific technologies, the general practice, and the formalized discipline premised on designing with ecosystems. The concerns of capital have impacts on each of these venues. Though elements of these constraints are shared amongst them, each venue faces unique challenges due to the nature of the institutional arrangements of which it is a part. As discussed in the first section below, access to funding lines for both not-for-profit and academic research centers can be a mediating influence on technology and practice innovation. For business the dual features of payment norms and labor commoditization can stymie interest and investment in alternative technology development, as will be discussed in the second section.

Funding: A Perennial Problem

To a certain extent, all three venues can be seen as being constrained by sources of funding. As discussed in the regulation section, even for-profit business ventures are affected by government agendas and subsequent funding lines. The synergy between regulation and funding in the Clean Water Act is a major case in point to the role of capital in either spurring or limiting innovation. That this funding may come in the form of loans rather than grants does not alter the fact that it can be the very *availability* of funds that alters decisions about what type of technology to develop or adopt. However, the idea of ‘funding’ is an especially salient constraint in the functioning of innovation at not-for-profits and for the establishment and expansion of ecological engineering as an academic discipline

Not-for-Profit

As not-for-profit research centers, New Alchemy and OAI had the continual challenge of securing operational funds. Acquisition of funds seems to have been a perennial problem throughout the years. NAI at times did not have enough funds to meet its yearly budget needs and at times could not meet its salary obligations. Supported in part by membership, large parts of their operational budgets also came from grants; the gathering of which was likened to a Sisyphean task.[266] In writing of the history of NAI, Nancy Todd highlights that it was acknowledged by NAI personnel that norms of funding were having an impact on their ability to continue to function as an institution. Funding sources often favor new projects, and getting funds for operation and maintenance of existing infrastructure is difficult. Cutting edge research is continually needed to maintain a funding stream and NAI was failing to capture those funding lines.[267] In the later years of NAI, the lack of economic stability of the institution became a point of discussion, and a site of desired reformulation by some.

> We are facing the next set of challenges: establishing ecological values within the commercial context. To be successful, we must cooperate with organizations and individual who share some of our values but are constrained by the need to make a profit, to satisfy public opinion or to meet customer expectations. Looking back, we see that demonstrating ecological ideals within the environment of a nonprofit research and education organization was comparatively easy. The problems to be overcome were biological and technical, not economic. Unlike commercial growers, we don’t have to make our living directly from our greenhouses, fish ponds, market gardens or leaf piles.[268]

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[266] (Todd 2005, p. 119).
[267] (*Ibid*, p.142).
[268] (Quinney 1989), speaking of NAI

The failure to demonstrate economic viability of the ideas investigated at NAI was an outcome of different perspectives on the goals of the NAI research.

> Some of us thought it was not our role to justify New Alchemy's work in terms of the marketplace. Others argued that this might be the most effective strategy in the long run.[269]

Similar funding shortfalls also plagued OAI throughout its operational years. Just as NAI fell short of budget and couldn't meet salary, so too did OAI in 1992.[270] Coming out of the hard, anti-environmental 80's, OAI already had operational debt[271] and then devastatingly in the mid-nineties the organization was embezzled by their office manager.[272] After the shutting down of the EPA research funding that had been supporting the South Burlington living machine, other research projects were conducted with the system. But OAI would struggle to maintain a funding stream to keep the South Burlington living machine (eco-machine) operational and in the fall of 2004 it had to be shut down.[273]And in 2005, when project funding failed to come through for a number of Restorer projects that were planned, the research and construction part of OAI was shut down. And most unfortunately, in the 2005 announcement of this shut down it is intimated that between the embezzlement and loans taken out to cover operational costs, OAI had been left in debt from their research days.[274]

Universities and Departments

> Now, you go to the dean, and you say, "We would like to have more faculty lines for ecological engineering." And he says, "Great. Give me a business plan." And I say, "What does that mean?" And he says, "You show me that if I invest $100,000 a year in this guy's – in this person's salary – that they will generate $3 million a year in research funds." And I say, "Well, I can't do that, because the research dollars aren't there in ecological engineering. That person will be very popular in the program, and the program that they're working in will be extremely popular, and

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[269] (Todd, 2005 p.118).
[270] http://www.ibiblio.org/london/agriculture/general/1/msg00088.html
[271] *Ibid.*
[272] (Todd, 2005 p.164) and & http://www.oceanarks.org/abo40_The_Next_Transition_at_OAI.php
[273] http://www.oceanarks.org/abo40_The_Next_Transition_at_OAI.php
[274] http://www.oceanarks.org/abo40_The_Next_Transition_at_OAI.php

> we'll have lots and lots of students." And the dean says, "I don't care about students. What I care about is research dollars." (pers comm.)

The institutional structures that impede the development of ecological engineering are tightly linked with issues of capital. Departmental reticence over developing new programmatic elements are not just outcomes of differing opinions and positions on what constitutes the appropriate direction for a department. Establishing new tracts requires that existing faculty devote time to curriculum development or that new faculty are hired. Both of these paths are filled with synergistically constraining relations between funding and institutional structures. As the quote above points out, hiring a new faculty line requires support from higher-up administrators. But convincing them requires justifying the change in the econometric language that is prevailing in the universities. Similarly, with current faculty, they are likely already contractually committed to a number of courses plus research, and finding the time for curriculum development work is difficult. Thus such internal development of programs often needs to be supported by external funding like education improvement grants so that the development of new curriculum is considered part of a faculties research time. However, though there might be some accolades for getting such a grant, the award structure of academic advancement still devalues this type of time investment on the part of the faculty as publication in engineering education journals is not highly ranked on bibliometric scales. Thus pre-tenure faculty risk not making their tenure requirements if they focus on education development, and departments risk having lower institutional rankings if their faculty are not publishing in the top ranked journals.

The issues of funding lines is important in maintaining research programs and venues just as much as in developing them. In parallel to the experiences of not-for-profits, garnering funding lines for operational and maintenance costs can be more difficult than gathering funds for a brand new project. Continuous novelty in research is preferred, and is often preferred on time frames that make long term ecological research more tenuous. Even world renowned research parks like the Olentangy River Wetlands can go through this frustration of trying to find funds to cover the day to day and long term research goals of the facility. Though funds come in for research projects, maintaining the day-to-day operations of the facility can become frustratingly difficult.

This type of accountancy can pervade the university and make justifying new programs difficult especially in the face of rising budget cuts. Though ecological programs may be popular, this does not necessarily ensure university level support. In one example, a senior faculty tells of adding an ecological track in his civil – environmental engineering department. With 14 faculty in the department, and one doing ecological, after the ecological track was listed, 80% of the applicants were interested in ecological engineering. Course popularity and large enrollments at the undergraduate level can have positive impact on flows of money into a department if graduate student assistantship funding is linked to undergraduate program size, but barring this type of accountancy popularity of a program is not as valued as grant success.

Acquiring funding in ecological engineering runs into the interrelated problems of the newness and the interdiscplinarity of the field. As a new field, there are not dedicated funding lines for research wherein evaluators might be starting from a baseline of understanding about the concept and goals of ecological engineering. Lacking an ecological engineering funding line, researchers with proposals for submission to NSF have either to apply through the engineering program or one of the sciences. More than one faculty had stories of getting rejections on the basis of “this is engineering” from reviewers in one of sciences, or “this has too much ecology, go to the ecosystems program”, from the engineering reviewers. One individual characterized these experiences:

> In the research arena applied ecologist would be are biggest competition. Because our work is often funded through NSF’s science division, not engineering division. And if you want to talk about a good old boys club that is hard to break into and that has a certain attitude about engineers, that is the ecologists.

Thus institutional structures in the very funding centers, coupled with conceptualizations of engineering identity, add to the constraints of developing this new field.

Engineering Firms - Profits and Patents

When the CWA provided funding for wastewater treatment development in the 70’s, it was not just the CWA’s interest in large point source polluters that drove the type of technological developments that were implemented. Structural incentives in the form of compensation norms for construction firms had the impact of encouraging very large, very high cost centralized treatment systems and discouraging smaller decentralized systems (Etnier, et al. 2007; Pinkham, et al. 2004). Engineering firms’ profits are drawn as a percentage of a projects cost. Thus firms have the incentive to seek larger projects, if not to also advocate larger ones.

> Within ecological engineering -- remember what we're trying to do is to minimize technology, and an engineers firm’s income is based on a percent of the cost of the project. And so the bigger the project, the more complex it is, the more it costs, the more the engineering firm stands -- will make in terms of their percentage – it’s something on the order of 10 percent, something or other. So to -- for an engineering firm to decide that, “We’re going to try to solve this problem in the least expensive way as we can” is counter to their good business practices. So the first question the engineering firm always asks their client is, “How much money do you have to spend?”

Though this pay structure in engineering firms can be seen to have had an inhibitory effect on small scale and natural treatment systems in general, in some cases this has actually aided the development of ecological engineering practice. One firm that has become a leader in constructed wetlands and other solutions for small cluster developments is North American Wetland Engineers (NAWE). The founders of NAWE, Scott Wallace and Curt Sparks, described the history of its development as partly an outcome of this very large scale bias in engineering firms. Both were working at the same large engineering firm, and both had begun to be aware of wetlands work through a number of experiences and projects. However, as they tried to encourage the company to consider doing smaller scale municipality work based on wetlands, the company had no interest in those opportunities.

> The pressure at [x company] was -- we were still always trying to get work, get work, get work. I was always trying to market for them. Their focus was always, where's the next million dollar job? Where's the next million dollar job? Where's the next million dollar job? It just got to the point where we said, "Guys, there's only going to be three million dollar jobs in Minnesota and we're not going to get any of them this year, because this one is going to go to this company, because they've done all their work for the last 40 years. And this one is going to go to so-and-so because he's been playing golf with the public works director for twenty – etcetera, you know. I said, "There's tons of work out there. Look all over Minnesota; people are building stuff, there are towns all over the place. We could be doing these smaller projects, a lot of them. I might not be able to get you the one big job, but I can get you 50 or a hundred little jobs. Those are all out there." That wasn't what [x company] really wanted to hear. They wanted to keep pushing the big jobs, the big jobs, the big jobs.

As work in the company progressed, opportunities to do wetland systems were arising. At a conference talk, wherein Wallace had been presenting on a wetland he had designed when at another firm, he was approached by the mayor of a city where they had recently enacted open-space development ordinances. The city was struggling with how to manage the septic systems if the housing was clustered. Wallace was invited to the town to give a presentation.

> Curt and I went there. And all of a sudden that night we've got 2 jobs to design constructed wetlands. Just like that. It was for these residential developers. However, all the people at [x company] -- the attorneys at [x company] are just spinning in their graves because what their standard form of agreement was a contract about an inch thick. "Here, sign this and we'll start working for you." It doesn't work with the developers…It just got to the point one day where Kurt and I just said, "We really want to pursue this market." [x company] sat us down and forbade us, said, "You will not do this work any more. You will stop doing it."

Wallace and Sparks ended up being terminated when they refused to stop advocating exploration of small scale systems and constructed wetlands. Leaving that firm, they set up their own, and their company has expanded in size since. It is also interesting to note that the start up funds for the new company came from an early wetlands mitigation project. The opportunity had arisen while they were at [x company], but that firm did not want to handle the wetland construction. So Scott and Kurt set up an LLC and got the mitigation wetland built. In selling it to [y company], the profit from that ended up being the seed money for NAWE.

The growth of the company was based in intensive marketing to establish a job base, coupled with research and design. The outcome of this research has been the establishment of 4 patents.[275] The special elements of NAWE's wetlands include methods of capping, which extends the cold weather treatment performance, and a system flow and aeration that achieves higher treatment rates with a decreased footprint.

This type of patenting of ecosystem designs has it proponents and its opponents. Some constructed wetland designers do not use patented wetlands designs, and do not feel limited by their lack of having patents. Others express the need for patents to protect the time and money spent in developing a new technology

> I feel like intellectual property is absolutely essential to everything ecological design is doing. It's the only – it's your goaltender that your money invested in R&D actually comes back to you in some sense. It's not even a great guarantee, but it's all you have to entice people to invest in this technology. And that's what we absolutely need. It is still totally in its infancy and we need an Apollo project type mentality of putting money into R&D and developing these technologies on all differing scales. So I would say patents on intellectual property are totally essential to that.

Another engineer raised the concern that without patents, it becomes easier for large firms to turn the labor of their subcontractors into commoditized goods. Thus a company goes from having a unique product to offer to just generating one of the widgets in the overall design.

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[275] 3 in the US, 1 in Canada.

> Because there is an urge through out the industry to commoditize engineering work. And a certain amount of commoditization is inevitable. I mean a culvert is a culvert. So 'my culvert is more special than yours,' or 'I design my culvert with more brilliance and insight than you did', that is ridiculous, so there is an element that is inevitable. And that goes on to wastewater treatment of some forms. But, to break out of commodity hell you have to have I.P. And in order to be able to get a payback on the substantial effort in innovation you need to be able to get I.P. Otherwise you get ripped off right away. Or if not right away, as soon as you are really successful and starting to make money. So, I believe patents are a necessary evil.

Thus with the development of innovative and new systems – like wetlands for clustered developments, or living machines – drives of capital will work in multiple ways. In order to protect investment in R&D, patents become a useful tool. Similarly, by having a patented technology that can be licensed companies maintain a control of the product and upon the implementation of the design. However, the flip side of the desire not to have one's technology become a simple commodity can mean that the design and construction costs can stay high.

This was a point of tension at LDG when I visited there. At that point, the Tidal Flow Living Machines® were just coming onto the market, as were their Hybrid Living Machines.® A constraining factor in the deployment of the technology was the high cost of design and planning. As the technologies were still new, and each application that was being done at the time were for very different water and wastewater problems, there was no "turning the crank" element to the work. One of the design engineers stated that that was a goal for the next period of time, to try to streamline some elements of the design so that the design costs would come down. Though the original living machines were often publicized as low cost, "Living Machines use no chemicals and are significantly less costly than conventional treatment plants", this was not always the case. To lower costs and make the technology more applicable in more places, LDG wanted to simplify the design plans and commoditize some of the elements.

Conclusion

The current world of capital markets decidedly affects the development of new technologies and new disciplines, but it can do so in direct and indirect ways. Acquisition of funding, through grants and contracts are the primary concerns of research centers and businesses respectively. Funding lines can aid educational initiatives and fund research centers that have developed these new technologies. At the same time, funding regimes for technological deployment can actually impede the development of innovative technologies if the regulatory environment in which those funds are dispersed does not provide incentive for such ecological innovation. This can occur at both the research level, where funding lines fail to provide space for innovation in a particular realm. For example, a common talking point among ecological engineers at AEES meetings was the need for a major funding initiative in ecological systems science and ecological technologies similar to the federal initiatives into nanotechnologies. . Even H.T. Odum made such a call, citing the need for money to be spent on ecology research rather than space exploration. In these cases, lack of funding is an outcome of lack of institutional support for the technological field.

