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Are There Ecological Problems That Technology Cannot Solve? Water Scarcity and Dams, Climate Change and Biofuels

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This paper illustrates through a comparative case study how contemporary engineers working on a technological response to climate change—biofuel production—continue to be guided by traditional ethical and historical principles of efficiency and growth in spite of the uniqueness of climate change as a problem unbounded globally in space and time. The comparative study reveals that in the past environmental issues like water scarcity were viewed as deficiencies of nature. In contrast, the development of biofuels as an engineering response to climate change shows that environmental and ecological issues today are viewed as deficiencies of technologies. Yet, just like large dams on rivers had (and continue to have) negative socioecological outcomes, political economy and political ecology research shows that current biofuel development has socially unjust and ecologically degrading outcomes. Many engineers continue to separate the "technical" from the "political" aspects of engineering work, resulting in lost opportunities to reshape the technological development paradigm. While every technology has some negative impacts, engineers, as socioecological experimentalists, must account for these outcomes in their work to mitigate them. Encouragingly, the engineers interviewed for this paper (along with the authors of this paper, who are all engineers) believe that problems like climate change are too narrowly defined. The engineers interviewed claimed that the problem-solving capabilities of engineers would lead to more favorable outcomes if problems were more broadly defined—by engineers and others—to incorporate concerns of social justice and ecological holism, thereby creating legitimacy for engineers in proposing alternative, radical, and paradigm-changing solutions to problems like climate change.

KEYWORDS: biofuels, climate change, dams, problem definition, technological solution, efficiency, carbon, political economy, aviation, socioecological experimentalist, science and technology studies

INTRODUCTION

Broadly, the prevailing self-image of engineers is that they are "problem solvers," and the image of engineering work is that it is about "solving problems."[1] Take, as illustrations, these reflections from practicing engineers (we describe later the source and circumstances of these quotes):

> [Engineers] are trained to be problem solvers. If you are able to describe, through interactions with other people, and frame the problem properly, generally, engineers can come up with a way to solve it.
>
> *A senior research engineer, NASA Langley Research Center*

[1] See Sheppard, Colby, Macatangay, and Sullivan (2006).

> [Engineers] are very good at problem solving. Once you define a problem, they can look and see what the causes are that are creating it, and figure out ways to approach those causes to remedy [the problem]. Generally, engineers are focused on more straightforward solutions and don't get distracted with some of the social, humanistic sensitivities that are associated with the problem. They are more direct for the [technical] solution.
>
> *An environmental consultant and co-winner of a Nobel Peace Prize*

But neither is the problem solving work of engineers solely technical, nor do engineers practice engineering in isolation—the discipline of engineering is *socially constructed* and has social and ecological impacts outside of the purely technical. Engaging in the "people-serving profession" (Vesilind & Gunn, 1998), engineers work within bureaucratic contexts, be they government, corporate, or academic. The problems engineers deal with have been framed in ways that reflect particular political motives and social and economic goals, as has been shown by significant research in science and technology studies.[2] The division of reality into "fact" and "value"[3] is perpetuated in engineering education and training, with engineers trained only to deal with the former, and either actively distancing the latter or reshaping it into the former.[4] For example, lifecycle analysis, which accounts for the material and energy resources used throughout the "life" of a product or process, does not account for the ecological, social, and cultural values and impacts of the resources, products, or processes. Furthermore, engineers are positioned within organizations and in the overall social and political order to bolster the industrial, capitalist economy.[5]

Engineers are not only problem solvers, they are also intentionally or inadvertently *socioecological experimentalists*; the problem solving work engineers do—whether it is inventing material technologies such as computer chips that require mined minerals and metals, building vast roadway infrastructures, or taking the tops off mountains for coal—is done often with limited understandings of the socioecological impacts of engineering work. While it is practically impossible to account for all outcomes and effects of a technology, to the engineers interviewed for this manuscript —as reflected in the second quote above and as will be discussed below—trying to understand these effects and impacts is currently beyond the scope of the engineering profession and hence bear little effect on the technical design process. Technologies—and by proxy the work

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[2] See, for example, Winner (1977). In chapter 4, Winner describes the power of scientific and technical elites and the relationship over larger masses of people that vie to make democratic claims. In chapter 6, Winner argues that in many cases, particular technologies that have *already* been developed are then applied to solve "problems" framed in ways that lend those technologies power. In this chapter, Winner also describes how and why large technical systems come to be controlled by the state. See also Mumford (1963). In this book, Mumford describes how self-imposed limitations on Western Europe allowed the creation of "the machine" and subsequently projected it as an artifact outside of "will." See also Hecht (2009) and Noble (1977, pp. xix, 34).

[3] We take the definition of *fact* to be something that stems from supposedly "objective" evaluations of the world. The scientific process is, for example, a generator of facts. We take *value* to be defined as something that guides how facts are acquired, or how facts are used. The political process, the give and take among groups with competing interests, is generally believed to be guided by fact. Different groups use different facts for their own advantage, and make claims with those facts consistent with their beliefs. See, for example, MacKenzie (1990).

[4] For examples see Noble (1977) and Porter (1995).

[5] Conversely, non-governmental organizations do not actively recruit new engineering graduates. Much can be said of this, but it is beyond the scope of this paper to detail why this is the case.

of engineers—thus shape our individual, social, and cultural behavior in ways not only expected but also unintended.

We live in a time when information about ecological degradation—climate change, biodiversity loss, air and water pollution—caused by industrialism abounds, a time when connections between technologies and the politics that lead to ecological degradation have been well established. Yet, in this paper, we ask the following questions: Has recent knowledge of ecological degradation and social injustice changed the way engineers consider socioecological problems? And how do engineers consider the capacity of technology to address such challenges?

