ARTICLE

Engineering Improvement: Social and Historical Perspectives on the NAE's "Grand Challenges"

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The list of engineering "Grand Challenges" lately developed by the National Academy of Engineering enters a long historical tradition of such epically scaled to-do lists, dating back to the profession's U.S. origins in the mid-19th century. The mission statements, codes of ethics, and, later, lists of so-called grand challenges that have issued from engineering societies have served the dual function of directing engineers' work and supporting particular cultural roles for these bodies of experts. Almost all such plans, regardless of period or sponsoring body, have also blended highly practical aims of industrial and infrastructural development with more inchoate projects of societal uplift. The *Grand Challenges* of the NAE, currently playing a formative role in many engineering organizations and research and teaching settings, extend this lineage, working from a selective and self-confirming view of human welfare. We might bring to the *Grand Challenges* the type of critical, politically informed analysis that historians and STS scholars have brought to other sites of engineering activity and professionalization, to detect the nature of interests that underlay all such projections of engineering's role in society. Who is served by the development of different technologies, products, and infrastructures? Who might be harmed? Most fundamentally, the *Grand Challenges* proceed from the premise that engineering research, construction, invention, and production are to take precedence over their absence, as befits a body dedicated not to the contraction of such enterprises but to their extension. Yet the interests of sustainability, global health, and other areas of human well-being might be best served in certain cases by just such a turning away from engineering. Making explicit the social and historical assumptions of the NAE's *Grand Challenges*, and probing the implications of those assumptions for a diverse range of actors and communities, may pave the way for more thoughtful engagement with the humanistic and democratic potential of engineering.

KEYWORDS: agency, engineering history, Grand Challenges, National Academy of Engineering, progress

INTRODUCTION

The *Grand Challenges for Engineering*¹ lately developed by the National Academy of Engineering, with their excited inducements for 21st century engineers to "Reverse-engineer the [human] brain," "Make solar energy economical," "Restore and improve urban infrastructure," "Enhance virtual reality," and undertake ten other tasks, enter a long historical tradition of such epically scaled to-do lists (National Academy of Engineering, 2008). As early as the 1850s, as the first formal organizations of American engineers took shape, the individuals involved sought to project long-term goals and professional guidelines for their groups. The mission statements, codes of ethics,

¹ Editors' note: The capitalized, non-italicized forms of "Grand Challenges" and "Challenges" found throughout this paper refer to the broader body of work stemming from the original 2008 NAE Publication. Where the actual publication is inferred, the terms are presented in italics.

and, later, lists of so-called grand challenges that have issued from engineering societies and other entities have served the dual function of directing engineers' work and supporting particular cultural roles for these bodies of experts (Christie, 1922; Downey & Lucena, 1994; Kline, 1995; Pfatteicher, 2003; Wisnioski, 2009). They have spurred countless responses and refinements among engineering subspecialties.

Almost all such plans, regardless of period or sponsoring body, have also blended highly practical aims of industrial and infrastructural development and more inchoate projects of societal uplift, of human betterment. While these prescriptions surely have arisen as part of American engineers' historical efforts to demarcate their occupation from those of artisans and scientists, it is the lists' implied social and moral authority I want to probe. We can see that implication of authority as one element of engineers' status-seeking strategies (alongside claims of technical and economic efficacy), as those strategies have been described by Ronald Kline (1995). It is an element that powerfully ascribes universal human value to the intentions and products of engineering labor. As Matthew Wisnioski frames this historical pattern, "By its very nature, engineering is a normative practice" (2009, p. 753), and since at least 1918 designers of engineering curricula have explicitly called for social and humanistic instruction. The *Grand Challenges* of the NAE, currently playing a formative role in many engineering organizations and research and teaching settings, extend this lineage (Aronowitz, 2010; Azarin et al., 2008; Taylor, 2007; Zappas, 2008). Their integration of economic and productive goals with explicit ideals of social and cultural welfare derives from historical precedents described in this paper.