Similarly, institutional support can impact business decisions in regards to technical innovation. Structures of remittance for engineering work, coupled with state and federal loan initiatives have influenced technological innovation in the wastewater sectors toward large scale structures. This intersection of governance and capital has effected the development of alternative technologies based on designed ecosystems. However, this effect has been both negative, in the sense that large scale institutional change has not been invigorated, but also positive, in the sense that entrepreneurial individuals have not only witnessed the technological void, but have then striven to fill that void through technological innovation.

In all, the role of capital as a constraint to the development of designed ecosystem technologies and ecological engineering is largely mediated by the enframing structures of regulations and large institutional policy goals on ecological technological innovation.

CHAPTER 9

MATERIALITY

Introduction

Sandy walked beside me, her body torqued so that she could reach to hold the handle of the red cooler. We were headed out into the wetlands to collect the water samples and dissolved oxygen level readings that would form a few of the test points in her model of wetland metabolism. Walking out to the wetland, we had walked side by side, the cooler held between us, each counter-balancing with our outside arms – me while holding the ubiquitous YSI probe, she while holding some folded metal contraption. But once we hit the wetland boardwalk we had to shift our walking position. However awkward it had been to traverse the boardwalk with me walking backward and her forwards, the clunky cooler knocking us both in the knees, we had not been upset about the narrowness of the boardwalk. We had just been grateful there was a boardwalk to use. The boardwalk allows researchers access to all the various sections of the wetlands, greatly facilitating higher research quality, and making it easier and cleaner. But ease and comfort for toiling graduate students was not the driver behind the construction of the boardwalk. More importantly, having the boardwalk permanently in place allows researchers to access various spots in the wetland without walking through it or boating over it, both of which brings with it a disturbance of the water column and the sediments. The boardwalk is there for the accuracy of science, not the convenience of researchers. But it *is* nice not to have to wade through the murky mud (more scientifically, and affectionately, known as *sediment*) to take water samples.

As I stood on the boardwalk and gently lowered the YSI into the water, Sandy unfolded her metal contraption. Watching her actions to discover her intentions, I soon saw the metal object was a type of grabber – like that 'thingy' you see advertised on late night television by a smiling elderly person who is using it to pick up their wallet off of the floor. "No stooping" "No bending" the ad touts. I looked quizzically at Sandy and she laughed. Bending over, she opened the cooler and pulled out one of the nalgene sample bottles. After removing the lid, she fitted the bottle into the grip of the 'thingy' and leaning slightly outward and downward she used it to pull up a sample of water from near where I am taking dissolved oxygen readings. "Ingenious" I cried. Laughing at my expression, she caped her sample. "Yeah, you should have seen me try to get my samples before I found this thing. I would lay down on the boardwalk, lean out, and down, and sometimes would be hanging almost upside down to get down to the water." I looked over the side of the boardwalk at the low water level – it was quite a ways down. Sandy then told me a short story:

> After my first data collection, I did research to try to find some sort of extender thing like this, looked into fancy things from a scientific equipment supply house – but ended up finding this at the regular store. It was only ten bucks. When I got the first one everybody was borrowing it, it was so handy. So I had to go back and get another one – this one – and I hide it – so that it would always be there when I needed to do my samples.

This day of sampling and the importance of the 'grabber thingy' stands out in my mind as a good metaphor for this section on the constraints of materiality. There is a material world out there that ecological engineers and eco-technology designers are attempting to grasp and manipulate. The various tools that they use to do this, and the various technologies that they make, affect a real tangible world. Though there are discourses, dialogues and debates occurring, these are occurring about real objects, real places amongst real beings. Though it would be possible to pick any of the previous three social constraints and focus on them in their entirety as a means to analyze the development and deployment of ecosystem design ideas, it is important to move beyond this fixation on, and privileging of, the social realm. The biophysical, material realm exists, it matters, and it must be grasped when discussing the evolution of technological systems. In this grappling with materiality I am not alone as scholars in sociology are again dealing with the problem of how to account for the ontological reality of nature (Carolan 2005) or "objects" as elements of sociological study (Cooper, et al. 2009; Epstein 2008). Similarly STS scholars, having gone through contentious discussions on how to balance between the study of science and technology as social process with the claims that a material reality exists in the early 90s, (Callon and Latour 1992; Collins and Yearley 1992; Latour 1993), are now again acknowledging the necessity of tackling materiality as a factor in the development of science and technology (Kuchler 2008; Roth 2009). Similarly, scholars are bringing the realm of materiality back into social studies of science with the realization that science knowledge and science identities are constituted by the *doing* of science (Roth and Bowen 2001) and that through shared practices of doing, shared identities can emerge despite formal disciplinary differences (Powell 2008).

In the following sections of this chapter, I will discuss three realms in which the concept of materiality can aid in the understanding of the history and development of both designed ecosystem technologies as well as the discipline of ecological engineering. In the first section I discuss the role of access to material spaces as a crucial element in the ability to develop new fields of technical practice. In the second, I discuss the way in which human physical actions over time represent sets of knowledge with are imbued with the materiality of practice. This embodied knowledge becomes an important resource in the dissemination of ecological design knowledge. Having discussed places, and human bodies, the third section turns to a discussion of the material reality of biological and technical things, and how these affect the development of designed ecosystem technologies.

Space and Places

I remember that day at the wetland so clearly. It was not a beautiful spring day, but it was a spring day. The gray Midwestern winter clouds were still there, but there was that something in the air that said spring. It was slightly warm, with smells of soil and damp and wetland fecundity, and action and activity were everywhere. The trees had that springtime hue that says "leaves are on their way." Birds and graduate students were flocking around the wetlands. Sandy was taking her water samples, Carolina was over in Kidney 2 testing the soil, Anne was over in the mesocosm area taking her gas samples, and I was doing my anthropology work of watching and participating, standing there dangling the YSI probe into the water, while thinking "This is awesome." I remember feeling like I really was somewhere that day. It was still early in my visit to the Olentangy River Wetland Research Park (ORW) and I was still feeling the elation of having managed to 'establish rapport' at my field site. I was glad to be finally out, in a place and doing something, not just talking about studying eco-technologies and the people who work on them. Here I was *in* one, and hanging out with the people who were actually *doing* it. But in reflecting on that day, I realize that though I was glad to be in that space and to be participating in the work that was going on, I was not really cognizing the importance of the *space* itself.

I had been told the history of development of the site; of how at first it was just the wetlands. There was no boardwalk, no observation deck, no research building. Just the wetlands and a shipping container. I had listened to the stories, but had as yet failed to really internalize the importance of the material nature of the research infrastructure that was now there: that the wetlands were there, were constructed and existed; that boardwalks had had the funds donated and then the days of labor to put them out; that a research building with multiple labs and office spaces had been built. I was thinking about the center as an amalgamation of people and projects, with outcomes of facts, knowledge and publications. I wasn't paying attention to the center as a materially real space.

This myopia of mine continued for quite a while. Later, when at NAWE one day I was going out on maintenance visits with Sam, one of the wetlands operators of EcoCheck.[276] Someone needed something picked up from "The Garage" and Sam offered to do it on his way out to one of the wetland sites. At that point the company president expressed pleasure that I was going to get to see The Garage. Sam and I headed out, chatting all the while about his job, and how he ended up working for EcoCheck. When we got to The Garage, I glanced around while Sam collected up some gear. I knew the history of the company, of the two engineers leaving the big engineering firm to start their company focused on using natural systems to provide water treatment. I knew they

[276] The small scale cluster systems that NAWE designs for municipalities and residential developments can run without a daily operator, but they do need to be monitored and have occasional maintenance done. NAWE created EcoCheck because there was no existing company that offered such monthly operational oversight.

had started out working from this garage that was attached to one of their residences; constructing a small office space in the upstairs and a research area in the ground floor. I knew that they had slowly added team members to the company, making the upstairs office space tight and crowded. I stood there looking at the large cement construction that hulked in the side of the garage and knew this was where they had done their research on wetland flow and aeration that led to their patents. But all the while I was thinking 'Hurry up Sam; I want to get out and see these wetland technologies I have been reading about.' Though the company President had intimated that it was important that I see The Garage, at the time I didn't understand why.

The same thing occurred again when I was at Living Designs Group in Taos, New Mexico. Having been there a while, and enjoying the fun, funky flavor of working in an office that was a cool adobe construction, I was singularly unimpressed when Fred took me by the research lab one day. We were out and about on some other errands and he offered to show me where they had done their research and development the first year that the ex-Living Technologies company was in New Mexico. Being amenable to seeing everything, we pulled up to this storage shed style building out on the edge of town. Surrounded by a chain link fence, the building squatted on its patch of desert like a corrugated metal wart. Singularly undistinctive, both inside and out, my notebooks for the visit are devoid of extensive details. "Tanks in corner" is as poetic as I got. Again at the time, I had the feeling of "This is nice, but really not apropos to what I am interested in finding out about."

In all of these experiences, I was seeing these places without *seeing* their importance. I cannot say that there ever was a eureka moment, when it suddenly dawned on me how tangibly important the material reality of spaces were in the production of ecosystem based technologies and the discipline of ecological engineering. As discussed below, materiality has an obvious role in that these ideas and discipline are about technical objects, made up of material substances and designed and manipulated by material human beings. But materiality also comes to bear in the spaces and places that this work can be done. To some degree, these spaces *are* the work, and lack of access to such places can have an impact on the overall developments of the field. The NAWE President wanted me to see "The Garage" because as a *place* it had been a vital component of the production of knowledge and the development of the companies practice. Fred wanted me to see the Lab because again it was a vital touchstone to the redevelopment and revitalization of the technology and the company. Having had that *space*, they were able to have their technology.

Spatial materialities are salient constraints in the development of ecological engineering and eco-technologies in two different ways. In the first, it is the need to procure space and the subsequent interactions of institutional and capital constraints that shapes these developments. The shortfalls of funding that plagued OAI were problematic in their effect on the ability to maintain access to experimental spaces like the South Burlington facility. Similarly, attempting to gain departmental support for a new program is not just about getting to establish a new curriculum, or redesign a course, but it can also be about procuring physical space in which to do research and to house students. Politics and funding issues over allotment of office, lab or research spaces can subsequently impede processes of programmatic development. A case in point was the attempt to develop an ecological engineering focus in one civil and environmental engineering department. The core of the focus was going to be in wetlands research and a number of faculty were involved in planning and designing a state of the art wetland facility which would allow many different modes of operation for testing different flow regimes on treatment capabilities. The project ideas garnered much institutional support and even became the recipient of a government earmark to support the development of a wetlands research center at the university. However, in the politics of that earmark allocation the control of the wetlands project moved away from the engineering program and to the horticultural program. And though the wetlands were built, they did not realize the goals of a research center as envisioned by the engineers. The ultimate outcome of this loss of the material space to do research was that one of the involved faculty failed to attain tenure as so much of their time had been spent in trying to get the center going, but they never managed to produce any publications off of it. Another faculty who had been involved did get his tenure, but in the face of the lack of an adequate research space for himself and his students, he soon looked elsewhere for a position.[277] Now the ecological engineering focus at this school is all but dead, remaining only in one faculty who teaches an integrative systems course and encourages all of the students to get exposure to ecological ideas.

The second manner in which spatial materialities are salient constraints in the development of ecological engineering and eco-technologies is from the core content of the practice which is ecology. It is not just actions in the social realm by institutions and capital that constrain, but it is also the material reality of ecosystems themselves. Unlike many microbiology studies that can be carried out over a 100 generations and with thousands of replicates without ever needing more space than one lab bench, nor more

[277] And is now involved at another university starting an ecological engineering focus.

time than one week, ecology studies can require long spans of time and expansive space. Though in theory ecosystems are scale-free, for some studies and some research questions the reality is that they need to be done over larger landscapes and over longer time periods. At one point, I was standing on the observation deck at the ORW with Dr. Mitsch and he was talking about the history of the two kidney wetlands that were in front of us, as well as the mesocosm studies that were off to the side. He was pointing out the constraints of the two different scales. Acknowledging that they had at least been able to make *two* kidneys he pointed out that a common limitation in doing ecology research is that "It is hard to do science with an N of 1." But the problems of statistical relevance that come from not having multiple replicates can be partially overcome by copying studies in the small mesocosm tubs. Dr. Mitsch explained how the tubs had been prepared with soils and plant cover and were being run on a pulse flow pattern to match pulse flow research in the kidneys. The goal of the mesocosms was to provide scale replicates of the processes occurring in the kidneys. But, he pointed out with a wry grin, the stochasticity found in a large ecosystem cannot always be implemented in smaller scales. "Where are you going to get .05 beaver to put in your mesocosm?"

Embodied Knowledge in Science and Engineering

It was the first day of lab and we all milled around in the lab space expectantly. The area was an odd mix of spacious and cramped. Spacious because we were in a large hanger-like building with a high ceiling crisscrossed with metal struts and large air conduits. Cramped because the space inside the hanger was parceled out into discrete work spaces by cabinets and work benches This lab space was outlined by the outer wall of the building fronted by standard black countertop covered lab benches and its inner wall defined by tall cabinets – two glass fronted and full of beakers and flasks, the rest more like hutches with cabinets above and below. The center of the lab space was dominated by the Ecological Treatment System (ETS). It was an unprepossessing set of interconnected black garbage cans, one closed, the others open with a few reedy and spiky plants growing out. These cans are connected with PVC pipes to each other and to a large clear tub filled with soil which also had plants growing out of it. Overhead, a square construction of pipes hung down from the distant ceiling. On this hanging rack, large spot light bulbs jutted downward. The metal frame was just above head height, but the dangling bulbs were certainly within skull-knocking distance.

In one perspective, the lab space seemed dismally unappealing, a mélange of techno-bric-a-brac and dirty tubs. But for all of that, an air of excited tension hung around the class group. Glancing into the next lab space I caught a white lab-coated individual regarding us quizzically. We were probably making a lot of noise as we were a sizeable group, and the lab tech probably wondered how long they would be plagued by these new noisy neighbors. This was the start up day for doing the hands on work of the course, and there was a palpable expectation while we waited for the instructor.

Later, after a brief introduction and training on how to run the YSI, the students were turned loose to prepare the system for the new round of class experiments. A number of volunteers went to collect the first round of effluent that would be treated by the ETS. This effluent was dairy waste slurry from the university barns that we collected in buckets, and then brought back to the lab very carefully.

Later, while two of the students were pouring the first round of effluent into the system, pouring a bucketful of dark, stinky, viscous, liquid dairy barn waste, I looked around at the collected students watching intently. Having already talked to a number of these students, and I knew that for many this course was an elective. An elective that they were willing to take in spite of the late Friday afternoon lab period; An elective they were interested in despite the fact that the central subject matter was, to be blunt, shit, and the processing of it. But for many, the draw to this course was the combined aspect of the subject matter: ideas of design and the possibilities of using ecosystems as solutions, coupled with the hands on, "You-actually-get-to-do-something" aspect of the course, even if that "doing" was related to buckets of manure.