The goal of this comparative case study is to examine whether and how past engineering thinking and decision-making is employed by engineers in the face of even larger and more complex socioecological problems. We consider engineering responses to two ecological "problems" displaced in time—the damming of rivers to address natural water scarcity in the American West in the early 20th century, and the current development of biofuels by the aviation industry in response to climate change, i.e. two "cases"—large scale responses promoted by powerful actors like governments and corporations. Specifically, we first briefly explore the historical context of the damming of rivers, the engineering ethic behind large dams, and their consequent negative socioecological outcomes. We then compare and contrast engineering approaches to "solve" climate change through aviation biofuel development in light of our understanding of the interactions between technological development, social justice, and ecological impacts. Interviews with engineers involved in aviation biofuel development conducted in October 2011 at the Third Sustainable Alternative Fuels in Aviation Workshop at the headquarters of the International Civil Aviation Organisation (ICAO), provide insights into how some contemporary engineers frame the problem of climate change and thus responses to climate change. Details on survey methods can be found in the Appendix at the end of this paper.

DAM THE RIVERS—"CONSERVATION" THROUGH USE

A century ago, the scarcity of water in the frontiers of the American West was perceived as an "environmental" problem, which was solved by large scale damming of the rivers—growth and development, guised under an ethic of conservation and efficiency, were imagined and created (Worster, 1985, p. 10).[6] Rivers were considered beneficial "when they yielded to humanity's needs, whether as mechanisms of transportation or as sites for nascent towns" (Ellison, 1999, p. 41). To achieve these aims, the federal government established the United States Reclamation Service (USRS) with the Reclamation Act in 1902, thus embarking on a program of irrigation development that relied on a favorite technology of conservationists—storage reservoirs. USRS engineers, especially Director Frederick Newell, promoted the idea of capturing spring floods in headwater reservoirs and putting the previously "wasted" water to constructive use (Ellison, 1999, p. 110).[7]

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[6] Take these quotes that capture the ethic guiding the human domination of waterways: "The conquest of nature, which began with progressive control of the soil and its products, and passed to the minerals, is now extending to the waters on, above and beneath the surface. The conquest will not be complete until these waters are brought under complete control." W. J. McGee, cited from *Water as a Resource* (1909) in Worster (1985, p. 127); and "One day, every last drop of water which drains into the whole valley of the Nile . . . shall be equally and amicably divided among the river people, and the Nile itself . . . shall perish gloriously and never reach the sea." Winston Churchill (1908) from McCully (2001, p. 18).

[7] Furthermore, in the early 20th century, people used "reclamation" to mean the process of turning desert or, much less frequently, swamp land into productive farmland, even though much of this land had never been farmland previously; there was nothing to be literally "reclaimed." The use of the term, however, points out

Dams were built to control the depth of rivers, to help navigation, to provide irrigation water to the arid West, to control flooding, and to generate electricity (Billington & Jackson, 2006, p. 17). Within fifty years of the late nineteenth century, the Imperial Valley of southern California was transformed by one of the most advanced hydraulic systems in the world, which continues to be elaborately modified to this day. The scarcity of water and the unchecked rivers in the American West were framed as a deficiency of nature, an "environmental" problem, which could be corrected through a single large-scale technology—dams—and today, on some rivers such as the Colorado, very little water makes it to the ocean.

These dams had overt economic and political purposes as well. In the early 1900s, citizens wanted the government to end the monopolies of the private electric power providers. Supporters of the USRS stipulated that the USRS could only provide water to farms of one-hundred and sixty acres or less—the established size for homesteads under American law—to ensure that government irrigation would support small family farms. Supporters hoped that "yeoman farmers" would improve the moral fabric of the nation. Irrigated farms would provide opportunities for the unemployed, immigrants, and other urban troublemakers, and convert them into valuable citizens for American democracy (Billington & Jackson, 2006, p. 8).

These political sentiments grew out of Progressive ethical traditions of efficiency, improved social bonds, and anti-monopolism (Ellison, 1999, p. 87); this was the Progressive "conservation" era of American politics. When Gifford Pinchot, the Chief of the U.S. Forest Service used the term "conservation" in 1907, it was already a mainstream American ethic. Progressive conservationists, who included federal engineers and scientists, made every effort to promote the ethic under the guise of national growth and strength (Ellison, 1999, p. 103). Time and again Pinchot pointed out that conservation did not mean protecting or preserving nature.[8] Rather, it was overtly anthropocentric; conservation stood for the control of nature and *efficient use* of natural resources to serve the material interests of humankind with an eye to long-term needs.

The political interests of the government and federal engineers guided the design of multipurpose dams. The ability of engineers to reduce the complexity of water storage and use into a differential equation allowed a technological "solution" to the problem of large-scale, multipurpose damming (Casler, 1926; Horton, 1918). These engineering designs promised the possibility of having full control over river water—not a drop would be "wasted." According to Hays (1999), conservation leaders were very active in professional circles, maintaining that their objective and rational thinking was superior to the give-and-take of politics:

> [l]oyalty to these professional ideals, [and] not close association with the grass-roots public, set the tone of the Theodore Roosevelt conservation movement. The idea of efficiency…molded the policies they proposed, their administrative techniques, and their relations with Congress and the public. . . . They emphasized expansion, not retrenchment; possibilities, not limitations. True, they expressed some fear that diminishing resources would create critical shortages in the future. But they…bitterly opposed those who sought to withdraw resources from commercial development. They displayed that deep sense of hope which pervaded all those at the turn of the century for whom science and technology were revealing visions of an abundant future. (Hays, 1999, p. 2)

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that Americans thought of a humid pastoral landscape as the norm and their technological interventions as an environmental return to normalcy (Ellison, 1999, p. 16).

8 Thus, the conservation preached by politicians and administrative officials during the Progressive Era was much different qualitatively than the environmentalism emergent in the 1960s.

The Harsh Realities of Dams

Engineers, who identified with the "conservation" ethic founded on efficiency and growth, were integral in *correcting the perceived deficiencies of nature through large-scale dams.* The scarcity of water and the courses of rivers in the American West were recast as environmental problems, creating a convincing rationale for creating large technological infrastructures that gave the federal government experience with hydraulic engineering, and allowed the breaking of monopolies, the provision of electricity, the navigability of rivers, the irrigation of desert and arid lands, and, in essence, the knowledge and tools to bolster the paradigm of efficiency and growth.