A perspective informed by the history of technology or by methods of Science, Technology and Society allows us to see not just conceptual continuity among such lists over time, but also their inherent social purposes. The NAE's recent Grand Challenges project, like many earlier prescriptions for engineering practice in the United States, posits extraordinarily broad societal benefits of engineering, using very selective logic to do so. A host of social differences, representing diverse occupational, economic, and global interests, disappear in its unalloyed endorsements of engineering as guarantor of material productivity and solution to human deprivation and suffering. The 2008 publication of the *Grand Challenges* culminated several years of research and review, including the Academy's 2007 solicitation of ideas from the public through a dedicated website. The composition of the final recommendations and oversight of the entire process were undertaken by "leading thinkers" drawn by the NAE from private industry and academia; eighteen people "dedicated to improving quality of life around the globe" constituted a main committee while some forty-eight additional NAE or NAS members and other prominent figures served as reviewers (NAE, 2008). The sense of professional and social prominence being re-inscribed through this project is strong; everyone listed bears the imprimatur of a prestigious university or established corporate or financial entity. The 1,000 suggestions made by the public obviously reflect only those of people who knew of and accessed the NAE's website, not a wide swath of humanity, but whatever the content of those suggestions, the final list of *Grand Challenges* nowhere diverges from a self-congratulatory outlook. It nowhere acknowledges that engineering has long brought differential impacts to persons of higher and lower socioeconomic standing in the U.S. and the world. It asks no questions about existing geopolitical advantages or corporate profit structures supported by engineering.

Another type of divergence is also elided in the *Grand Challenges* document: the ideas of the many engineers inclined to raise such concerns about undemocratic features of their field. Although commendations for NAE's efforts and for the list itself are easily found among engineering groups (Aronowitz, 2010; Azarin et al., 2008; Taylor, 2007; Zappas, 2008), we can understand the creation of the *Grand Challenges* to have been a consensus-building exercise rather than a reflection of

universally held aims among American engineers. Amidst this project of professional self-definition, any possibility of systematic self-critique by engineering is blunted by the document's totalizing claim that, "Throughout human history, engineering has driven the advance of civilization" (NAE, 2008). However well intentioned, the NAE's *Grand Challenges*, as was the case with earlier examples of such lists, forward some ideas of human betterment and not others, some unexamined notion of what might constitute "advance." With this paper I want to highlight the extremely robust nature of uncritical depictions of engineering over the last 100 years, and the enduring marginality within engineering of voices that seek to identify the interested features of that discipline. My aim is to show that qualifying statements which might alert us to the potential limits of engineering as a force for humanistic reform or to the field's negative effects on human welfare *do* exist, often side by side with strongly positive statements. However, the sweeping nature of positive claims about engineering, such as those framed in the NAE's list of Grand Challenges and its historical precedents, help discourage critical assessments of engineering and its products. Instead, we can envision a mission statement or list of priorities for engineering that is conducive to self-critique in this influential field, and crucially, free of occupational risk for those who wish to engage in that self-critique.

CHALLENGING THE CHALLENGES

The NAE's *Grand Challenges* project a vision of an audience for engineering, and for the document itself, that is above all unified. The document opens with a powerful association of engineering with universal human benefit:

In each of these broad realms of human concern—sustainability, health, vulnerability, and joy of living—specific grand challenges await engineering solutions. The world's cadre of engineers will seek ways to put knowledge into practice to meet these grand challenges. Applying the rules of reason, the findings of science, the aesthetics of art, and the spark of creative imagination, engineers will continue the tradition of forging a better future. (2008)