The *ideas* of designing with ecosystems are coeval with *practices* of designing with ecosystems. To discuss the development of practices means attention must be given to practitioners and what they *do*. Just as the 'spaces of practice' mentioned above provide material realms for learning, the direct tactile involvement of humans within those spaces is another important material realm that can aid or hinder the development of ecological engineering and ecologically-based technologies.

Understanding human actors and their processes as instantiations of materiality is aided by the idea of *techne,* or embodied knowledge. At the heart of these concepts is the realization that there are forms of knowledge and praxis that are outside of the realm of verbal or written communication. Through construction, manipulation, tinkering, fixing, messing around with, working on, etc., forms of knowledge are created that are embodied in the individual actor. More than muscle memory, though this too plays a part, embodied knowledge highlights the ways in which the generation of new forms of technology can rely upon actions and practices that are learned through *doing*.

The importance of this hands-on learning was an undergirding principal in early engineering training. In fact, before the twentieth century this emphasis was so strong that the majority of engineers in the United States received their training through apprenticeship programs rather than formal school curriculum. However, even as the early civil and mechanical engineering coalesced into academic disciplines, experiential learning was still maintained as a central component of the educational process through machine shops. Though engineering education has undergone many changes over the century, an emphasis, at least in the epistemological distinctions drawn between science and engineering, is still placed on this role of hands-on design work, and tinkering as core components in an engineering education.[278]

This emphasis on *doing* generates a second key engineering identity construct, that of "learning through failures". This was an oft repeated maxim in AEES meetings and in interviews. In a way, it is the engineering equivalent of rejecting a null hypothesis. In engineering, you can never be certain you have the best design in the first plan. "You learn the most from your failures" is how one engineer put it. It is through the breakdowns or non-standard functionings that design ideas and underlying assumptions get tested. It is for this reason that ecological engineers have stressed in their definitions of the field that it will be an "acid test of ecological theory." Failure of designs becomes a

[278] The role of the material practice of making and doing still underpins the distinction that is drawn between engineering and science as practices. However, many engineers and engineering studies scholars have pointed out the slow 'science-tization' of engineering education that has occurred over the later half of the twentieth century. A general trend in closing of machine shops, and decreasing lab spaces and design studies has been documented. Undergraduate engineering students now may sometimes only undergo a hands-on design class in their senior year. Cited as causes in these closings is the space expansive nature of machine shops, or design studies, and thus their expensiveness in terms of departmental overhead. Similarly, faculty-student ratios have to be lower in design courses, and subsequent faculty-student contact hours also increases. Running lectures for 150 students examined with a multiple choice test is much less resource intensive than a design studio. Regardless of these changes in practice, the cultural identity of engineers is still constructed around the core idea of their being problem solvers and doing design.

source of learning and it is through-hands on design work that individuals get the chance to fail.

In was the second lab meeting of the ETS class and the students were busy fixing up the components of the systems that were going to be the base of their studies. One student was weighing some goldfish he bought which were going to be added to the last cell of the system. Another student was tagging plants in the wetland to be able to measure their growth over the course of the class experiment. Another student was rigging up a means to collect sediment from the bottom of the tank to determine sludge settling rates. The tool generated was a sawed off section of a 9-inch diameter PVC tube. Using that section as the frame, the student was stretching a heavy cloth across the bottom and strapping it to the tube. As the lab wrapped up that day this catcher was lowered into the clarifier. The following week, as data collection was under way, the student pulled up the catcher which seemed to come up all too easily. There was no sediment collected, because there was no base to the collector anymore. It had been eaten away by the high acidity wastewater. Other students gathered around and a discussion ensued about what she could use to form the bottom of her catcher that would not be dissolved. Though the student had likely heard before that wastewater can be acidic, or even caustic depending on the type, hearing those facts is very different than experiencing the outcome of them. In that moment of pulling up and seeing her dissolved sediment catcher, the fact of wastewater's acidity changed from abstract knowledge to experienced knowledge, and its likely that she has not since forgotten it.

The identity constructions of engineers keep in the forefront the notion that knowledge is learned through practice.[279] Subsequently, the claims that there are forms of engineering knowledge that are more "art", "gestalt" or "knowing how it feels" are not problematic. Thus in these constructs of engineering, the engineer, as a material body, as an actor, is a central component of the story. Engineering authority comes from how many years you have been doing a certain type of work, how many projects you have successfully created. The engineer and their *techne* is part and parcel of the technology they create. Science too can have *techne,* but in the reverse of engineering, science works to elide the material practices of the scientist themselves, stressing in turn only the material nature of the objects studied or the objects used to do the study. Though scientists are as much present materially in the production of science as an engineer is present in the production of engineering, in the stories of science, the action and presence of a physical tinkering, doing, scientist is generally avoided.

Recently, I was reading through the PhD dissertation of one of the graduate students I had met at the ORW. Part of the dissertation was on methane production in mesocosms under different hydraulic pulses. In the method section for this study, part of it reads:

> During gas sampling, the bags were rolled up around the chamber frames, and sealed at the top with .5 cm diameter rubber bands. The top of each bag was affixed with a grey butyl rubber sampling port and 2-m Tygon tubing for equilibrating the chamber with atmospheric pressure. Sampling was conducted one day before flood pulses were delivered to pulsed tubs, and one day after, as well as on numerous occasions between flood pulses. Sampling sessions were conducted over approximately 1.5 hours in the morning (between 7:30-10:30), afternoon (between 12:30-4:30) and after dark. Five gas samples were collected from the headspace of each mesocosm chamber over 20-30 minutes, into pre-evacuated 10 ml autosampler vials. The mesocosms at which sampling was started were chosen randomly each sampling day…. Environmental parameters measured in each mesocosm during gas samples included soil temperature at 5 and 10 cm

[279] Whether or not the majority of engineers actually practice design is a different question. With the professionalization of engineering degrees in the early twentieth century, and a rise in engineering managerialism, for many, engineering is actually a path toward management, not practice.

> depths, temperature within the chamber when each gas sample was withdrawn, and water level.…Gas samples were analyzed on a Shimadzu GC 14A equipped with an HTA Autosampler, with a thermal conductivity detector (TCD) and flame ionization detector (FID) in series. A 1.8-m Porapaq-Q column was used for sample separation, with helium (approximately 25 ml min^{-1}) as a carrier gas. The GC oven and injection temperatures were maintained at 40°C; detector temperatures were 200°C (TCD) and 150°C (FID). (Altor 2007, p.90-91)

I had the opportunity to interact with Dr. Altor during her study, and witness some of the research in progress. I recall things that the above text fails to depict. On one cool, drizzly morning I ran into her at the door of the research building. She had her arms full with a box containing a mish mash of objects – I could see a clipboard, a large ruler, a thermometer, a plethora of little bottles. Asking her what she was up to I found out she was heading out to the mesocosms for one of her methane gas sampling sessions. Though the day was very uninviting for outdoor work, this was the scheduled day for sampling, so it had to be done. I offered to come along and help if she could use extra hands. Glancing over my shoulder at the dismal slime of weather, she said with a raising eyebrow "Really?" I replied "Sure, why not? Remember for me this is novel and fun, and I don't have to do it. If I get too cold and miserable, I can quit." Giving me both a glare and a smile, Anne and I headed to the mesocosms.

Throughout the morning, we had a good, wide-ranging conversation while the data collection was conducted, as the actual collection was not mentally tasking just time consuming. I was instructed in how to take the soil temperature readings at two depths and document the water level in each mesocosm through measuring the water height in the stand pipe. Meanwhile, Anne proceeded to pull the bags up and seal off them of for methane collection.

Reading over the description of that process of gathering the methane in her dissertation, I can visualize her pulling up the bags, but after that I can not really say how they were tied off. In my own notes I had jotted down ". . . and then she ties off the bag so that there is one of those rubbery caps that you can stick a needle through." But between my own notes and the formal description, I still wouldn't be able to recreate that method of capturing and collecting methane. Science method write-ups are intended to convey the necessary description of events so that some one could replicate the experiment. However, this concept elides the fact that there are so many small elements that make up the *techne* of a science experiment that it is impossible to fully describe them all succinctly.[280] Even more, I was there and watched the process, and yet I still can not visualize clearly enough how it was done to recreate it. What is lacking is my own physical experience in having done the process. The knowledge of how to do the work is in the *doing,* not the seeing or reading.

At a later date, I had been wandering the halls of the ORW peeking into labs to see what sort of action people were up to. In the end lab I found both Carolina and Anne running analysis on samples. Carolina was running nitrogen content analyses on the backlog of daily water samples from the kidneys. Anne meanwhile was running her methane samplers on the gargantuan Shimadzu GC 14A, an impressively complicated looking piece of techno-gear. Making myself at home to watch, I reflected on a couple of conversations that had occurred at the last lab meeting. One point of discussion had been the issue of the missing lab technician, who had been absent from the university due to family troubles. That absence was looking to last a while longer, and thus the need to find new technical help was considered a most pressing problem for the research center, as the

[280] Sciences studies scholars also argue that even if a scientist did try to write down every single action that it took to produce a data point, the account would still likely be incomplete, as there are elements of practice that are so engrained as embodied knowledge that the scientist themselves would not be aware of the practice as specialized knowledge. For instance, the angle to hold a pipette, just how you tap an agar plate.

daily water samples from the wetlands were building up to quite a large pile in the freezer. However, recognizing that that process of acquiring a new lab technician could take a while, Carolina had been tapped to dedicate some of her graduate student assistantship hours to running the samples. Part of the conversation at the lab meeting had entailed the acknowledgement that "Carolina already knows how to use the equipment, so it makes sense to move her hours to working on this, but we do need to get more of you trained." A second conversation at the lab meeting had had to do with the Shimadzu GC 14A and its non-functioning auto sampler and how to get it serviced and how to find the funds to pay for the servicing. Watching Anne now, I realized why she had been so pressing at the meeting about needing to get it repaired. For one day's collection, she would have 300 vials of gas to analyze.[281] The auto sampler would have allowed her to place 50 vials in a tray, and set the machine and walk away, letting the machine extract the gas from the vial and run the test all on its own. Without the functioning auto sampler, the process was more like this: pick up a vial, extract a gas sample in the hypodermic, turn the knob on the sampler, stick the needle in the membrane, inject the sample, turn the knob, wait, watch the screen, pick up a vial, extract a gas sample, turn the knob on the sampler, stick the needle in the membrane, inject the sample, turn the knob, wait, watch the screen, pick up, extract, turn, stick, turn, wait, watch, pick up, extract, turn, stick, turn, wait, watch; again and again throughout the afternoon. With the analyzer taking a couple of minutes to run each sample, there was no time to really do anything else in between injections. But with the machine taking a couple of minutes per sample, it meant that running one day's collection could take two to three days in the lab

[281] 20 mesocosms with 5 samples from each mesocosm, with collections run morning, midday and evening on a collection day.

to run all the samples. When I asked Anne why she did not wait for the Autosampler to be fixed her response was a good exemplar of realism, pragmatism and stoicism. Her response amounted to who knows when it will be fixed, if ever, and these need to get done, so I will just stand here and do them. Despite its central importance, this labor and skill do not show up in her methods section.[282]

As Anne worked on this machine, so too did Carolina process samples in the other corner of the room. The flow of their work, the efficiency of motion and economy of time were outcomes of experience and training. Though the machines processed the samples, the knowledge and skills required to run the machines were elements of embodied knowledge that were valued commodities at the research center. The complexity of the machinery, all lumpy, and knobby with little tubes coiling every which way, belies a simple 'read the manual' approach to use. When these analyzers had been bought training sessions had occurred with the equipment salesman; however now in the lab the concern was that this knowledge was not being passed along to the new lab members. At that lab meeting, a subtle negotiation occurred over which of the senior, and trained graduate students, should be in charge of running demonstrations and trainings for the new cadre of students. The older students were fine with giving up some time to train the younger, but there was hesitancy on the part of some of the untrained younger graduate students about participating. They knew that if they were trained, they might be called on to use that training, and then they too might end up injecting, and turning and pushing and waiting.

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[282] In fact the autosampler did get fixed. In communicating with Anne later that summer I asked about it and got the response "Yes, the autosampler was finally fixed, thank goodness. Although I've caught up on running all but the latest samples through the GC, I haven't even looked at the results yet."

Maintenance of skills to do tasks, and the people to have those skills, becomes an important challenge and limitation of research and innovation. Like the engineers above, knowledge is embodied in scientists and as such, continuity of action can become important to the continued viability of research centers and innovation deployments. For example, in the deployment of the alternative wastewater treatment technologies, the embodied knowledge that operators develop through their interactions with the system can become a key element in the continued success of a project. The long durability of the SAS at PAWs in Muncie, Indiana has been facilitated by the existence of a single operator who was there at startup in 1990, and who through experiential learning could maintain the system through subtle manipulation of flow values and feedback loops as determined by his own sense of "how the system feels." Having worked with the system for so long, he knew exactly how far to turn down the flow volume control knob at the start of weekends to keep the system balanced even under the low input regimes of the weekend company closure. In contrast, the SAS system at Ashfield had an initial operator who developed a rapport with the system (Fraulo n.d.), but in the interplay of town politics, when he was fired and the other part-time workers dismissed, there was no exchange of knowledge between them and the later hired replacement (Kipen and Kipen 1999). Lacking experiential learning from knowledgeable practitioners, the new worker adopted a maintenance practice that was both more labor intensive and less effective than actions taken by the previous workers; this lack of knowledge transfer likely added to the judgment that the SAS did not work and its eventual decommissioning (Fraulo n.d.).

The value of the investment of time into the acquisition of skill sets by one individual is amplified by the passage of that information to their peers and colleagues. It is in this augmentation that the value of research centers and labs becomes most salient. Labs and centers, or even garages, become spaces in which shared learning through shared practice can occur. Thus material nature of bodies and the realms of *techne* and embodied knowledge are not so much constraints to the development of eco-technologies and ecological engineering, as they are important opportunities. Generating or maintaining the ability of individuals to learn from one and other, to work on systems, to tinker, try and fail together, is what will engender practical knowledge in individuals as to how to go about actually doing ecological engineering or ecological design.

<u>Things</u>

Living

Late one day at the ORW, I was walking down the hall toward the mudroom.[283] As I walked past the first lab, it was dark and initially I thought it was unoccupied, but then through the gloom I caught a glimpse of motion. Stepping into the doorway, I could make out a white lab coat moving about the room. Stepping further into the blackened space and moving cautiously forward, I got close enough to see that the motive force behind the labcoat was Sandy. My enquiry into why she was working in the dark elicited a long technical answer, which in short can be boiled down to it was necessary and it was easier. It was necessary to keep her water samples in the dark so that the algae in the water column would not continue to photosynthesize. This is why we had had the cooler out in the wetland while we collected – to keep the samples in the dark, not in the cold. As to it being easier to work in the dark, Sandy directed me to a large apparatus in the corner. This she explained could be used to work with her samples – keeping them in the dark while she stands outside in the light. But working within that system was difficult, and

[283] And yes, I did spend a lot of time walking up and down the hallway.

one often ended up with a lot of light leakage anyway. In the end it was easier just to work in the darkened lab to filter her samples. I left Sandy as she was fiddling with a vacuum pump and groped my way to the door.