However, the technical expertise proved to be myopic and narrow, as engineers had limited understanding of the socioecological impacts of damming. Damming created an illusion of an abundance of water in arid areas and has led to every major waterway in the American West being dammed, with dam building peaking in the 1970s. The visually stunning nature of large dams has also inspired a correspondingly strong anti-dam activist movement (Goldsmith & Hildyard, 1984). The highly localized and immediate effects of dams—the displacement of people and the immediate destruction of ecosystems—provide a strong locus for rallying. Yet, large dam building is continuing at a rapid rate in the industrializing world, even after the emergence of clear evidence showing the ill effects of large dams.[9] Little of the food grown through the dam-irrigation schemes goes to those who need the food most. Millions of people are continually uprooted and forcefully resettled from their traditional lands to make way for dam reservoirs with the added risks loss of wildlife and estuaries, the loss of silt and fertility downstream of dams (Barrington, Dobbs, & Loden, 2012; Goldsmith & Hildyard, 1984; McCully, 2001). According to McCully (2001) and Goldsmith and Hildyard (1984), further negative effects of dams include decreased water quality, reservoir-induced earthquakes, increased water-borne diseases, and salinization of fertile agricultural lands. McCully (2001) shows also that the reservoirs created by dams release significant quantities of greenhouse gases. Indeed, anti-dam environmentalists have argued that water impoundments and clear cuts have also infringed on the rights of nature itself.[10]

Biofuels, Aviation, and Climate Change

Whereas water scarcity was identified as the environmental problem in the 1900s in the Old West, climate change is arguably the most important *global* environmental and ecological problem we face today. Greenhouse gas-emitting engines used in aviation are increasingly contributing to climate change as global air traffic continually increases.[11] ICAO corporations such as Boeing and

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[9] Goldsmith and Hildyard (1984) provide recommendations for alternatives to large dams, many of which encourage learning from past traditional irrigation techniques—the *qanats* of Iran, the use of *tanks* in the dry zone of Sri Lanka, alternate-year fallowing as practiced in Mesopotamia—and more fundamentally, learning to live with nature. McCully (2001) recommends changes in land management practices, flood management and rain harvesting, and basic plumbing infrastructure maintenance to reduce the need for large-scale damming.

[10] See, for example, "The San Francisco Declaration of the International Rivers Network" in McCully (2001, pp. 313–314).

[11] Aviation is responsible for 2–3% of total anthropogenic carbon dioxide emissions (Kahn Ribeiro et al., 2007). Aircraft also emit other greenhouse gases—such as water vapor, ozone, and methane, along with unburned hydrocarbons and particulate matter that have radiative forcing impacts on the Earth's climate—directly into the upper troposphere and lower stratosphere (Penner et al. 1999). In light of the growing impact of aviation emissions on the climate, the International Civil Aviation Organisation was delegated responsibility to address greenhouse gas emissions from international aviation by the 1997 Kyoto Protocol.

Airbus, aviation industry trade groups such as Airlines for America and the Air Transport Action Group, government regulation agencies such as the Federal Aviation Administration, and government-industry consortia such as the Commercial Aviation Alternative Fuels Initiative, have agreed that several measures will need to be taken to reduce carbon dioxide emissions over the next fifty years—operational measures, technical improvements to aircraft, economic measures, and use of biofuels.[12] While operational measures are changing (in air traffic control, for example); economic measures such as the European Union's Emissions Trading Scheme are being implemented by some governments (and vigorously fought by industry and other governments[13]); and technical improvements to aircraft are continually being made, the growth in overall air traffic has completely outpaced efficiency gains.[14] The aviation industry thus views biofuels as an essential technology that will eventually eliminate the industry's contribution to climate change. Intended to be "drop-in" fuels that would require little to no engine modification, biofuels would fit within the existing aviation infrastructure. To date, there have been several successful test and commercial flights using biofuels produced from non-food plants such as *jatropha curcas* and camelina.[15]

The perceived role of biofuels within the aviation industry is captured in Figure 1, which depicts the optimism that biofuels will eventually lead to a 50% decline in carbon dioxide emissions compared to 2005 levels. Biofuels, as many engineers, government and corporate officials, and technocrats repeated at the ICAO workshop, must be produced *efficiently*, so as to allow "carbon-neutral growth"[16] of the aviation industry for the foreseeable future,[17] which many claimed as essential to the economic growth of countries and improving people's quality of life. An aviation fuels specialist for the Federal Aviation Administration summarized the industry's vision of and confidence in biofuel development to enable this growth, also invoking efficiency as a guidance principle in technological development, by saying that:

> I am confident that [through] engineering resources . . . we will come up with solutions to make [biofuels] work, and make [them] efficient enough such that you can make a synthetic jet fuel for basically the same price as a petroleum derived jet fuel. I am extremely confident that we will be able to solve those problems.

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[12] See the Air Transport Action Group's web page about environmental efficiency in the aviation industry, (http://aviationbenefits.org/environmental-efficiency).

[13] For examples see Aviation Environment Federation et al. (2012) and Sundaram, Krukowska, and Lin (2012).

[14] Models developed by the Intergovernmental Panel on Climate Change (IPCC) show that by 2050, the greenhouse gas emissions from global aviation will grow to between 1.6 and 10 times the emissions in 1992, and that the emissions increase in their reference scenario is threefold compared to 1992, equivalent to 3% of the projected total anthropogenic CO2 emissions relative to the mid-range IPCC emissions scenario. Global passenger air travel has been growing steadily and quickly in recent decades, and is projected to grow by about 5% until 2015, whereas total aviation fuel use is projected to increase by 3% per year until 2015, the difference being due largely to improved aircraft efficiency, cited in Metz, Davidson, Bosch, Dave, and Meyer (2007). Therefore, it is widely accepted that the overall emissions of greenhouse gases will *increase* for the foreseeable future, and aviation's share of overall greenhouse gas emissions from transportation *will also increase*.