Throughout the 56-page document, which specifies the need for engineering attention to each of the fourteen challenges, similar formulations assert that scientists and engineers engage in a "great quest for understanding many unanswered questions of nature." Such invocations of the inherently praiseworthy character of American engineering, as it has been practiced both in the past and present, draw on generations of similarly selective timelines of human accomplishment (Kline, 1995). A few representative quotes (thousands more are readily found in textbooks, newspapers, speeches, and policy documents across the 20th century) reflect this enduring framing of technical enterprise as invariably a welcome contribution to general human welfare. In 1923, a journalist's profile of General Electric president Gerard Swope noted that the American engineer promises "industrial well-being, of creating greater happiness through the wider distribution of nature's gifts and resources, and through a general furtherance of the march of civilization" (Adams, 1923). Prominent civil engineer William Barclay Parsons, then supervisor of subway construction in New York City, told an audience at Columbia University in 1927 that, "should our civilization perish, its ruins, if excavated, will disclose that it rested on engineering" ("Visions," 1927). General Parsons surely had immediate, perhaps careerist reasons to make such claims for his discipline, but not only engineers raised these points. That same year, the editor of *Nation's Business* told readers that the engineer "designs the useful harness for power, conquers the earth and the water under the earth [and] prospers the works of physicist and chemist. . . ." to function as nothing less than "the prodigious servant of mankind" ("Chips," 1927). In 1938, the author of the popular text, *Builders of Civilization: The Story of Engineering*, proffered ". . . an arresting account of the triumph of the modern engineer," who with scientist and inventor does nothing less than "drive back the brute darkness of ignorance by the light of civilization" (Bennett, 1938, front cover).

UCLA economist Dudley Pegrum in 1944 added a note of historicity to such claims by naturalizing the application of engineering to capitalist culture:

The resources which constitute the basis of man's economic life are labor, the gifts of nature, and accumulated wealth. The dominant characteristic of the last two hundred years of western civilization has been the amazing expansion of man's capacity and the consequent growth of population enjoying a standard of living heretofore unknown. The basis of the great change we call industrialization has been the application of physical sciences to the production of economic goods. (p. 158)

This kind of language gained wide resonance during and after World War II by outlining a close fit between processes of human cognition and presumably universal ambitions for material prosperity, reflecting a long-developing American faith in applied scientific knowledge, as has been described by Kline (1995). A collectivity among all those who live with and around the products of engineering was routinely asserted in this kind of formulation. General Motors headed a 1945 magazine ad with the phrase: "Progress More Quickly," assuring readers that its new technical research center in Detroit would "bring about MORE and BETTER THINGS FOR MORE PEOPLE (original capitalization)." In 1948, Gulf Oil promoted the work of its refinery engineers with ads claiming that its engineers were "well aware that there is a 'plus' for everyone in petroleum's progress." Undeniably, wartime had brought a certain urgency to encouraging public faith in American industry and infrastructure, but this was lasting rhetoric about the assured benefits of engineering beyond immediate national security needs. Western imperialism had long rested on dovetailed images of technological modernization and universal human uplift, albeit uplift that would deliberately bring variable improvement to the lives of persons seen to be of different races or nationalities (Adas, 2006; Anderson, 2002; Mrazek, 2002). For some, the geopolitical realignments wrought by the war seemed to call for a reassertion of older views of American technological hegemony. Writing in 1950, John Charles Lounsbury Fish opened his treatise on "The Engineering Method" by quoting in full a 1925 presidential address by William Frederick Durand to the American Society of Mechanical Engineers, in which Durand reminded his audience that "we are engineers and as such hold a position of peculiar trust and responsibility in connection with the progress of civilization" (p. 1).

In many of these endorsements, whether corporate, journalistic, popular, or scholarly, the sheer variety of engineers' contributions invoked by the writers affirmed engineers' value to society. A 1942 book written for young people, part of the "Way of Life Series," describes the products of the civil engineer's labor:

... a new sewerage system stem, or a water supply improvement for your own home town. It might be a railroad plunging through forests, deserts, swamps, and mountain, where finally you see the shiny rails leading on and on before the eye. Or canals to make a desert green; dams to harness the white horses in a mountain stream and turn their ageless energy to electricity; a pipeline to bring oil or gas to a large city or seaport. ... And the loftily beautiful skyscrapers reaching for the clouds depend for their sturdy assurance on the skill of the civil engineer. (Bennitt, 1942, p. 6)

If the scope of engineers' contributions to humanity was wide in such depictions, the origins of engineering were also seen as fortuitously heterogeneous. In 1954, Linton Grinter, preparing his seminal report on engineering education, described the field as resolutely synthetic, applying while transcending the "methods of mathematics, physics, and chemistry" by merging those methods

with "engineering art in a professional way to provide for the convenience and welfare of the public" (p. 259).