To say that scientists have to engage in sometimes strange, or tedious, or laborious processes to collect the data they require is not a striking claim. Nor is it all that profound to point out the vast array of technological do-dads, from the highly complex and patented spectral analyzer, to the metal grasper thingy, down to a pencil nub, that are required to do science. But thinking back on that episode of Sandy working in the dark lab, I find it a striking example of the problematics that beset the development of designing with ecosystems.

Sandy was working with her samples in the dark because her samples were a living organism. As a sentient animal, perhaps at times it is easy to forget the 'livingness' of the other Kingdoms of life, but when one really stops to contemplate it, the algae that Sandy was filtering out of the water was *alive*. It has (had) its own agenda, though perhaps not as complex as Sandy's, but given the opportunity (i.e. an energy source in the form of light) it was going to get on with its own business of photosynthesizing, even if that was not in the best interests of the science project it had been enlisted into. At the heart, this is both the possibility and the problem with designing with ecosystems. The possibility of utilizing the self-designing capacities of organisms, to provide a space wherein processes of selection and adaptation occur, is an amazing concept in utilizing the motive forces of life to generate solutions to the various problems that have been generated by human- environment interaction. At one end of the design with ecosystems spectrum you have the interconnected 'cell' ideas of the solar aquatics and living machines, each seeded with a variety of life forms that are then allowed to self design into ecosystems that feed on and grow based on whatever input of waste is put into the system. At the other scale of designing with ecosystems are ideas of landscape level reforms wherein through hydraulic modifications of old dams and dykes one can let riparian and wetland areas reemerge, providing increased flood control for humans and habitat for many species at the same time. In each of these cases the biological components of the ecosystems are enrolled in the process, but rather than directly manipulating the biological components the 'control' that is exerted is through the manipulation of the forcing functions (wind, sunlight, temperature) and gradients. Thus utilizing the complexity of ecosystemic self-design to create novel situations that can manage or ameliorate the problem at hand

But it is the very complexity of ecosystems that means there are many aspects of their form and function that are still black boxes to science. It is in these unknowns that the constraints to ecological engineering practice really raise their head, especially when coupled with the institutional constraints of a professional engineering practice. An engineering design must be stamped by a professional engineer (P.E.), and with this stamp, the P.E is thus saying this 'technology will do what it is designed to do.' Thus the push in engineering is toward control and redundancy in design to be able to provide the certainty necessary to an engineering design. But the conceptual openness of an ecologically engineered technology, in its fundamental precept that a design could be let loose to self-design, is radically challenging to these core precepts of control in engineering. And though science provides guidelines to what can happen under changing energy regimes, or changing flows of water or temperature, it does not (yet?) have the ability to predict all of the ecosystemic outcomes of such fluctuations. This is especially true if the ecological engineer has followed the idea posited by H.T. Odum of mixing and matching, of drawing from the diverse palate of life around the planet, for species to place into a design. For example, in the start up of the iterations of enclosed tank based water treatment systems developed by John Todd the microbial and benthic communities were to be introduced to the system by collecting materials or waters from surrounding areas or from places that had experienced similar problems. If treating pollution, try to find bacteria that are living in the zone polluted and throw them into each of the tanks. By starting with a diversity of life forms, the ones that can grow in the face of that pollution, that can utilize the pollution, will develop and over time emergent ecosystemic properties will develop. It is the abilities of *life* itself that becomes the motive force behind these systems.

But there in lies a problem for the deployment of these technologies and the subsequent development of the field. Life is idiosyncratic. Life is messy. And life can be especially problematic if one wants to draw from all over the world and if one wants to allow self-design. The possibilities of self-design are so strong that an extreme precautionary principle is needed before some of the more radical tinkering and species palate mixing should occur.[284] As mentioned in Chapter 5, self-design is a powerful idea, but when self-design includes pipe breaking tree roots or dyke destroying nutria, self-design is less tenable as a design basis. Similarly, the precept of self-design relies upon the notion that time is not a constraining factor. Systems can be seeded with life and then allowed to sort themselves out (this is an especially prevalent idea in the writing of John

[284] This is where the enclosures on Solar Aquatics and Living Machines have an advantage. Separated from the outdoor environs there can be a bit more safety of introducing non regional bioforms into the systems.

Todd on the general concept of living machines). But the time element that self-designing systems need to generate a treatment function is problematic in the world of regulated pollution management. Systems designed to treat sewage need to treat sewage *now,* not in a half a years time. This was in fact a problem with a number of the early Solar Aquatics systems in that they took many months to begin operating at a steady state (EPA 1996; EPA 1997; Peterson and Teal 1996; Teal and Peterson 1993; Todd, et al. 2003; Todd and Josephson 1996). This long duration of start up actually caused one system to be decommissioned just as it was becoming functional. A detailed history of the attempted adoption of a Solar Aquatic system by the township of Ashfield in the mid 1990s was written up by Jennifer Fraulo and posted on a website.[285] In short the systems vagrancies in the beginning months, coupled with over budget costs had dis-enamored some in the community with the system. The town commission began seeking additional funds from the state to help pay for the overbudget and problematic system. Just as the additional funding was being authorized by the state, the Solar Aquatics achieved a steady operational rate and was producing effluent to treatment standards. However, the extra state funding was tied to the existence of a failed system that needed an overhaul. In the outcomes of the pursuit of this funding the fact that the system was now working was marginalized in the discussions, and subsequently the SAS was decommissioned and the facility converted to a standard activated sludge system. The overall history of this development is strewn with common problems, such as miscommunications between design firms and the construction firm, engineering conservatism leading to extreme over design and thus significantly higher costs, and inadequate costing, such that the need to pay an operator's salary was not considered in the cost of the facility in the budgeting

[285] No date of writing given. http://www.thoughtsnmemories.net/solaraquatics.htm

process. But adding to all this was also the idiosyncratic nature of the biological system itself. Not only did the operator have to tinker with some of the material construction problems, but also there was just a period of time needed while the biology of the systems began to function correctly.

The long term processes of self design do not make ecologically designed systems amenable to every situation. Or if ecologically designed, the human actors will have to have a more active role in establishing the initial communities, and perhaps in managing those communities over time too. An example of this was the case of a constructed wetland that was built in Florida to polish water to a tertiary level. One of the touted ancillary benefits of constructed wetlands is their ability to become habitat for wildlife. However at this wetland, so many geese began to feed and live there, that the effluent quality of the wetland decreased and actually began to fail to meet treatment standards. An operator had to scatter the birds with shotgun blasts to keep them from utilizing the wetland. Self-design indeed.

Technical

It is the living nature of designed ecosystems that is often the hawker for these systems – 'nature, nature, come and see the nature. Step right up and be amazed by the power of biology.' Well, to be fair, none of the systems I visited ever *said* anything like that, nor did their human caretakers. But this caricature does represent the way in which the literature highlights the natural and biological, and elides how vastly technical and complex these systems can be. This is especially true for the enclosed tank based systems like the SAS and early Living Machines, but even passive wetlands are also an amalgam of biological things, pipes, grinders, pumps and even gravel that can itself have been made in a factory.[286] The living components were definitely a driver for some of the enthusiasm generated by living machines. But coupled with the biophilia generated by the aesthetics of the system, was a tendency to speak and write as if the systems were simple, or simpler than conventional wastewater systems.

> Designed ecosystems are typified by human-made environments consisting of constructed wetlands, soil filters, and various combinations of these. These are relatively low-tech systems which mimic natural environments to treat wastewater from both households and industries. Designed ecosystems can remove a wide range of potential pollutants with processes similar or identical to mechanically sophisticated systems, but using simpler components. Because they are based on soil and plants rather than concrete and metal, they can potentially treat wastewater with low costs and low maintenance.[287]

> And I'd say that people are attracted to living machines because it sounds like an easy solution. Oh wow, they've figured it out, these ecological systems take care of all of our wastes and all we need is more of them. And it's an easy way to say, 'problem solved' in people's minds. (interview)

But the materiality of these systems is actually also very technical. And the fact that these *are* very technical, and require a fair amount of design work and planning work is obscured by the overarching media representations of them being 'simple' because they are using nature.

In the greenhouse-based systems this tendency was perhaps particularly problematic. Like in the Ashfield case where the community thought they were getting a simple natural solution to their wastewater needs, the subsequent technical problems perhaps seemed all the more surprising. Many of the early systems did go through periods wherein the operators needed to modify aspects of the systems. But these limitations are not necessarily outcomes of these having been systems based in ecosystems, but from these systems being new, and therefore still needing to have kinks in the design worked out. Problems with technical components, like failing plant racks, or

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[286] I just find the concept of technical gravel fascinating. Because many design parameters can rely upon porosity of the fill, and even through natural gravel is graded into size classes, there is still variation in types and dust. One engineer told me about all this and showed me the special designer gravel, i.e. gravel made out of a composite material, which had lower variability and dust. It still just amuses me to think about – some where there is an industry that makes bits of imitation gravel.
[287] Waterrecycling.com, downloaded Jan 2001

delaminated greenhouse glass highlights the way in which these systems, like all human constructions have the potential for design failures. In many of the early tank based greenhouse enclosed systems, operators made on the spot adjustments to improve operations. In many installations inlet pipes were changed, clean out taps were place in drain lines and the lines in between tanks, and aeration rates were changed (interviews and articles).[288]

As mentioned above, operator embodied knowledge can become an important component in dealing with the idiosyncratic nature of designed ecosystems. In the solar aquatics and living machines operational experiences would lead to a number of process redesigns. The materiality of the technical components of the systems is very salient to their functioning. However when coupled to claims about the function of the biological components conflicting materialites can occur. For example, in the early SAS and living machines, the theory of the ecosystemic function was that with the complexity of the ecosystems and multiple trophic levels, much lower sludge volumes than conventional treatment would be created and sludge accumulation would not be of sufficient volume to warrant a clarifier. However, the early systems did accumulate sludge, but due to a lack of a clarifier the sludge settled in the outer ring of the EFB from whence it had to be

[288] This brings up the interesting tension between engineers and operators. Not all engineers actually construct or run the systems they design. Systems operators sometimes have sets of knowledge about the performance of a design that the engineers lack. To an engineer a valve placement may make sense from a process function standpoint, but to an operator it can be in such a place to make its use problematic or uncomfortable. As one engineer / operator put it "I got very, very interested in waste water treatment, biological waste water treatment. It was fascinating to me that having been an engineer and abandoned that career path and being fully steeped in that blue collar wastewater operator world -- and I saw a lot of things that were just bad design that -- things that were hard to get at or the operators couldn't do efficiently or issues with the plant and it gave me a very keen appreciation for good design, in equating good design with good operations instead of the attitude that a lot of engineers have 'Well, hey, we design it -- the operator, that's his job. I'm not going to do any extra work on my part of the project to make things better for him.' (This individual had started engineering school, then left it due to financial reasons, then worked as a wastewater operator, then went back to school and got their B.S & Masters in Civil and Environmental Engineering, respectively)

manually wasted.[289] Similar interactions of technical design and biological action came from the copious plant growth. In many of the early systems, the shear volume and weight of the plants destroyed the racks through which they were growing. And with these massive amounts of root growth, and subsequent sloughing off of materials coupled with the original stand pipe design, some early systems had problems from masses of biological material moving into the lines and causing clogging (hence the need for the clean out tap retrofits). From these early systems, design modifications were made to the treatment process in that clarifiers were added into later designs. Similarly, the effectiveness of the early systems in treating the waste meant that by the time the water was reaching the final treatment tank there wasn't sufficient carbon for denitrification processes. Addition of methanol became a common process retrofit.[290] Later systems were designed with a wasting cycle from the clarifier back into the process change, thus increasing denitrification rates without the need of methanol additions.

Conclusion

For designing with ecosystems to be more than just a cool idea, the material realities of the processes have to be tackled. Materiality doesn't act as a constraint in ways that parallel the social realms of institutions, regulations and capital, but is more of an all-pervading base out of which action and applications occur. Within the realm of materiality of space, designing with ecosystems encounters both mundane and unique problematics. Mundane, because all research and innovation must take place somewhere, and the need to procure office, lab, or demonstration spaces is not unique to this

[289] 'Wasting' is the technical term for removal from the process chain. Reported to me by both an operator, and an engineer.

[290] This is not problematic in itself, but it is an expense and it does fly in the face of the rhetoric that the systems don't need additions of chemicals.

innovation realm. However, the scale issues of doing research with ecological systems can add unique temporal and spatial scale constraints that other realms of innovation may not have to deal with. If investigating the long-term self-organization of ecosystems, these research zones need to be funded for long stretches of time. Thus the capital – wherein requests for maintenance and continuation funds can be institutionally more challenging to procure – affects the abilities to establish research parks for ecosystems that are land extensive. The establishment of these material spaces for experimentation are constitutive of the second way in which materiality is important in the innovation of designed ecosystems. The need for tactile, hands-on experiences as incubators of learning and innovation is an important way in which the notion of materiality needs to be considered in the innovation of ecotechnologies. Just as the early development of mechanical engineering was first incubated through apprentice-based learning and then through the instantiation of machine shops in academic situations, so too does the development of an ecosystem design practice or ecological engineering discipline need these spaces of practice wherein individuals learn through the act of physical interaction and manipulation. Similarly, the need of such spaces for tactile learning is important not just for individual learning experiences, but rather these spaces become zones of interaction and exchange between people, and as such are incubators of communities of practice and subsequent knowledge flows. And finally, materiality needs to be considered as a constraint in the development of designed ecosystems in the fact that these are not merely ideas or social constructs, but are rather real and extant things. *Discursive claims* about the way ecosystems function, or about the operational parameters of ecological technologies, are meaningful only if the actual material instantiations of those systems function as claimed. Thus the very base of the concept of 'designing with ecosystems' becomes both the source of inspiration for innovation as well as potential sticking point for success. Working with living things means that one has to support the life functions of those living things, and working with multiple trophic levels of living things, and in particular attempting to let those living things "do their stuff" means that ecosystem-based designs are open to surprises and idiosyncratic outcomes. These outcomes can be partially controlled for through design features and the interaction of the life components with the technical material components of designed ecosystems. Thus dealing with the materiality of biological things in regards to innovative ecosystem design means also dealing with real, extant technical things that need to function. Materials need to be durable under caustic conditions: pumps need to produce enough airflow, fill materials need to be stable and not abrade, pipes need to be unclogable, and support structures need to hold up. The continued functioning of mundane materials in ecotechnology design can become an important element in judgments of the overall viability of the ecosystem design concept. As such, the materiality of both living and technical objects in ecosystems designs need to be considered as constraints in manners similar to the investigation of social structural constraints arising from institutions, regulations and capital.