[15] For examples see "Finnair's scheduled commercial biofuel flight marks a step towards more sustainable flying, says airline" (2011); "Lufthansa's biofuel trial takes to the air with first commercial flight" (2011); and Reals (2011).

[16] See, for example, International Air Transport Association (2013).

[17] For the purposes of this paper, we take the notion of "efficiency," a common engineering design goal, and "growth"—the growth of profits, the growth of corporations, and the growth of industry—at face value. For detailed explanations of "efficiency" and "growth," see Daly (1977) and Princen (2005).

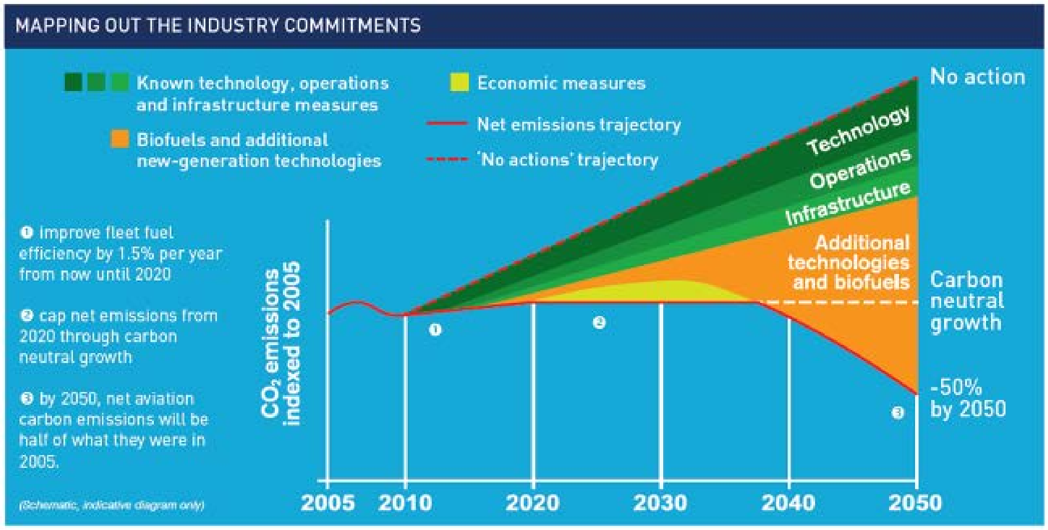

Figure 1: Of all proposed carbon dioxide emission reduction measures for the aviation industry, biofuels represent by far the largest potential source of cuts, thereby allowing "carbon-neutral growth" of the industry through close to the year 2040. Image courtesy of Air Transportation Action Group, (http://aviationbenefits.org/environmental-efficiency/aviation-and-climate-change/our-climate-plan/).

The unprecedented global problem manifested in climate change has not changed the paradigm of efficiency and growth through technological development, evident in the damming of rivers a century ago. Yet as we later explore through biofuel development in response to climate change, what engineers consider an "environmental" or "ecological" problem has in fact changed markedly since the early 20th century. Before we get there though, we briefly explore the socioecological and economic outcomes of biofuel development, and then show how our engineering profession continues to silo itself from the political dimensions of climate change, while bolstering the technopolitical regimes that have caused climate change (Hecht, 2009).[18]

The Harsh Realities of Biofuels

Biofuels are envisioned by governments and industry as a technological response to the interrelated problems of an "energy crisis," climate change, and dependence on the Middle East for oil, presenting a win-win-win scenario to the Global North and to the current economic system of growth (Borras, McMichael, & Scoones, 2010). It is in the Global South, however, where much of the biofuel feedstock is being grown. For example, major plantations of *jatropha curcas*, a biofuel feedstock of particular interest in aviation, exist primarily in Asia, Africa, and Central and South America, and approximately 15 million hectares are projected to be under cultivation by 2015 (Friends of the Earth International, 2010; Global Exchange for Social Investment, 2008). Governments and industrial agribusiness have touted that biofuel production will reduce poverty, enhance rural development, create employment opportunities, and create energy security (German,

[18] Hecht describes technopolitical regimes in chapters 1 and 2 as the interweaving of the technical and political aspects of engineering and nation building, the influences of which stretched beyond public discourse to influence all levels of technical development, "from the interactions between nuclear leaders and government officials to the artifacts and practices of reactor design" (2009, p. 56).

Schoneveld, & Pacheco, 2011). However, the optimism surrounding biofuels has not led to positive ecological, economic, or social outcomes.

Ecologically, biofuels have been tremendously negative so far, resulting in soil loss and water depletion (Borras et al., 2010). Palm oil biofuel plantations have played a huge role in the destruction of 80% of the Indonesian rainforests, which covered 77% of Indonesia in the mid-1960s (Gouverneur, 2009). The "carbon debt" associated with biofuel plantations can make biofuels a more significant source of carbon dioxide emissions than conventional fossil fuels (Fargione, Hill, Tilman, Polasky, & Hawthorne, 2008).

Economically, *jatropha curcus*, like so many other "miracle crops," has turned out to be neither profitable nor pro-poor and instead has benefitted middle-income to rich farmers who had access to capital. Further, poor farmers who have planted *jatropha curcas* have become dependent on investors. For example, in Tamil Nadu, diverse plantations that provided small and marginal farmers with food for self-consumption, fodder, firewood, and cash, were replaced with monocrop *jatropha curcas* plantations. Plantations required higher than expected irrigation inputs but yielded one-tenth of the forecasted crop. The widely held idea that non-food biofuel feed stocks such as *jatropha curcas* can be well cultivated where irrigation networks do not exist appears misleading (Ariza-Montobbio, Lele, Kallis, & Martinez-Alier, 2010). Deforestation to create sites for biofuel plantations has also made it difficult to access forest products, thereby decreasing self-sufficient supply of foods and resources (German et al., 2011). Local realities in industrializing countries show that "idle" or "under-utilized" land being bought by foreign investors are lands that in fact are neither idle nor unused, but rather provide important means of livelihood, particularly for women (Borras et al., 2010).