As I will discuss below, the 1960s began to see a pronounced concern among public and some expert groups about the impacts of modern science and technology on human society and the planet as a whole, which continued as an identifiable movement through the early 1980s. Yet the self-descriptions of engineering institutions maintained a thread of sweeping positivity about the field's contributions to the human condition, in some instances by minimizing the real world origins and impacts of technical knowledge. New knowledge has thus been cast in these self-descriptions as inherently desirable. Five and a half decades after Grinter's report appeared, the NAE's *Grand Challenges* echo his correction to the popular misapprehension that, "scientists and engineers have distinct job descriptions" when in actuality, the NAE's document explains,

... the distinction is blurry, and engineers participate in the scientific process of discovery in many ways. Grand experiments and missions of exploration always need engineering expertise to design the tools, instruments, and systems that make it possible to acquire new knowledge about the physical and biological worlds. (2008, p. 48)

The continuity between historical ideas about engineering and those found in the 2008 *Grand Challenges*, and the uniform commitment across the decades to a final and positive judgment regarding an entire area of human endeavor, is fascinating to the cultural historian. How can such a sense of assurance possibly have persisted in the face of cultural change? For one thing, we assuredly feel, albeit impressionistically, that in our own lifetimes we have a fuller understanding of human culture than did people of previous generations, that knowledge about our human culture somehow accretes. Otherwise the experience of being "modern" would have no meaning. Much of the language used in essays of 1927 or 1957 sounds florid and fusty to our ears; we might wonder: "how can the ideas expressed since that time not also have changed?"

Perhaps more concretely (and defensibly), we might simply observe that in the early 21st century we have the benefit of many counter-arguments that have drawn our attention to the questionable benefits and manifold risks of engineering (Sismondo, 2008). As the existence of this journal itself indicates, engineers contribute to that critical perspective. Yet those critiques have not obviated messages, such as that delivered by the *Grand Challenges*, asserting the collective good inherent in engineering; we might take a moment to try to understand why not.

PROGRESS AND CRITIQUE

Critiques of industrialization issued from 19th century American philosophers and critics with the first factories, but during the Great Depression and World War Two these analyses perpetuated. At mid-century it was not just well known figures such as Lewis Mumford and J. Robert Oppenheimer but many progressive writers and thinkers who saw science as fueling the "harmful factors and effects" of industrialization and geopolitics, one economist summarizing that "the control and direction of scientific progress should be considered wishful thinking" (Slaton, 2010; Sullam, 1942, p. 393). In a great many cases academic critiques of mainstream science and technology and public sentiment built on one another. During the final third of the 20th century, Americans encountered not only Rachel Carson, but highly organized anti-nuke, back-to-nature, and environmental movements in their own communities. Influential figures such as Herbert Marcuse, Jacques Ellul and Theodore Roszak supplied a literature on which countless college courses' syllabi were based. By 2008, "eco" sensibilities had revitalized in the face of global warming and catastrophic oil spills. Anti-industrial activists, while fewer in number than in Europe, organized around U.S. meetings of

the World Trade Organization and similar bodies felt to be responsible for the worst environmental transgressions and economic inequities of globalizing capitalism (Wisnioski, 2009; Sismondo, 2008). Recent critical studies have also incorporated growing concerns about the privatization of the American university and worrisome exertions of influence by industry on academic scientists (Croissant & Smith-Doerr, 2008; Newfield, 2008).