CHAPTER 10

ECOLOGICAL MODERNIZATION AND COMPLEMENTARIZATION-ENTHUSIASM AND THE PRODUCTION OF SCIENCE MOVEMENTS

Introduction

In examining a processes of ecological modernization this research investigated a particular processual idea, designing with ecosystems, and adopted a meso-level for investigating the sociotechnological processes. This meso-level of analysis involved multi-sited ethnography which followed a diffuse array of actors through the spaces of their production of alternative technologies and new disciplines related to the idea of using ecosystems as a core element of design. Having described two different (but entwined) realms of designing with ecosystems in Chapters 4 and Chapter 5, and having laid out the range of constraints from social structures and materiality that influence the developments of these realms in Chapters 6-9 the question remains: What *are* the processes and means by which the ideas and technologies of designing with ecosystems are becoming incorporated into mainstream practice? Answering this question for the development and adoption of designing with ecosystems aid in building an understanding of how under ecological modernization science and technology will develop new "sociotechnological approaches that incorporate environmental considerations from the design stage." And similarly, the analysis of designing with ecosystems as a technical and disciplinary practice that respectively have roots in the 70s environmental movement and strong social change values allows for a critical engagement with the ideas of complementarization and science movements.

In the first section below the living machines/Living Machines™ case will be used to discuss the interacting constraints that can lead to the need for complementarization of a proposed alternative. Similarly, the empirical details of the Living Machine story also suggest that rather than seeing incorporation as capture of a radical idea, and subsequent design changes as capitulation, one needs to look at the ways in which realms of alternatives and conventional technologies can co-create each other from their very inception. And finally, this case also highlights the way in which complementarization of the technical function need not be at a loss of larger social or environmental values, but rather might actually be constructive of an increase in those environmental values.

In the second section below, the case of ecological engineering as an emerging discipline and a commercial practice also challenges a singular narrative of alternatives moving from the outside to the inside of mainstream practice. The development of ecological engineering speaks not so much to the capture of the environmental movement by academia, but more to the existence of those environmental sensibilities inside 'the mainstream' from the start. Herein this case points to the importance of quiet science movements as motive forces in the ecological modernization of science and technology.

The outcomes of both these cases point to the answer of the question of the processes by which ecological sensibilities get instantiated in science and technology practice. The development of ecological engineering inside of academia occurred as a process of internal upwelling inside of mainstream institutional spaces through an expansion of knowledge and practice to fill interstitial niches of undone science. Thus both this case, as well as the entrepreneurial activity of living machines, requires attention be focused on the role of committed and driven individuals in the inspiration and development of ecologically designed technologies and fields as will be discussed in section three below.

<u>Living Machines: Rethinking Complementarization</u>

The case of the history of the transformation of living machines – from a generalized alternative approach to the singular patented technology Living Machines® – seems at first glance to follow a complementarization path as laid out by Hess. The living machine concept and technological applications were generated by Dr. John Todd, a widely acknowledged visionary and entrepreneurial leader in the environmental movement. The concept of living machines followed from a line of similar technologies and innovations all of which had explicit normative goals in regards the adjustment of the relationship of human society to its resource base. The vision of changing human cultural practices was manifested in technologies that incorporated rich ecosystem based technologies as the functional elements, but also stressed the importance of the aesthetics and subsequent biophila as a base goal of the technologies. Thus, not only did the technologies *materially* link ecosystems with human culture, they were also intended to generate ideological values about those linkages. In speaking of the potentials of ecological design and ecological technologies in general, Dr. Todd stated

> The important point for me is that these are beautiful, amazing stories. Just think of it! If we could decode the instructions from nature and learn how to use shape, light, architecture and nutrients as brilliantly as a coral reef does, sitting there in the midst of storm-ravaged waters in a sea that's almost devoid of nutrients, creating all that beauty, if we could decode that information and design with that information, we'd be tapping into a three-plus-billion-year legacy of design, and we could change how we live in the world. We could heal it, and I'm passionate about that story, and I believe it. (pers. comm.)

As an alternative technology linked to a social change perspective, the living machines concept quite clearly falls within the provenance of Hess conceptualization of technology-and-product oriented movements. The material technology of living machines was important, but so was the possibility they represented. They were designed as embodiments of a set of values.

However, as the living machine concept was implemented, infusions of money were needed to build the business and under these conditions John Todd lost control of the company that had been created to implement living machines designs. Under the new management, the company underwent restructuring and the living machines concept became more completely Living Machines® through legal action that designated Living Machines® a brand entity. Under this new management, design modifications were done that seemed to fundamentally change the Living Machines.® No longer were they the tank-based systems that supported verdant tropical growth in greenhouses, but now they functioned as high-rate subsurface flow wetlands that were not necessarily housed in greenhouses. And just as Hess's cycles of complementarization suggests, these design changes were outcomes were influenced by he role of capital. A designer working on the formulation of the new Living Machines® described the goal of the design change:

> So now we're trying to design systems that are easier and cheaper to integrate into projects that are site based projects or even building based projects. And still maintain the aesthetics and still maintain that feeling - maintaining the sort of intangibles we developed with our earlier technologies, but now make them make sense from an economic perspective and from a site planning perspective. (pers. comm.)

Subsequently, as the new company moved forward with the complementarized Living Machines® the alternatives movement went through a process of reinvention. Though John Todd can no longer advocate for living machines, his visions for designing with ecosystems continues as an alternative movement through his work on his general advocacy for ecological design and through his current round of inventions of Restorers®, which are designed ecosystems that clean up pollution while floating on the top of standing waterbodies, and through Eco-Machines®[291], the new generalized term that has taken the place of living machine.

However, though capital considerations did play a role in this evolution of living machines to Living Machines® this is not the only factor that came to bear upon the early living machines technologies. Let us first consider their status as 'alternatives.' Taken as a whole technological and ideological complex, the living machines did represent an alternative to mainstream technological practices in regards to wastewater. The goal of developing an attractive amenity has not been a major design assumption of standard large wastewater systems (nor even for small scale systems). In fact, the systems most similar in treatment capacity scale to the extant Living Machines® would be a package plant, a system that is notorious for its unattractiveness. To place such a high value on creating a system that would inspire people to think about the role of natural systems as intrinsically important to human culture and intrinsically linked to our survival makes the living machines concept indeed a radical alternative. However, accepting as a given that human wastes would be transmitted to the system in a water matrix was in fact starting from a very mainstream and conventional assumption. Though the living machines as a generalized concept could be utilized to do many different functions, the early demonstrations of the concept focused on processing of wastes; subsequently in the early attempts to popularize and commercialize the technology the focus was on wastes in water, whether industrial process wastes or city and town wastes.

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[291] Though the term has been trademarked, it is not used to designate a specific invention as much as the whole oeuvre of designed ecosystems that John Todd has been involved in.

In places where the living machine was to replace existing infrastructure, it makes logical sense that the underlying waste carriage infrastructure was not challenged. But in other spaces, Living Machines® were adopted into site designs that were being planned from the ground up. In these cases, the water-based treatment emphasis of living machines actually represents a capitulation to mainstream values and technologies, perhaps even more than it represents a radical alternative approach. In discussing living machines with a volunteer at a Living Machine® installation, the operator pointed out this is a "neat system" but then stated "I don't think we should be putting our wastes in water in the first place." Similarly, while observing a meeting between an engineer and two individuals from a small liberal arts college that was pursuing green design options for their new residential development, the Living Machine® was discussed as an option that had come up in the student lead technology investigations. The engineer, after pointing out some of the added difficulties that come with having a learning lab based on black water rather than greywater, further suggested that energetically it made most sense to use dry composting toilets rather than perpetuating "the conventional water based carriage of wastes." But then they noted that this requires more change at the personal level from the bathroom user.[292] As the engineer said this, the other two nodded and agreed that "expecting compliance in the residential building with such an alternative [as a composting toilet] would be much harder." Technologies such as composting can ask for individual users to change their behaviors in relation to waste production, whereas Living Machines® leave personal behaviors less challenged and instead focus on

[292] Instillations of Living Machines® do also require some behavior modifications on the part of uses, such as avoiding dumping heavy chemical loads down drains or flushing inappropriate objects. But these are actually behaviors that are true for all wastewater systems, but having the Living Machines® close by makes the outcomes of these behaviors more salient.

changing the waste treatment process. So though living machines were in some ways radical alternative wastewater treatment options, they start from the assumption that wastes will be conveyed in water and as such they are not propagating more radical ideas of how to manage wastes through non-water borne systems. As one ecological designer put it "We are addicted to flushing," and the existence of Living Machines® as a perceived green alternative lessens the push for the more culturally challenging technologies as composting toilets or even urine separating devices.

The mixed nature of Living Machines® as both alternative or not alternative, depending upon perspective, is aptly stated in the EPA review of the technologies published in 1996.

> Dr. Todd promotes his "Advanced Ecologically Engineered Systems (AEES) or "Living Machines" as a new, low cost, solar powered, no chemical use alternative wastewater treatment technology capable of being constructed in modules as additional capacity is needed. These systems incorporate many of the same basic processes (e.g., sedimentation, filtration, clarification, adsorption, nitrification, denitrification, volatilization, anaerobic and aerobic decomposition) utilized in more conventional advanced biological treatment systems. Dr. Todd is trying to simulate these processes as they occur in natural biological ecosystems (such as lakes, rivers and wetlands). He is attempting to encourage them to operate at optimal rates under controlled conditions. Still, his ecologically engineered systems incorporate variations of well established treatment technologies such as anaerobic bioreactors, complete mix aerated tanks, aerobic fluidized bed reactors, clarifiers, high rate constructed wetlands, and plant-covered ponds. However, Dr. Todd approaches the design and operation of his facilities from an ecological systems point-of-view and attempts to incorporate objectives well beyond just achieving the desired wastewater treatment goals into his projects. For example, Todd emphasizes the importance of snails, freshwater clams and other invertebrates in his "ecological fluid beds," as well as utilizing a variety of aquatic and wetland plants throughout his systems. He also stresses the value of his systems as a potential opportunity to produce fish as well as aquatic and wetland horticultural plants to be marketed locally, and for educating the public about the importance of natural biological systems in purifying and recycling wastewater (EPA 1996, p. v-vi).

The overarching goals of the systems are unique; the concept of an aesthetic wastewater treatment system was a unique contribution to wastewater management and made for powerfully compelling technology.[293] But as this EPA passage points out, the unit

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[293] This aesthetic draw is also acknowledged as a major driver in the adoption of wetland treatment systems, which may become a more important deciding factor in choice for adoption than mere functionality of those wetlands. (EPA, U.S. 2000, p.7)

processes employed in the technical treatment chain are in many ways identical to processes in conventional wastewater treatment, whether at large or small scale, and even employ some of the same technologies to achieve these process goals. Conventional treatment has long replied upon biological processes as the core basis of meeting secondary treatment standards though albeit this biological treatment focuses on the use of only one or two bacteria species in the process (See Appendix A for overview of conventional treatment processes). But even beyond the low diversity application of biology in activated sludge plants or trickling filters, the 'conventional' toolkit has been expanding over the years with the adoption of number of biological treatment processes. It is in these preexisting overlaps of material process that makes problems for a simple notion of complementarization, as the technology was already utilizing base processes of the system that were already very mainstream.

Similarly, just as the notion of Living Machines® as an *alternative* can be problematized by its actual perpetuation of a water-based mentality about wastes handling, so too can the notion that Living Machines® became complementarized under capital constraints be problematized. It is here that the ideas of embodied knowledge and the existence of material constraints have relevance in a discussion of the processes of change in Living Machines® technologies. When the company Living Technologies was acquired by investor Tom Worrell, a number of a LTI personnel transferred to work with the new company, thus taking with them a set of experiences with the design and construction of Living Machines®. The embodied knowledge represented by these individuals informed the new round of research and design. As mentioned in the quote from the ecological designer above, the goal in the redesign was to make the technologies easier to deploy and to make "them make sense from an economic perspective." Making sense in an economic context referred to concerns about the material nature of the treatment process and the added costs of the ancillary benefits. The original Living Machines® relied on the aerobic tanks for much of their treatment processes. These tanks, though capped by the living plants, were deemed by the technicians and multiple researchers to be functioning primarily as activated sludge systems (EPA 1997; Norström 2005). The verdant growth on top was independently referred to by several individuals as a "green beanie." Or, as one engineer put it, "A very expensive green beanie." The individuals who moved with the technology to the new company worked to redesign the Living Machines® to require lower energy, to take less materials and to be more operationally stable. As such, the decision was made to move in the direction of wetlands-based systems and away from the "energy hogs" of aerobic activated sludge. Similarly, the company worked to remove the necessity of the greenhouse enclosure to decrease overall materials used and thus costs of the systems. But though removing some of the iconic visual elements of the Living Machines®, the company still feels it is offering a service that reconnects people and the environment and that can be an educational tool both figuratively and literally. Though the material system has changed, elements of the intended value base still remain. In discussing the new wetland based Living Machines®, the company senior vice president stated, in the past "We've used technology (traditional waste treatment plants) to replace nature, but now we can use technology to recreate nature, and bring that back to balance" (McNair 2009). The owner of the company states about the technology "It's based on how the earth works and when it comes to a solution for fixing our water problems, I put my money on the earth" (McNair 2009).

All of this is not to claim that capital constraints did not influence the trajectory of living machines and the subsequent legal wrangling over the brand. However the fact that many individuals who had had their hands in and on various manifestations of the Living Machine® technologies point out the material limitations to their operation, emphasizes the importance of paying close attention to these material claims, as well as analyzing the discourse around the technology–and product–oriented movement. Originally, the radically alternative nature of living machines was in the potential for enthusiasm and hope generated by the ideas of ecological design as depicted by these lush systems. The other ideological values of pursuing lower energy use, recycling and reusing water, and creating aesthetically pleasing environs have persisted into the new iterations of the technology. Complementarization of living machines did occur, but it occurred steadily all along the chain of its existence, from the initial choice to support water based systems of waste management to its fundamental similarity to existing wastewater treatment systems, not just at the point of capitalization.

Ecological Engineering - Ecological Modernization as Internal Development

The concepts of designing with ecosystems continue to have visibility in the environmental movement. The work of New Alchemy and Ocean Arks can be seen as exemplars of Hess' notions of the technology- and product-oriented movements. As such, some elements of the changes that these institutions underwent, and the outcomes of some of their technological innovations, do seem to support Hess' complementarization. But as pointed out above with the more detailed empirical analysis of the living machines case, the simple dichotomous line between outsider technology movement and insider mainstream is not always an easy, clear and distinct boundary. Without a clear boundary, the notion of being complementarized becomes less tenable as an explanatory tool for understanding how new technologies and practices become incorporated into mainstream practice. A case in point to this difficulty is the development of ecological engineering as a discipline and a practice.