Biofuel development in the Global South has also had little to no focus on local social justice concerns, such as land rights, water rights, and employment. Compared to family farming, only one-tenth the numbers of jobs has been created by biofuel crop farming (Borras et al., 2010). Moreover, the majority of jobs on biofuel plantations in Indonesia and Malaysia have gone to migrants from outside the affected communities because the skill base and work ethic of local residents have been considered inadequate by managers (German et al., 2011). The distribution of benefits to the broader community have been undermined further by poor employment conditions for unskilled laborers and restricted access to economic benefits to employees (German et al., 2011). Dauvergne and Neville summarize how current industrial-scale biofuel development bolsters the paradigm that has created socioeconomic injustice and climate change:

> [P]roduction and consumption patterns of biofuels will benefit . . . [those] groups already integrated into commercial production systems . . . with even well-intentioned efforts to mitigate climate change and support development through biofuels likely to accelerate deforestation and further marginalize vulnerable people and ecosystems. (2010, p. 655)

Regardless of these negative impacts, the aviation industry is relying heavily on biofuels to mitigate the industry's greenhouse gas emissions while simultaneously enabling and ensuring the continued growth of the aviation industry. Engineers are involved in all aspects of biofuels—from production, storage and distribution to end-use. Engineers are also involved in setting research agendas and regulatory frameworks to enable biofuel development.

BIOFUELS AND THE EXISTENTIAL PLEASURES OF ENGINEERING

Historically, especially in the Enlightenment period, technological development and the human shaping and manipulation of nature was understood to form the basis of a stable society. Social stability rested upon the ability to move away from an imperfect past and to overcome external limits forced upon humans by nature (Davison, 2001, pp. 67–72).[19] Dam building to combat the scarcity of water in the American West in the late 1800s and early 1900s is a quintessential example of this ethic. In today's world, philosopher and the author of *Technology and the Contested Meanings of Sustainability* Aidan Davison writes, "[t]echnological society names a particular political and moral condition in which the greatest common good is understood as the greatest possible productivity of technosystems" (p. 93). Biofuels are a technology thus being developed not only in response to climate change, but also in response to a perceived scarcity of fossil fuels to stabilize current modes of trade and economic interaction.

The engineer's analytical framework tends not to include intangibles like politics, emotions, and other ethical concerns.[20] Reductionism,[21] empiricism, positivism,[22] and dualism[23] form the cornerstones of modern engineering and technological development. Reflecting on the definition of what success is to an engineer, an engineer responsible for fuel purchasing in the treasury department at Delta Airlines said that:

> . . . building [a material technology] and having it work is a success [to an engineer]. That might be a different perspective than for the person who wants to use it, for good or for bad. . . . Whether this thing is a computer, or whether it is something used for chemical warfare, it's a success.

According to the engineers interviewed, the current metrics for success to engineers are purely technical, and metrics and tools to assess socioecological and political implications of engineering work do not fall under the purview of current engineering practice; these implications are evaluated by politicians, lawyers, economists, sociologists, and others. The *seamless web* of the political and technical thus continues to be recast into the *isolated spheres* of the political and the technical through the division of labor, and through the conceptualization of the technical as "fact" and the political and the generally non-technical as "value" (MacKenzie, 1990, pp. 413–414). Take, for example, this quote from a leading engineer for Energy and Environment at the Federal Aviation Administration (FAA):

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[19] See in particular p. 69: "In the world Descartes and Bacon saw, external limitations are overcome, and thereby progress attained, to the extent that rational knowledge about natural machinery takes over from the inefficient meandering of evolution. A lack of rational development in existing social practices, a lack of material advance, i.e. a lack of progress, appeared as backwardness, idleness, moral decay. Yet, notions of progress and stability do not stand over and against each other so much as they inform and shape each other. The Enlightenment idea of stability was derived instrumentally from the antecedent metaphysical conviction that the purpose of social life was to develop the raw stuff of existence into a rational form, a Paradise on Earth."

[20] See, for example, Vesilind and Gunn (1998, pp. 30–32).

[21] We understand reductionism as the division and discretization of complexity into well-defined parameters that can therefore be adjusted. An example of reductionism is how federal engineers converted the storage reservoir problem into a differential equation with terms that could be manipulated. Reductionism thus sets up cause-and-effect relationships, and is also referred to as "atomism"—see Hauser-Kastenberg, Kastenberg, and Norris (2003).

[22] Positivism, which is the application of the empiricist tradition of Francis Bacon and Isaac Newton, allows the engineer to stand as a supposedly neutral observer to the forces of nature that dictate empirical outcomes (Vesilind and Gunn, 1998, pp. 30–32).

[23] Dualism is related to positivism—it is the separation of humans from the environment, the distinction, particularly in Western philosophical traditions of mind and matter.

> [L]ast week, I was having a conversation with somebody about the [carbon dioxide] standard for [aviation], and [an] individual asked me, "Knowing what you know of the industry, do you think we can get them to cut a deal?" Cut a deal? We haven't even figured out how to measure [how changes in the aviation infrastructure will reduce carbon dioxide emissions] yet. . . . *We don't have any data*. . . . *I think that individual is reacting to [their] political realities*. (emphases added)

When considering what this engineer self-identified as a "moral issue," the engineer wanted "data" on the technology metric, i.e. the performance of the technology for reducing carbon dioxide emissions. As discussed next, several interviewed participants articulated that engineering solutions to climate change are currently limited to the technical. This is because of how the problem of climate change is defined.