If one is interested in the development of ecological engineering as a disciplinary practice, with all the attendant standardizations of the field through professional societies, formal curricula and licensed practitioners, then ecological engineering is a very young and perhaps even non-existent discipline. But if one is interested in ecological engineering as a set of emerging concepts and practices based on 'designing with ecosystems,' then it is a vast and dynamic amalgam of practical activity and inspirational thought that is arising endogenously inside of mainstream institutions.

Of course, the very concept of mainstream is not with out its difficulties, largely because it is over-simplified and not empirically supported. In examining ecological modernization theory's general treatment of technological change, and Hess's particular treatment, one sees that both create dichotomies that are based upon reified categories that sharply distinguish a mainstream from a non-mainstream (Hess) or an old mainstream from the new "ecologicalized" mainstream (ecological modernization). This dissertation, for the sake of discussion follows suit and use the concept of 'mainstream', while simultaneously problematizing it. Universities – and all of their attendant norms of practice, internal laws, departments, colleges, and physical structures – are entities of mainstream culture. How then do new ideas and practices come to exist in these institutions? To be sure, these institutions are capable of incorporating, and complementarizing alternative technology movements, as some might argue the development of a strawbale construction demonstration and testing lab in an engineering department demonstrates, but not all inclusion of alternative ideas can be categorically assumed to be outsider to insider moves of a concept or technology.

Ecological engineering is a case in point. H.T. Odum initially posited the idea in the early 60's, and then included a strong definition of the practice in his *Environment, Power, and Society* (Odum 1971). This text was a seminal publication in a number of ways. Laying out a method of understanding and mapping flows of energy through systems in itself was a significant development. However, not only were "natural" ecosystems amenable to these energy flow analysis, but so is human society, in as much as it is embedded within ecosystems. Odum's analyses showed how modern industrial societies are based on an unsustainable through flow of energy, funded by tapping solar reserves in the form of gas, coal, and oil. Odum posited the need for societies to plan for futures that would have different energy budgets and advocated the planning in advance for such changing conditions.

> Certainly it is an important contingency to consider the possible future of civilization if and as the energy budgets recede back toward the level of energy available from solar income….. The challenge to any national task force assigned the responsibility consists of preparing for the contingency of declining power to develop such a transition plan for man. That pattern need not be sudden collapse, although precedent exists for both adjustment and catastrophe (Odum 1971, p.307-308).

One element in this planning was the necessity of citizens understanding and thinking in terms of systems. As such, Odum was an advocate of general education in systems thought, for everyone from grade schoolers to religious leaders. Another element of planning for changing energy futures was in the development of the science and practice of ecological engineering.

> A bright possibility is ecological engineering. Adequate knowledge about the natural solar-energy-based system may allow a small concentrated loopback of energy to guide the systems of fields, forests, and seas to stabilize and produce for man. Although there is yet excess energy, it might be better to put crash efforts into ecological engineering rather than into space. A knowledge of natural system control will be of vastly greater survival value to man than a memory of space exploration (Odum 1971, p. 309).

This "partnership with nature" (*ibid,* p. 275) was premised on the self-designing capacities of ecosystems. Ecosystems could be guided to emerge that would have benefits to humans through production of environmental services. Rather than using technologies that require high energy inputs to achieve human needs, the potential of ecological engineering was to develop self-sustaining ecosystems that would function off of solar energy flows while at the same time providing services like food production or pollution mitigation.

Though Odum is credited with positing ecological engineering as a possible aid in solving the problem of declining energy futures, he himself did not publish much directly on the idea. Rather, his role as father of ecological engineering was in establishing the first cadre of inspired scientists who themselves would over time catalyze the emergence of the field. Speaking of the atmosphere at Odum's Center for Wetlands at the University of Florida one ex-Odum graduate student, who went on to a leader in ecological engineering, stated "It was a heady time, a heady experience."

Of importance is that Odum's writings were a source of inspiration to many, both *inside* and *outside* of academia. For example, Odum's writings influenced counter-culture movements like the environmental movement and back-to-the-land group at the New Alchemy Institute (as discussed in Chapter 5). The audacity of Odum's idea was in the assertion that humans could and should be proactive in the creation of new ecosystem forms. Acknowledging that we were already doing so intentionally in relation to agricultural production systems, and unintentionally through waste and pollution, he advocated a more purposeful plan to design with nature. By creating environs and then seeding them with organisms taken from all of the world, new ecosystem forms could be created that would provide services to human societies. It was a radical idea.

> I mean, here was this man who was outrageous. He pissed off the whole conservation movement! They wouldn't even read him anymore, because he said "The world is a vast bin of living parts available to the ecological engineer." Oh, did that get conservationists off their butts and shouting and screaming (pers. comm.)

But for all of this radicalness, Odum was also very much a part of the 'mainstream' scientific practice. Through he did alienate parts of the academic community by advocating new ideas, he was still thoroughly grounded in the academic processes and institutions, as were many of his students. Though you can find Odum-inspired students applying 'designing with nature' in more radical ventures, including the enclosed ecosystem project of Bioshpere 2, many individuals inspired by Odum remained in academia, working in a wide array of departments and fields. Out of this thoroughly academic home, a long and slow incubation of the various ecosystem ideas and ecological engineering precepts followed as Odum's students dispersed and pursued their own careers. Years later, it was Odum's students who took, and continue to take, strong leads in developing ecological engineering inside of academia.

Beyond Odum, other trends in academia also fed into the development of the early ecological engineering initiatives in the U.S. Odum wasn't the only ecologist investigating the ecosystem properties of wetlands or coastal regions and similar interest in natural treatment was growing amongst environmental engineers (Kangas 2004, and

Mitsch and Jørgensen 2004). This slow foment of ideas about wetlands and the possibilities of these natural systems to treat wastes developed into a more concerted research effort in constructed wetlands for treating wastewater.

The point of this brief history is that the idea of 'designing with ecosystems' has been embedded within mainstream institutions all along. Though it may have been a minor and perhaps initially subaltern practice, this just highlights that insider/outsider dichotomies are not empirically observable in this case of ecological modernization. An idea generated inside of the institution persisted inside, and has slowly grown despite the numerous structural constraints arrayed against it (as discussed in Chapters 6 – 9). If a metaphorical description that invokes movement is going to be used to describe the growth of "preventive sociotechnological that incorporate environmental considerations from the design stage onward" (Mol 2003 p.311-312), then it should be the metaphor of a wedge prying open a log, or perhaps that image of tree roots breaking up concrete rather than the construction of " the centripetal movement of ecological interests (Mol 2003 p.310) that implies that ecological modernization is the outcome of externally generated ideas moving into mainstream practice (in similarity to Hess's (2007) "incorporation and complementarization", or Jamison's (2006) "appropriations"). The mainstream that is characterized as monolithic and solid, is actually full of gaps, unused space, or what Hess would call "undone science." The growth of ecological engineering occurred under many names and in many places as individuals found means to nurture and develop the discipline's ideas and practices inside heterogeneous mainstream spaces.

Inspiration and Enthusiasm

In ecological modernization theory, the emphasis has been placed on the role of policy and institutional change in developing the new ecologically modern world. With Hess's model of complementarization the emphasis is also put on structures, whether the structures of social movements or of the "mainstream" which adopts and modifies the developed alternatives. What is left out of this overarching view is the role that committed and enthusiastic actors have in the development and adoption of new technologies. In the development of the idea of designing with ecosystems, there are some elements of complementarization,. But as discussed above, this notion of incorporation does not fully explain how ecologically modern ideas come to be instantiated in more mainstream institutions, nor can the claim that values and ideological aspects are lost be empirically supported.

In the course of this research, informants kept directing my attention to the physical spaces in which they worked, or had worked, on technological innovation. In my initial denseness, I had dismissed these experiences and had wanted to maintain the conversation in the realm of the *ideas* of designing with nature or to discussions of the various social structural constraints that they had faced in the pursuit of their interests. It was only in the work of analyzing my own field notes and interviews that the importance of these material spaces and the actions of individuals within them really became clear. Just as I had been frequently urged to give my attention to the material spaces, so too had people reiterated over and over again the important connecting theme that developing the *idea* of designing with ecosystems was intrinsically embedded within the *doing* of designing of ecosystems. Over and over again, the recurrent theme of "doing" things, of being involved in "problem solving" was what threaded through individuals' life histories of how they got involved in the ideas of designing ecosystems. For many, the fact that they were "good at math and science" had led them to consider engineering as a possible career path in general, and their own values and interests made ecological engineering attractive to them. For others, a preexisting interest in the environment and awareness of environmental problems underpinned their interests in pursuing ecological engineering.

> I liked the fact that it was centered around something that I could connect with. I connect with the environment. I connect with the mindset behind wanting to preserve or improve the environment and that was just – it just made sense to me and it just fit and it was – it was a really big relief to be like, "Okay. Well, I like this. I found this thing. It matches with my view of the world and how I think things should be, and it's something that I can go into and feel like I'm making a difference." And that was my big bag. With most of the other engineering tracks, I didn't feel that connection. So I'm sitting here and I have the math and the science skills to be an engineer and I just wasn't feeling like I could put them to good use.

Others were not at first interested in engineering because, as one graduate student put it

> I didn't really know what an engineer was, or did, so it was so much easier to pick a major that had the word environment in it, because I knew I wanted to be outside, knew I wanted to clean things up.

But this student continued by explaining that they had switched to an engineering program after their experiences in an environmental sciences class had left them with out a sense of how to *solve* the problems.

> And so it was a constant bombardment of what we are doing wrong – oil spills and pollution – and I just got so depressed. And really in the entire class of Environmental Science One, I never saw how we could do something. We never talked about solving a problem, we talked about identifying a problem we talked about studying the problem, but never passed the studying or data collection, the monitoring.

The desire to do something concrete, to be solutions-oriented in regard to environmental problems meant that for many, the moment when they learned about the possibility of a field like ecological engineering (or ecological design for some) it was a revelatory moment. A number of individuals reported discovering ecological engineering through exposure to some of the seminal texts, others from hearing talks by inspirational leaders in the fields. What is striking in these stories is the similar 'eureka moment' that they express as an outcome of hearing about this possible field.

> I always wanted to do something outside with nature, and I looked at environmental engineering, but it seemed like it was just environmental chemistry and pollution. It was very technical-oriented pollution control type stuff, and it just didn't really excite me that much.… This was still when I was still an undergraduate, and I was in the library one day, and I came across this book. It said Ecological Engineering: An Introduction to Ecological Engineering, and it was Mitsch and Jørgensen, that '89 book, and I thought, "Wow, ecological engineering." Of course, you just read the words, and I'm like, "Oh, my God! Is this real? This sounds perfect." So I just started reading, and I'm like, "**Oh, This Is It!"**

> And so I remember as an undergraduate reading Odum's book *Environment, Power, Society* and just really being blown away by that and wanting to do that kind of stuff.

> Actually, I heard John Todd speak. It was just one of his intro to what a living machine is and what living technologies are. That would have been in '99, my fall semester. I spent my whole second semester trying to figure out how I could become an ecological engineer. He used the term ecological engineering, and I wrote it really big in my to-do book, my planner "Become an ecological engineer." I was just so inspired by what he had to say, just describing living technologies, treating waste using plants and bacteria and I just thought it was the coolest thing ever and I immediately wanted to do it.

The importance of these narratives is they highlight how the enthusiasm generated by the idea and practice of ecological engineering is the enthusiasm of people who have normative values about the world they would like to see and would like to help create. The discovery of the potential of designing with ecosystems is the eureka moment of how to put those values into action. The inspirational role of innovator and visionary speaker Dr. John Todd, or the science and engineering leadership offered by the works and writings of ecological engineers like Dr. Odum and Dr. Mitsch, are powerful not because they generate the interest and desire to do something in the world, but because they offer a potential solution to people who *already* want to do something in the world. The discovery of the messy, heterogeneous space that is, or is becoming, ecological engineering – or is, and is becoming, various ecologically designed technologies – allows these individual to simultaneously engage their abstract, normative values, as well as engage with the materiality of the world in a concrete and systematic way.

Conclusion

The processes and means by which the ideas and technologies of designing with ecosystems are becoming incorporated into mainstream practice are the actions of individuals. These individuals' feelings motivate them to make a difference in the world, creating healthier and more socially just environments for humans, as well as improving conditions for myriad other species. They have been inspired by the potential of the joining of ecological systems with human technological ingenuity to develop new forms and processes "for the benefit of both." The actions of these individuals in carrying out the science, in developing the curricula, of implementing the practices despite the range of constraints that impede such actions are what really drives the upwelling of 'designing with ecosystems.' Changes in regulations may change price points, and make certain technologies more commercially viable, but these changed regulations neither generate nor motivate all of the individuals who will pursue the new opportunities for innovation. Macro-level social changes might impact large social structures like engineering professional societies, but again it is the interest of individuals that suggests the ways in which societies can shift to incorporate new practices. Government initiatives and funding structures might open up venues for new explorations of a topic, but the topic preexists the funding and is driven forward by the committed individuals, not generated fully formed out of the funding possibilities. All of these larger structural changes can aid in the development of the ideas and technologies of designing with ecosystems, but they are not the key explanatory cause for how these ideas have been generated and propagated. Rather it has been, and continues to be, the committed and sustained activity of individuals who, motivated by an array of personal beliefs, experiences and desires, want to *do* something in and for the world.

The early 20th century was characterized as a time of “technological enthusiasm” (Hughes 1989) wherein science and technology were valorized as the engine for the speedy development of more prosperous and satisfying lives. The slow disillusionment with the unintended consequences of this progress was itself the groundwork for the environmental movement. But even then, the appropriate technology movement held on to some optimism in the creative capacity of humans to design technologies in ways that were supportive of the earth’s functions. That optimism continues today, as people with the desire to *do something*, innovate, develop and adopt new science and technological practices that incorporate ecological concerns from the design stage outward. The case of the technologies and practices of designing with ecosystems shows how commitment and action on the level of individuals can find interstitial spaces for the furthering of these ecological science movements. And it is the ‘ecological enthusiasm’ of these individuals that keeps the practices and technologies moving forward despite the myriad constraints.

Next steps - engaging with the interstitial spaces in the social studies of science

Just as the advancement of science and technology that incorporates ecological concerns from the design stage onward is emerging out of a mélange of activities and is establishing itself through the occupation and enlargement of spaces of undone science inside of academia, so too should the social science study of these technological changes exploit its own little occupied interstitial spaces. Increasing calls in the social studies of science have pointed to the need to rethink the artificial distinction made between social movements and scientific actions that has left realms of activity understudied (Moore

2008). Similarly Hess (2007b) has called for anthropologist's of science and technology to move their work away from its focus on discourse and opposition towards a rapprochement with scholarship in social movement studies. For Hess this conjoining would aid in overcoming the resolutely "idiographic method of ethnographic particularism" but would simultaneously avoid "the over stated nomethetic universalizing theory" often found with macro-social change theories (Hess 2007b p.469).

This call of Hess's is particularly salient in light of congruent interests in expanding the realm of ecological modernization studies. The conclusion of the 2009 overview reader lays out a call for the future directions of this field which includes "further extending the geographical scope of ecological modernization studies; deepening our understanding of global flows, the institutions and social relations necessary for their governance, and related processes of reform; and strengthening knowledge about the cultural dimensions of ecological modernization " (Spaargaren et.al 2009 p.511-512). In discussing this third realm of expansion, the authors acknowledge first the tendency to break the social into separate economic, political and cultural spheres and then state "while the relationship with economic and political rationalities has already been discussed and explored in some depth by ecological modernisation scholars, the theoretical and practical or political anchoring of ecological rationalities in the socio-cultural sphere of civil society remains an especially huge task." (*Ibid* p.513). To address this undone science, the authors purpose the need to address the "lifeworlds and lifestyles of the citizen-consumers" to understand how ecological rationalities connect to everyday life.

However, I propose that this interest in exploring the cultural dimensions of ecological modernization needs to include not just an interest in the culture of consumers, or lay citizens, but needs also to incorporate the lessons from science and technology studies that science itself is a cultural practice. Similarly, drawing on this dissertations findings, I point out that the day to day actions of scientists and engineers are as much a driver of ecological modernization as an outcome. Thus the further rapprochement of the anthropology of science and technology with ecological modernization would add more nuanced understandings of some of the process by which ecological ideas are incorporated into the action of science. That ecological modernization theorists have largely worked at the structural level has left these actions of scientists and engineers largely understudied inside the ecological modernization tradition. Though the turn to an interest in consumption studies does bring ecological modernization theory into contact with the individual, this call still leaves an area of undone science. And though Hess himself is no advocate of ecological modernization theory, his calls for the engagement of anthropologists of science and technology with the comparative and generalizing studies of social movement studies parallels my call for an engagement of ecological modernization theory with anthropology of science and technology. Just as this study attempted to understand the development of particular ecological practices and technologies from the perspective of the individuals involved in their development and deployment so too could other studies follow the advancements of new ecological technologies, companies, and disciplines through the history and action of individuals involved in their development, and in so doing add to the understanding of how ecological ideas are becoming centralized in society and science.

EPILOGUE

We were nearing the end of the tour and as the entrance to the wetland boardwalk came into view, the cacophony of children's excited voices reached a new pitch. "Cool!" "Can we really walk on it?" "Oh, man, somebody better not push me in". Ever since the three bus loads of local 3rd graders had disgorged across the wetland parking lot, the OSU wetland's normal peaceful mien had been transformed into this bustling, jostling, giggling, exploring mass of youthful humanity. The tour of the various regions of the wetland research park had met with varying levels of interest (and subsequent noise). The overlook, with its run-upable ramp had been an enticing space for races and self exploration on the way up, but the enclosed space at the top had made an excellent kid corral in which to do an overview of wetlands in general. But that overview was mostly unneeded as these kids had been studying wetlands in their classrooms, and they were primed to answer such questions as "What are wetlands?" "Why are they important?" These kids knew their stuff and could even list types of animals and plants they might be present in a wetland. The possibility of seeing a snapping turtle had been a key point of discussion. After the lookout tower, we had wended our way past the fenced-in mesocosm area, which, as one student astutely put it, "sure looks messy." Coming around the back corner of the wetlands, we had ducked into the riparian forest that was undergoing experiments with pulsing water flows. As we came up to the dike next to the Olentangy River, the students started commenting on the mud and puddles "Eww, its muddy" "Don't you push me in" "Look at that worm." At the edge of one of the cuts in the dike, we had had a discussion on the purposeful breaching of the dike, and how the river could now flow into the riparian forest whenever the water was high. The persistence of a long puddle stretching between the two sides of the dike demonstrated that this flow did occur. Leaping across this "raging river" from one side of the dike to the other became the object of challenge to the daring students. Having successfully leaped across had became a point of pride for those who had dared the muddy chasm, and was the point of much discussion as we had walked our way up to the center of the wetland complex. But now, here at the edge of the wetland was the ultimate test of courage and fortitude: walking on water. The students were set loose on the board walk with strong injunctions against falling in (or aiding someone else in that process), not because we cared about the students getting wet (a comment unappreciated by the teachers), but because it would be bad for the scientific research on sedimentation.

In the brief quiet moments while the students were dispersed across the wetland, I thought of the comment Dr. Mitsch had made to me after the lab meeting when I had volunteered to be one of the leaders for this field trip. During that meeting, he had had to put gentle pressure on his students to volunteer to lead these tours. His first announcement that four volunteers would be needed for this upcoming event had been met with the subtle slumps and adverted gazes of the unenthusiastic. Having spoken with students before about the various tours and other outreach they did when visitors randomly visited the wetlands, I knew that many weren't opposed to the process in *principle*, but like many graduate students, they just didn't feel they had the time to spare. Thus I had garnered both surprised and grateful looks when I had volunteered to lead not one, but two tours. After the meeting, I asked Dr. Mitsch about these tours and how they fit into the overall operating strategy of the research complex. As we had previously discussed the issue of funding and the role of university budgeting structures in acquiring that funding, I asked him about these tours and how they were accounted. “Not at All” was the reply. The use of the wetlands complex for public outreach and tours of non-university students did not fulfill any official center mandate, nor was it supported by any formal funding structure. But as Dr. Mitsch elaborated “It’s not part of my job description, but it is part of what we as a university should be doing.”

As I stood there and watched these young students striding across the wetlands, sticking their arms out straight from their bodies, moving forward in bold steps to show their daring at walking on so narrow a set of planks, I thought these are the things they will remember. Perhaps they learned about wetlands in their classroom, and have just been lead on a tour of a wetland by the world renowned wetland scientist Dr. Mitsch, but what they will remember is their actions in that space – their jumps, their pokes at mud, their traverse of the waters – and the connections they felt through the experience.

It is through such material experiences that new knowledges are generated. And just as the development of the *idea* of designing with ecosystems is fully and inextricably tied to the *practice* of designing with ecosystems, the development of new ideas about human – environmental relations are based in the practice of those new forms. This co-emergence of the ideas and the practice thus relies upon the actions of individuals who both make the physical realities emerge as well as advancing the idea of these possibilities. Thus ecological modernization might be conceptualized as large systemic shifts, but it is the outcome of the committed practices of real people, in real places.

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APPENDIX A

A BRIEF OVERVIEW OF THE HISTORY AND TECHNOLOGIES OF CONVENTIONAL WASTEWATER TREATMENT

A Very Brief History

There began to be an increase in interest in wastewater transport and treatment in the mid 1800s. With the advent of piped water into households, new mechanisms to deal with household waste were needed. The household cesspools that had previously been used to collect wastes were no longer amenable to the hand emptying and trucking to nearby fields that had previously been the norm for many urban areas (Melosi 2000; Orlando 2001; Rockefeller 1996). Subsequently sewer systems that had been built to drain rain water from urban areas were beginning to be utilized to purge household cesspools that themselves were being overstrained by the advent of piped household water and the adoption of flush toilets[294]. Outbreaks of cholera in urban areas spurred the debate on how to handle waste. The major argument of this time period can be boiled down into the "use it", vs. "get rid of it" camps in regards to human biological waste products. The basic question was whether human waste was a resource as a valuable fertilizer or more a nuisance and health risk (Beder 1997; Gandy 1997; Goddard 1996; Odum 1971; Ogle 1999). The questions revolved around the ideas of if it is a quality

[294] Though conceptual coupled, and materially linked through water flows, water systems for bringing potable water into buildings, and systems for piping sewage out and treating said sewage treatment have different histories, and often different managerial bodies. Subsequently, it is not uncommon both historically and currently in developing nations for regions to have water distribution systems put in place, or being put in place, without a commiserate investment or development of a wastewater transport and treatment system.

fertilizer, how should the carriage systems be designed to facilitate the use of the effluent, but if it is merely a noxious odorsome nuisance, how best to safely and efficiently move the mass from the urban areas. The British Royal Commission into Sewage Disposal which sat from 1898-1915 chose the get-rid-of-it method (Beder 1997). Mainland Europe, and the Americas largely followed on this decision and settled into a period of wastewater management and disposal that was premised on the idea of removal, centralization, and the production of a minimal standard of water quality before the disposal of the wastestream into a receiving water body. Not only did the British Royal Commission set up a discourse of effluent as pollutant, but it was pivotal in setting expectations about treatment levels that still persist to this day for developed nations. The main focus of the Royal Commission was the need to reduce (not completely remove) the biological oxygen demand (BOD) of wastes and to decrees the total suspended solids (TSS).

Out of the Royal Commission's decision to focus on adequate treatment (rather than complete remediation of the water or use of human effluent as a fertilizer) forms of treatment were developed to reduce the amount of suspended solids and BOD of the waste. Justification for the incomplete treatment of wastewater was also premised on conceptualizations of riverine and estuarine systems as "self-purifying" (Melosi 2000; Shapiro-Shapin 1997). Wastewater treatment and the subsequent big system engineering that went with it also developed into its own professional practice (initially Sanitary Engineers and then in a re-packaging of their identity in the 70s they became Environmental Engineers). Overtime wastewater technicians have codified a number of technologies that have become the hallmark of conventional (and developed world) wastewater treatment.

‘Conventional’ Sewage Treatment

Conventional wastewater treatment plants rely on some form of collection system that brings wastewater to a centralized location where it is treated before release. Release is often back into surface receiving water, though injection into underground aquifers, agricultural application, or even direct reuse back into the water supply is possible. This type of treatment is referred to as centralized treatment, which emphasizes that waste products are being treated after they have been transported away from the point of origination. This is in contrast to ‘onsite’ or decentralized treatment systems. ‘Onsite’ typically refers to septic tanks and leach fields for houses or business, but can also include small-scale wetlands. One problem of centralized systems that multiple waste streams have often been combined, combining household waste to wastes from businesses and industry. Thus conventional waste treatment plants can have extreme variations in the type, strength and quality of the wastewaters they have to process. Due to the legacy of how wastewater treatment developed, many older cities have combined sewers, wherein domestic wastewater and storm water become mixed, with subsequent impacts on flows into the treatment plant. The variability of flows, especially under storm events, has significant impacts on wastewater treatment efficacy.

Conventional sewage treatment plants can vary widely in the type of wastes they are treating. Thus the actual of treatment performed on a waste stream can vary from plant to plant. However, there is a general progression of treatment that is followed by most wastewater plants. The major stages of treatment are called preliminary, primary, secondary and tertiary treatment. This stepwise treatment of the wastes represents not only the different types of treatment that need to be done to waste streams in order to clean them, but is also a legacy of the historical development of conventional wastewater treatment plants. Waste treatment technologies have grown from simply removing the solids (primary treatment), to breaking down the biological matter (secondary treatment), to removing nutrients and metals (tertiary treatment). There is even now some discussion of the potential evolution of waste treatment to include a process for removing hormone and antibiotic residuals from the waste stream.

Wastewater treatment facilities often consist of two process streams – the effluent system and the solids handling. A brief overview of the major stages of wastewater treatment follows to introduce some of the basic technologies and treatment goals that are the corpus of 'conventional treatment.'

Preliminary Treatment

Bar screening, grinders, barminutors, comminutors, horizontal velocity grit settling chambers, diffused air chambers, square settling chambers, flow equalization basin

Preliminary treatment processes are added to waste treatment in order to increase the efficacy of the other steps and to decrease the wear and tear on the mechanical equipment involved in waste treatment. In this stage large objects that may have ended up in the sewer are removed (bar screening), the sewage is shredded or ground up (grinders, barminutors, comminutors), and the grit may be settled out (horizontal velocity grit settling chambers, diffused air chambers, square settling chambers). The shredding or grinding is important in order to create a uniform waste mixture, and increase the overall surface area of the organic material that will be exposed to bacterial digestion. Settling out the grit (most common in industrial waste streams) is important to decrease wear on pumps, and to avoid grit clogging in the other settling basins. Diffused air chambers for grit settling have the added advantage that they aerate the waste stream at the same time. A final part of Preliminary treatment might be a flow equalization basin, which is basically a holding tank from which the wastewater is pumped to the rest of the treatment facility. This provides for a steady rate of influent into the main facility, which can increase the quality of treatment.

Primary Treatment

Sedimentation Basins, clarifiers

This stage of treatment is aimed at removing a large portion of the suspended solids from the effluent and is considered a physical treatment process as it premised on physical separation. The influent enters a basin (square, round or rectangle) wherein it is retained for a period of time (the detention time). Detention time is a function of flow rate and the size of the basin, and these parameters are determined by the design criteria of the plant. Typically detention times are from 45 minutes to 2 hours. Tank design can vary, but features generally include a scrapping device that pulls or pushes the settled materials toward an outlet for sludge withdraw which is at the bottom of the tank. The clarified fluid generally spills over a weir at the top. Also along the top can be a scraper arm which scrapes of the 'scum' layer (scum is comprised of grease and fats that separate out of the wastewater and float to the top). This primary sludge and scum will generally be treated in the solids handling portion of the plant. (See below)

Secondary Treatment

Trickling filters, rotating biological contactors, return activated sludge, oxidation ponds, stabilization ponds, sand filters, constructed wetlands, and others

This stage of treatment is done to decrease the organic material in the waste stream. Organics are measured in water by the amount of oxygen that would be used by aerobic microorganism as they digest the organic materials. This measurement is called biological oxygen demand (BOD). It is important to decrease the BOD of wastewater so that it can be discharged in to receiving waters without increasing the oxygen use of microorganisms in the receiving stream. A waste stream with high BOD that was released into a stream would cause a bloom of microorganisms that feed on the organic materials. This is of course beneficial to the microorganisms (manna from heaven to them), but as they breakdown the waste they would use up the dissolved oxygen available in the stream, which could cause fish kills.

BOD reduction in wastewaters is done by creating conditions for microbial activity within the treatment systems, rather than letting this happen in the receiving waters. Thus the fundamental aspect of secondary treatment is the ‘biological’ nature of the process (as compared to primary treatment which is largely a ‘physical’ treatment process). There are many different technologies for secondary treatment. Probably the simplest to construct, and the cheapest are pond-based systems. However these generally require long detention times and thus large land area. Where land availability is limited (or too expensive), secondary treatment is accomplished by speeding up the microbial activity- thus allowing smaller tanks and decreased detention times. Because one cannot make bacteria work at double-time rates, the process is sped up by increasing the number of microbes available to do this breakdown work. By using aeration and return activated sludge, treatment time can be decreased to hours instead of days. Pond systems and activated sludge systems are both ‘suspended’ systems – wherein the microbes are unattached to anything and are suspended within the wastewater. In activated sludge, the suspension is maintained by constant mixing. As the waste stream leaves the activate sludge tank, it enters a secondary clarifier (or sedimentation basin). Here the suspended solids settle out. The majority of the suspended solids at this point are simply the mass of bacteria that have grown as the waste was being broken down. As these bacteria settle out in the clarifier, they are collected and pumped back to the activated sludge tank. By constantly re-adding the bacteria, overall bacteria levels are much greater (100x) then they would be if simple reproductive accumulation were relied upon.