ENVIRONMENTAL PROBLEMS: NO LONGER A DEFICIENCY OF NATURE

Climate change represents a vastly different kind of environmental and ecological problem than the scarcity of water in the American West. Even though the sources and effects of climate change are at local scales (just like the effects of dams), climate change is unbounded in space and time, has emergent, non-linear properties, and is likely to only show its full effects over the coming century and beyond (Beck, 1992).[24] Addressing climate change demands a new spirit of sociotechnical interaction (Jonas, 1984).

While the scarcity of water in the American West was considered a deficiency of nature, climate change is attributed—by engineers (and as discussed later, by governments and businesses)—to a deficiency of our technologies: "I think the climate change situation right now is an . . . unintended result of our technological progress," reflects the aviation fuels specialist from the FAA. Given that "solutions" to climate change commonly proposed by governments and industry are "non-greenhouse-gas-emitting" (at least over their lifecycle) technologies, it is clear to the authors that the specific technological deficiency causing climate change is that current technologies rely on combustion and thus emit greenhouse gases. Biofuels serve as the technological response to this perceived technological deficiency, as the chief executive officer of a biotechnology company claims: "The aviation industry would like to be zero carbon. So there is an environmental issue. Biofuels can [be zero carbon] if you use the right biofuels. . . . [Technologically] is the only way you are going to solve [climate change], I think." These quotes reflect the perception that the only problem with aviation is the industry's dependence on fossil fuels and the greenhouse gas emissions from their use, and that technology can adequately address this problem. According to engineers, then, is there an ecological problem that technology *cannot* solve? An Environment Officer for ICAO claimed that:

> [e]very technological achievement reflects the fact that we have learned something new . . . to the point where you can create something that leverages that understanding. We're getting to the point where we understand the environment more. So, that gives me confidence that with that improved understanding, we can then come up with [technological] tools to address . . . [ecological] challenges.

The CEO of the genetic engineering company argued further that:

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[24] For detailed descriptions of the nature of climate change, see also Nixon (2011, pp. 2–3, 266) and Princen, (2012).

> The reality is that technology has always solved social and environmental problems, like the Haber Bosch process, which they invented [to] make fertilizers. Before that process, the world was extremely concerned about how much fertilizer there was. And [people said],"Oh we're going to run out of food," and "We're never going to be able to meet all of these growing needs . . ." and [technology] solved that problem. . . . So, I think everything that is good comes from technology . . . and some of the bad things, too. But I don't think we should focus on that. Over and over, mankind has been able to innovate its way out of problems.

Placing these reflections in the context of the conference the interviews were conducted during—a gathering dedicated to "sustainable alternative fuels in aviation" replete with presentations from engineers who likely have progressive attitudes towards sustainability—and within the context of the broader discourse around how technological advance is necessary to address sustainability challenges, the above reflections provide illustrations that to many engineers, environmental and ecological problems are results of technological deficiencies that can be solved with *new* technologies, industrial in scale and founded on efficiency and growth. This ethos of technological development allows engineers to focus on purely technical work.

Climate change is, however, a problem that has at its root a socioeconomic and political order that has been shaped by combustion technologies for transportation and electricity generation that require fossil fuels; nation states and corporations have encouraged and subsidized greenhouse gas emissions (Mitchell, 2011). Responses to climate change derive from and rely on this very order, a conclusion was articulated by a scientist working for an international non-governmental organization (NGO) promoting clean(er) transportation:

> Why are we doing biofuels? . . . [I]gnoring for a moment [whether or not these statements are true], [biofuels] have a lifecycle analysis that says we [can achieve] a level of carbon savings. [But] *[n]o one has to do anything* (emphasis added). We're not going to charge anyone [or] spend any public money. All of the funding will be taken from the consumer at the pump, at a level that is too late to be noticed. We can chalk it up on our renewable energy targets [and] on our climate change targets. And we have *more* energy rather than less (emphasis in original). . . . We have a "*more* energy solution [that looks] great" (emphasis added). So, we love biofuels policy. . . . You ask, "What do we want to do?" Well, the last thing we want to do is change anything that we do. . . . [B]iofuels are a great way . . . of really not changing anything and "achieving change" . . . if you believe you are achieving change.

The technological fix (Weinberg, 1966) of biofuels is one that offers "engineering as an alternative to conservation or restraint" (Fleming, 2010, p. 8), particularly to the aviation industry. But technological fixes—instead of placing more faith in or trying to enact policy and behavioral changes—have come to connote "simplistic or stopgap remedies to solve complex problems, partial solutions that may generate more problems than they solve" (Fleming, 2010, p. 8). Note that planned reductions in air traffic are not considered by the aviation industry as a means to reduce emissions in Figure 1, re-enforcing the tenet that boundless growth will be enabled by engineering "solutions," the same tenet of boundless growth that endorsed the widespread damming of rivers in the old American West.

What Is the Problem?

Engineering has been thought of as the most liberating of professions; regardless of monetary and social concerns, engineers are freed to perform the technical tasks for which they were trained and which they find most pleasurable (Florman, 1994), and thereby to "solve problems." The participants interviewed recognize that they often do not define or frame problems (like climate change), but are instead handed problems to solve—"[y]ou are kind of taught not to ask questions, [but rather to] just . . . design [technology]," said the Delta engineer. A senior environmental consultant for the aviation industry commented similarly that, "[s]o often, engineers are employed by industry or somebody who is looking to solve a very near-term problem that can be narrowly defined, and so that's all engineers are asked to do and that's what they do." The engineer's work is fragmented, with individuals making small contributions to much larger projects, whether it is designing turbines for a pump in a dam or a transistor for an integrated circuit. Further, the engineer's positions in large corporate and government bureaucracies are "designed to diffuse and delimit areas of personal accountability within hierarchies of authority," and there is pressure on engineers to move on to new projects before operating projects have been observed for long enough to observe and analyze performance and broader impacts (Martin & Schinzinger, 1996, pp. 94–95). Therefore, says the Delta Engineer, ". . . engineers, like accountants, get stuck in a little bit of a [closed world]. . . . Why isn't an engineer a whistleblower when he's creating some horrible, horrible chemical weapons? Because that's not their role." Engineers are thus distanced from the moral accountability of their work, and have consequently "continued to serve capital, wittingly or not, their habits of thinking about problems and formulating solutions constituting for the most part but a highly refined form of capitalist reason" (Noble, 1977, p. 323). The most recent science and engineering labor statistics published by the National Science Board (2014) imply clearly that technical work continues to bolster for-profit capitalist businesses and corporations.