Other secondary treatment systems don’t rely on the bacterial activity to be suspended, but rather provide a media upon which the bacteria grow. For trickling filters this was typically gravel or crushed stone, but synthetic materials have begun to be used. The media is contained within a tank and the waste stream is sprayed over the top. As the wastewater trickles down, the bacteria attached to the filter materials decompose the organic materials. These systems can be done in sequence or with recycle. They are typically followed by a secondary clarifier. Rotating biological contactors use large discs (usually plastic) along a shaft. The disks are rotated through a trough, in which the waste flows. The waste in the trough covers approximately 40% of the disk, and as the disk turns, the bacteria and waste on the disk are rotated into the air and back into the waste stream. Thus aeration is provided to maintain the aerobic activity of the bacteria. Secondary clarification also follows this system. In some systems, ponds are utilized for this secondary clarification. This is more typical if tertiary treatment is unneeded.

Trickling filters are easy to operate, yet are prone to smelling (as they go anaerobic near the bottom of the tank) and in many U.S. communities they have been replaced by Activated sludge systems.

Tertiary (or Advanced) Treatment

Lime treatment, coagulation and sedimentation, electrodialysis, reverse osmosis, ion exchange, oxidation ponds, filtration, land treatment, constructed wetland, and others

This level of treatment is the most varied, in intent as well as in technical process. The technologies can utilize physical, biological or chemical treatment to further treat the water before release. The goals of tertiary treatment can be for the removal of nitrogen, phosphorus, dissolved organic materials, heavy metals, dissolved inorganic solids, suspended solids, and heat. The water might also need to be recarbonated to balance the pH. The number of technologies involved in these processes range from simple to very complex, and from passive to requiring lots of energy. Increasingly in the U.S., treatment plants have had to add tertiary treatment for nitrogen and phosphorus removal as these nutrients have come under regulation in waterways.

Disinfection

Chlorination, U.V. radiation

The final step in many wastewater plants is disinfection, which generally done by the addition of chlorine to the effluent. Because of chlorine's effects on aquatic life, a large number of systems provide dechlorination prior to final release of the effluent. Due to the toxicity of the materials involved in chlorination and dechlorination, this practice is still under debate in some circles. Disinfection is also achieved through the use of U.V radiation and due to the dangers of chlorine use, the use of UV disinfection has been on the rise.

Solids Handling

Many of the unit processes of waste treatment plants have two outputs – the clarified water, and a solids component. The sludge and scum from primary clarifiers need to be further treated. Clarifiers after secondary treatment also produce a sludge, which may be treated separately or mixed with the primary sludge. In general the sludges undergo a series of processes, which include thickening, stabilization, conditioning, and dewatering.

Thickening

Gravity thickening, air floatation, centrifugal thickening.

The sludges that come from the clarifiers are usually only at 1% to 3% solids. Though called 'sludge', at this stage the material mainly has the viscosity and handling properties of water. Thus thickening is done to remove some of the water in order to decrease the amount of 'sludge' that has to be treated by other processes. Gravity thickening is simply another form of clarification (with a few added pickets to help the settling).

Stabilization

Anaerobic or Aerobic Digestion, Oxidation pond, others.

Primary sludges are very raw putrescent materials. Stabilization is the process where by the organic matter in these sludges is digested by bacteria. This can either be an anaerobic or aerobic process. The anaerobic process has the advantage that it produces methane as a by-product, which can be collected and used as an energy source. However, this process requires careful control to maintain an appropriate pH level. The aerobic process is more energy intensive, yet it is easy to maintain, as the microbial processes are not as sensitive to perturbations as are the processes in the anaerobic digestion.

Conditioning

Chemical, elutriation, heat, ash addition

Laws regulate the ultimate disposal of sludge at landfills. For landfilling, the sludge usually has to be at about 20% solids (a dry cake like consistency). After thickening and stabilization the sludge is usually only at 8-10% solids. Further dewatering is necessary. However, the sludges don't dewater easily. Conditioning is the process of adding chemicals or heat, in order to change the properties of the sludge in order to facilitate the dewatering processes.

Dewatering

Rotary vacuum filter, pressure filter, belt presses, centrifuges, sludge drying beds, heat drying, incineration

Generally, this is a physical process of extracting water from the sludge. The sludge is either squeezed, sucked or rotated in order to forcibly remove the water. If land is available, the liquid sludge can be spread in shallow concrete beds where it is left to dry. Heat drying can be done, but is expensive

Ultimate disposal

Land fill, land application (surface or injection), ocean dumping

Land application can be done with dry or semi liquid sludge. However, regulations vary within states. Concern over airborne volatile compounds from the dry sludge has increased the usage of injection systems. These systems inject a semi liquid sludge beneath the soil, thus avoiding the oxidation and subsequent blowing away of land applied sludges. Ocean dumping was once common for coastal cities, but is now under stricter regulations. Many municipalities send their sludges to the landfill. Some have attempted to compost the sludge and make it available to citizens for home use, but citizen concerns about contamination, and environmentalists' concern about heavy metal residues in sludges have limited their acceptability.

APPENDIX B

PRINCIPLES OF ECOLOGICAL ENGINEERING

The underlining principles of ecological engineering have been listed in a number of articles, as well as in the two textbooks released in 2004. Here in follows a sampling of some of the different ways in which ecological engineering principles have been delimited. Text following each citation copies both the actual text and layout from each publication.

Mitsch, William J. 1998. Ecological engineering—the seven-year itch. Ecological Engineering 10:119-138. On page 123:

> The fundamental concepts of ecological engineering that make it different from other engineering fields are as follows:
> 1. self-design (self organization) is a cornerstone
> 2. the field involves biological systems
> 3. sustainable ecosystems are the goal

Mitsch, William J. , and Sven Erik Jørgensen, eds. 1989 Ecological Engineering: An introduction to ecotechnology. New York: John Wiley & Sons, Inc. On pages 27 -28:

> There are a few basic concepts that collectively distinguish ecological engineering from more conventional approaches to solving environmental problems through engineering approaches. These include the following concepts about ecological engineering:
> 1. It is based on the self-designing capacity of ecosystems.
> 2. It can be the acid test of ecological theories.
> 3. It relies on system approaches.
> 4. It conserves nonrenewable energy sources.
> 5. It supports ecosystem conservation

Kangas, Patrick C.2004 Ecological Engineering: Principles and Practice. Boca Raton: Lewis Publishers. On page 17:

> …Three principles of ecological engineering design, common to all of the applications shown in Figure 1.5 and inherent in ecological systems, are describe in Table 1.8.

TABLE 1.8
Principles for Ecological Engineering

Energy Signature	The set of energy sources or forcing function which determine ecosystem structure and function
Self-organization	The selection process through which ecosystems emerge in response to environmental conditions by a filtering of genetic inputs (seed dispersal, recruitment, animal migrations, etc)
Preadaptation	The phenomenon, which occurs entirely fortuitously, whereby adaptations that arise through natural selection for one set of environmental conditions just happen also to be adaptive for a new set of environmental conditions that the organism had not been previously exposed to

Bergen, Scott D., Susan M. Bolton, and James L. Fridley, 2001. Design principles for ecological engineering. Ecological Engineering 18:201-210. On page 202:

In Section 1, we presented a definition for ecological engineering that is a modification of Mitsch (1996), i.e. ecological engineering is the design of sustainable systems, consistent with ecological principles, which integrate human society with its natural environment for the benefit of both. This definition [of ecological engineering] has a number of important elements that should be in any definition of the discipline:

1. that the practice is based on ecological science,
2. that ecological engineering is defined broadly enough to include all types of ecosystems and potential human interactions with ecosystems.
3. that the concept of engineering design is included, and
4. that there is an acknowledgement of an underlying value system

[After discussing the meaning of these for definitional elements, the authors continue with a description of the range of application of ecological engineering and then delve more specifically into principles for design in ecological engineering] . On pages 204-208 they detail five principles:

4.1. First principle - design consistent with ecological principles
4.2. Second principle - design for site-specific context
4.3. Third principle - maintain the independence of design functional requirements
4.4. Fourth principle - design for efficiency in energy and information
4.5. Fifth principle - acknowledge the values and purposes that motivate design

APPENDIX C

PILE SORT DATA

	ER	AE	E	BR	ECOE	CB	GC	ED	BE	IE	NRM	CVE	ES	CME	SS	RE	LA	EE	B	GE	WE	ME
ER	1.00	0.05	0.30	0.68	0.45	0.30	0.17	0.70	0.05	0.25	0.43	0.08	0.17	0.05	0.28	0.73	0.22	0.10	0.15	0.20	0.43	0.03
AE	0.05	1.00	0.08	0.13	0.32	0.10	0.08	0.13	0.82	0.13	0.05	0.65	0.15	0.68	0.00	0.05	0.20	0.68	0.13	0.20	0.08	0.63
E	0.30	0.08	1.00	0.22	0.20	0.60	0.20	0.30	0.03	0.22	0.43	0.13	0.47	0.10	0.28	0.43	0.13	0.15	0.75	0.10	0.77	0.08
BR	0.68	0.13	0.22	1.00	0.35	0.17	0.30	0.65	0.13	0.30	0.28	0.17	0.17	0.10	0.25	0.43	0.15	0.28	0.10	0.22	0.30	0.08
ECOE	0.45	0.32	0.20	0.35	1.00	0.08	0.20	0.47	0.35	0.28	0.17	0.28	0.20	0.25	0.10	0.35	0.15	0.40	0.10	0.32	0.20	0.20
CB	0.30	0.10	0.60	0.17	0.08	1.00	0.20	0.25	0.08	0.28	0.52	0.10	0.43	0.13	0.32	0.55	0.15	0.10	0.60	0.10	0.60	0.10
GC	0.17	0.08	0.20	0.30	0.20	0.20	1.00	0.22	0.17	0.47	0.13	0.13	0.15	0.15	0.32	0.22	0.10	0.15	0.15	0.52	0.17	0.08
ED	0.70	0.13	0.30	0.65	0.47	0.25	0.22	1.00	0.15	0.28	0.30	0.13	0.15	0.10	0.28	0.55	0.28	0.17	0.15	0.30	0.38	0.08
BE	0.05	0.82	0.03	0.13	0.35	0.08	0.17	0.15	1.00	0.17	0.05	0.55	0.10	0.55	0.05	0.05	0.13	0.60	0.10	0.28	0.05	0.50
IE	0.25	0.13	0.22	0.30	0.28	0.28	0.47	0.28	0.17	1.00	0.17	0.17	0.20	0.25	0.28	0.38	0.17	0.17	0.20	0.45	0.28	0.15
NRM	0.43	0.05	0.43	0.28	0.17	0.52	0.13	0.30	0.05	0.17	1.00	0.10	0.45	0.10	0.45	0.38	0.17	0.10	0.38	0.08	0.40	0.08
CVE	0.08	0.65	0.13	0.17	0.28	0.10	0.13	0.13	0.55	0.17	0.10	1.00	0.15	0.75	0.03	0.08	0.15	0.80	0.13	0.15	0.10	0.75
ES	0.17	0.15	0.47	0.17	0.20	0.43	0.15	0.15	0.10	0.20	0.45	0.15	1.00	0.15	0.35	0.25	0.15	0.20	0.60	0.08	0.43	0.10
CME	0.05	0.68	0.10	0.10	0.25	0.13	0.15	0.10	0.55	0.25	0.10	0.75	0.15	1.00	0.03	0.05	0.15	0.65	0.17	0.17	0.08	0.80
SS	0.28	0.00	0.28	0.25	0.10	0.32	0.32	0.28	0.05	0.28	0.45	0.03	0.35	0.03	1.00	0.30	0.08	0.03	0.20	0.28	0.28	0.00
RE	0.73	0.05	0.43	0.43	0.35	0.55	0.22	0.55	0.05	0.38	0.38	0.08	0.25	0.05	0.30	1.00	0.22	0.08	0.28	0.25	0.63	0.03
LA	0.22	0.20	0.13	0.15	0.15	0.15	0.10	0.28	0.13	0.17	0.17	0.15	0.15	0.15	0.08	0.22	1.00	0.17	0.13	0.22	0.15	0.15
EE	0.10	0.68	0.15	0.28	0.40	0.10	0.15	0.17	0.60	0.17	0.10	0.80	0.20	0.65	0.03	0.08	0.17	1.00	0.13	0.17	0.10	0.60
B	0.15	0.13	0.75	0.10	0.10	0.60	0.15	0.15	0.10	0.20	0.38	0.13	0.60	0.17	0.20	0.28	0.13	0.13	1.00	0.08	0.60	0.15
GE	0.20	0.20	0.10	0.22	0.32	0.10	0.52	0.30	0.28	0.45	0.08	0.15	0.08	0.17	0.28	0.25	0.22	0.17	0.08	1.00	0.13	0.10
WE	0.43	0.08	0.77	0.30	0.20	0.60	0.17	0.38	0.05	0.28	0.40	0.10	0.43	0.08	0.28	0.63	0.15	0.10	0.60	0.13	1.00	0.05
ME	0.03	0.63	0.08	0.08	0.20	0.10	0.08	0.08	0.50	0.15	0.08	0.75	0.10	0.80	0.00	0.03	0.15	0.60	0.15	0.10	0.05	1.00

Figure 3. Aggregate Proximity Matrix: 40 pilesorts on 22 items
Generated with ANTHROPAC 4.983/X

informat	CORR	informat	CORR
1	0.601	21	0.293
2	0.733	22	0.421
3	0.595	23	0.603
4	0.290	24	0.679
5	0.550	25	0.377
6	0.384	26	0.501
7	0.551	27	0.154
8	0.528	28	0.698
9	0.203	29	0.244
10	0.663	30	0.375
11	0.445	31	0.442
12	0.564	32	0.702
13	0.372	33	0.285
14	0.510	34	0.288
15	0.478	35	0.429
16	0.568	36	0.493
17	0.694	37	0.524
18	0.641	38	0.302
19	0.240	39	0.637
20	0.476	40	0.311

Figure 4. Individual to aggregate correlation
Generated with ANTHROPAC 4.983/X

Table 2. Pilesort terms and abbreviations

B	Biology
CB	Conservation Biology
NRM	Natural Resource Management
ES	Environmental Science
E	Ecology
WE	Wetlands Ecology
SS	Sustainability Science
LA	Landscape Architecture
RE	Restoration Ecology
ER	Ecosystem Restoration
ED	Ecological Design
Br	Bioremediation
EcoE	Ecological Engineering
IE	Industrial Ecology
GC	Green Chemistry
GE	Green Engineering
ME	Mechanical
CmE	Chemical Engineering
EE	Environmental Engineering
CvE	Civil Engineering
AE	Agricultural Engineering
BE	Biological Engineering