The tendency to understand problems, analyze information, and propose actions through the lens of technological development is created through engineering education, the paradigm of which was established during the early days of the professionalization of the engineering profession (Noble, 1977; Seely, 2005), and according to Seely (2005), substantive progress in revolutionizing engineering education to include non-technical content remains stagnant. This technological development lens decontextualizes the technical and scientific tools from the world the tools were developed for by institutionalizing specific epistemologies of what constitutes "factual" knowledge (Murphy, 2006, pp. 81–110),[25] enabling engineers to dismiss non-technical forms of knowledge and ethical concerns as "soft" or not quantifiable and therefore outside the realm of an engineer's consideration. The NGO scientist commented that:

> . . . policy questions [run] into problems when you ask scientists and engineers because you get an awful lot of cognitive bias. . . . In general, if you ask a bunch of scientists a question, they are going to try and come up with a scientific solution. If you ask a bunch of engineers a question, they are going to want to build something. . . . [Y]ou already know what the answer is going to be before you ask them. [So], the question is, [since] you know what the answer is going to be, do you think these people are the best people to ask the question to?

Engineers form essential nodes in the network of actors involved in technological design. As the people who are handed problems to solve, engineers' world views thus propagate an ethos of efficiency and growth through techno-optimism. Framing an ecological problem as a technological deficiency allows engineers to combine their existential pleasure of creative problem-solving effort that is embodied in technological projects with the intention of "[contributing] to the well-being of his fellow man" (Martin & Schinzinger, 1996), thus reinforcing, perhaps unintentionally, a narrowly

[25] For example, in the case of sick-building syndrome, claims of the negative health effects of working in modern office buildings, with their plastics and ubiquitous chemicals, were countered with the epistemologies of industrial hygiene that required toxic exposures to chemicals to be both regular and specific, which rendered the effects of constant low-level exposures improvable and imperceptible. Therefore, dominant epistemologies and ontologies shape the framing of a problem for those that are trained in those dominants, rendering alternative and opposing framings powerless.

technical belief system, which in turn stabilizes a particular technopolitical order. Environmental and ecological problems consequently serve as the impetus for technological development, with the environment serving as the source of material inputs of technology, as well as the sink of outputs and fallouts of technology.[26]

Yet, interviews with several participants also revealed a more nuanced reshaping of the current engineering paradigm with the movement of social and ecological concerns to the forefront of engineering thinking, as shown next.

ENGINEERS REEVALUATING THE PROBLEM

We posed the question to our interview participants, "What are two or three things that engineers are good at, and two or three things engineers are not so good at, related to thinking about the environment?" and their responses indicated struggles with the limited design space allocated or assigned to scientists and engineers. The Delta engineer observed that:

> I think oftentimes the impacts on the environment [are] sometimes not known when the technology is being created. [For example], folks thought corn-based ethanol was the most brilliant invention ever. Then they realized, "Wow, we are running out of corn, and people aren't eating," or [since] corn was subsidized . . . farmers in the [United States] stopped growing wheat and they moved to corn . . . and the price of wheat [went] up. . . . We may not know what [technology] really does damage and what doesn't. . . . When it comes to the environment, I think that [understanding what a success is] becomes very, very difficult because there is no framework anymore.

Notions of sustainability, including climate change and water scarcity, require broader thinking than is currently employed in engineering work, as the quote above reflects; engineers are indeed socioecological experimentalists: engineers manipulate physical artefacts, and develop and construct technologies and infrastructures without a full picture of the broader impacts of their work; they are experimenting and hopefully apply learning from their experiments to their next exercises. The aviation environmental consultant elaborated on this point, noting how ecological damage could be seen as an unintended consequence of engineering work:

> Many times the problem is too narrowly defined. So you have a lot of unintended consequences that end up as [a negative] environmental or social impact. . . . [Engineers tend to look] for the immediate problem, and they don't draw the bounds of what they are studying broad[ly] enough. If they did, I think they would come up with better solutions.

This statement implies that engineers *do* have agency in defining what "the problem" is, and that their ability as problem solvers can allow them to propose more holistic solutions to problems. Further, engineers are increasingly considering the social and ecological effects of technologies, as reflected in the following comments of the CEO of the genetic engineering company: "[E]nvironmental and social implications have come to the forefront of scientists' and engineers' thinking. More people will now ask you about lifecycle analysis. Thirty years ago nobody would have asked, 'Do you have a lifecycle [analysis] for that?' " It is thus imperative that educators train

[26] Murphy (2006) describes how the framing of problems and accepted technoscientific norms dictate responses to those problems. Actions to address problems are taken only when understood by the powerful in the language they have created and under the norms they have promulgated. Murphy describes how sick building syndrome (SBS) emerged and materialized as an occupational illness in middle-aged working women, and how its existence was questioned and rendered imperceptible to industry-sponsored toxicology.

engineers to incorporate broader social and ecological concerns into engineering work. The authors of this manuscript argue that engineers of all kinds and at all levels must be involved in transforming the current technically-focused engineering paradigm into one with public legitimacy in advocating for more nuanced and thoughtful responses to social and ecological problems. As it stands, the NGO scientist remarked:

> How do we solve climate change? Engineers have a limited toolbox. . . . They don't deal in behavior[al] change. . . . People know that their job is to engineer and science-ize. [But] then if . . . an engineer comes back to you and says, "It's all fuckin' ridiculous. You should just all ride bicycles," people will say, "Why are you telling me this? You are . . . an engineer. What do you know about getting people to ride bicycles?" Not only do [people] know the answer [they] are looking for, but [they] are also sort of predetermined to reject an alternative type of answer, because [they] don't trust engineers' [non-technological responses].

In summary, argues the Delta engineer, the existential pleasure of separating the technical aspects of technological development from the political and generally intangible aspects is "probably what engineers are good at *and* what they are bad at. It's good because [an engineer] can get something done without bringing emotion into it, and it's bad because you don't step up and [ask], 'Is [developing this technology with this parameter space] really a good idea?' "

CONCLUDING THOUGHTS

When in the past engineers perceived the scarcity of water as a deficiency of nature, engineers now perceive problems such as climate change as deficiencies of technologies. In both cases, technological solutions were and are encouraged. Specifically, notions of efficiency and growth pervade the current engineering response to climate change just as they did a century ago when rivers of the American West were dammed. While the engineers interviewed believed that most if not all ecological problems could be solved using technology, the interviews also revealed that engineers could be better equipped to address large socioecological problems like climate change if the problems were defined more broadly than just technological problems. Solutions to climate change that consider social, political, economic, environmental, and ecological facets provide the best opportunity to redefine the current engineering paradigm and the technopolitical regime that has caused climate change.

In practice, however, biofuels development continues to separate the "technical" from the "political," resulting in a lost opportunity to reshape the technological development paradigm. Climate change is being used as an opportunity to develop new technologies without questioning the industrialism and capitalism that has created climate change. Framing a problem like climate change as a technological deficiency has unleashed a tsunami of capital investment, incited debates about government regulations and market distortions, and prompted concerns about intellectual property and competition, just as previous technological developments like dams or genetically modified foods have. "Carbon-neutral growth," for all its apparent balancing of the economic and the biophysical, remains a goal founded on *efficiency* and *growth*, both economic and physical. Unless accompanied by changes in socioeconomic behavior, technologies tend to perpetuate established socioeconomic outcomes (Pfaffenberger, 1990).[27]

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[27] In the case of irrigation schemes in Sri Lanka's dry zone, the change to land-based rights access to irrigation water during British rule turned the gravity-flow irrigation system into a socioeconomic differentiation mechanism that created capitalistic class hierarchies, when in fact the previous water-based rights access had allowed equitable access to irrigation water. It was not the technology that had changed, but rather the socioeconomic and political contexts within which it existed that caused drastically unequal outcomes.

Climate change represents a system destabilizing problem (Hughes, 1987), and the framing of climate change as a “carbon” problem is “possibly the greatest and most dangerous reductionism of all time: a 150 year history of complex geologic, political, economic, and military security issues all reduced to one element” (Princen, Manno, & Martin, 2013). To frame climate change as a carbon emissions problem is to invite what Princen et al. (2013) call “end-of-pipe” solutions where “the problem” is that which occurs at the point of combustion—carbon dioxide emissions—and it is the carbon dioxide that must be dealt with through advanced energy solutions. To go upstream—to refining, distribution, drilling, and exploration, let alone investment and, yes, technological development—is to necessarily frame the problem as a complex set of socioeconomic and political decisions influenced by nation states, corporations, and engineering firms. Yet another way to frame the problem, as the significant body of work in political ecology, political economy, and political sociology has shown (Ariza-Montobbio et al., 2010; Borras et al., 2010; Dauvergne & Neville, 2010; German et al., 2011) is as a matter of social justice, particularly when large-scale responses such as biofuels unfold on the local scale.

An important case study to guide future engineering education and technological development is to investigate the role of engineers as political actors working close to or at biofuel plantation sites. In particular, researchers should explore how the engineers integrate local social justice concerns into their work. Research that highlights innovative problem definitions and solutions that challenge traditional engineering paradigms can serve as critical foundations for changing engineering education and practice.

The reality is that every technology causes some negative impacts, at a minimum through consumption of finite resources. That does not mean that we should abandon technology, but rather that we—engineers—need to be better socioecological experimentalists by better accounting for the problems technologies cause so we can mitigate them. Indeed, the engineers interviewed for this paper believe that the problems they deal with are too narrowly defined. Instead, we must live and design within ecological bounds. The authors believe that the problem-solving capacities of engineers can be best used if they are given the more agency and expertise to frame problems technologically *and* socially and ecologically (Karwat, Eagle, Wooldridge, & Princen, 2014), thereby creating legitimacy for engineers in proposing alternative, radical, and paradigm-changing solutions to problems like climate change.

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APPENDIX: STUDY METHODOLOGY

Data for the dam case study involved researching literature on the history of dams, focusing specifically on the framing of the scarcity of water as an environmental problem, and the underlying ethic that guided the federal government and engineers in embarking on a mission that has left every major waterway in the West heavily dammed, with many unintended and ecologically harmful consequences.

To explore engineers' conceptions and technological responses to climate change, one of the authors conducted ten individual, one-half to three-quarter hour, semi-structured interviews with engineers and scientists involved in biofuel work in the aviation industry at the third Sustainable Alternative Fuels in Aviation Workshop at the headquarters of the International Civil Aviation Organization (ICAO, the United Nations body that oversees international aviation) in October, 2011. These interviews provided us with empirical examples of how contemporary engineers and scientists think of problems like climate change. We analyzed interview responses through historical comparison and by placing the interview responses within the context of the philosophy of technology and science and technology studies. The main questions of the interviews were (not all of these questions were asked to all participants given the trajectory of the interviews):

- What are the key features involved in your engineering and technological decisions?
- At what point do you personally consider the social/environmental/ecological impacts and outcomes of a technological solution?
- What gives you confidence in engineering and technology to solve social/environmental/ecological problems?
- What gives you confidence that biofuels will be able to combat aviation's impact on the environment and climate change?
- Is there an environmental/ecological problem that you think technology cannot solve?
- In your experiences as an engineer, how much do you think engineers are involved in framing what "the problem" actually is? Do you think engineers are actually involved in framing what the [climate change] debate is?
- What are two or three things that engineers are good at, and two or three things engineers are not so good at related to thinking about the environment?