It is thus apparent that American culture regularly generates doubts about the safety and democratic potential of science and technology, and that for some citizens at least, those activities are no longer imagined to be tethered to a positivist science in ways that once supported unidirectional, entirely upbeat narratives about human ingenuity (Appleby, Hunt, & Jacob, 1995). Matthew Wisnioski and Rebecca Slayton offer particularly suggestive accounts of experts from within science and engineering who have experienced such doubts (Wisnioski, 2009; Slayton, 2004). So the historical question for me, in the face of the NAE *Grand Challenges*, is not how optimism about engineering can persist; engineers today make tremendous contributions to human welfare through both dramatic innovations and the routine work of designing, building, and manufacturing our material reality. Rather, the question is how it is that *unalloyed* praise for engineering can persist, as seems to be the case through much of the *Grand Challenges* document and as is very much the undertaking's overall impression.

Crucially, I am not seeking a singular, let alone dismissive, evaluation of the Grand Challenge's intent and/or outcomes. The document has value to any society that hopes to spread the benefits of health, shelter, and ease of living that technologies can provide. It gathers persuasive arguments for the application of ingenuity, energy, compassion, and inclusive impulses towards those ends. Such impulses have always been part of the motivation and function of engineering in the United States. In an important sense, however, all self-defining projects undertaken by authoritative scientific bodies (for example, any such report issued by the National Academies) might be said to be more or less concerned with reputation. This is in fact true of all expert practice, but as historians of science have demonstrated, the norms of Western science discourage explicit or implicit acknowledgement of the field's subjectivity, let alone fallibility, by that field's practitioners and patrons. To the contrary—it is observers' trust in scientific practitioners that lends a sense of facticity to those practitioners' findings. (Shapin, 1994). In the same way, the *Grand Challenges* both presumes and helps to create trust of engineers among readers by foreclosing any discussion of doubts about engineers' knowledge or practice.

This is by no means to say that the NAE is *not* trustworthy, but the organization's production of reliable, definitive engineering knowledge necessarily includes the production of trust. For the authors of the *Grand Challenges*, that creation of trust is apparently (and regrettably) a process to be devoid of criticality or debate. This is a deflection endemic in Western engineering: As Sarah Pfatteicher has shown, codes of ethics that historically have urged engineers to practice only within the limits of their own competence have rarely defined those limits clearly. In this way engineers have made their own standards of competence more or less loose, but also, crucially, made them virtually impossible for non-experts to apply (Pfatteicher, 2005; Slaton, 2001). We could add that these efforts to demarcate the competence of engineering sub-fields virtually never suggest that engineering as a overall category of practice may hold risks for human society (Pfatteicher, 2005). I am drawing critical attention to the near complete absence in the *Grand Challenges* of points that might suggest any such practical uncertainty or social complexity. I hope to encourage greater openness in our everyday thinking about what engineering has done, historically, and what it can do (Brown, Downey, & Diogo, 2009).

SELECTIVE DEPICTIONS OF AMERICAN ENGINEERING

In order to draw this more nuanced and open-ended picture of American engineering, we can start by identifying ways in which the *Grand Challenges* direct our attention away from flows of power and privilege in technical practice. This occurs in part because the *Grand Challenges* document does not refer to the complex social conditions of its own creation. To take an example, who participated in the writing of the document and who did not, and in what capacity? Readers are provided with a list of names of those who served on the "diverse committee of experts" responsible for the document's content. We are told that they are "some of the most accomplished scientists and engineers of their generation" whose work was then reviewed by "more than 50 subject-matter experts." Some of the names are instantly recognizable as prominent inventors and entrepreneurs, their fame confirming their accomplishments in those particular realms. But we learn nothing of these participants' experience (if any) in the study of societal impacts of engineering, their ideological standpoints, or their relative influence on the composition of the document. We know nothing of what counted as valid expertise in the creation of the *Grand Challenges*, let alone as credible "worldwide input" from persons or publics deemed to be non-experts by those in charge of the report (Zappas, 2008). Critical engineering studies of the last decade demonstrate that participation in engineering enterprises is largely determined at the major points of entry into engineering, such as public education systems and universities, and professional work settings. These institutions do not yet represent all sectors of our society equally; persons of minority and economically disadvantaged background and, in many instances, women are still underrepresented. It is not clear if or how the production of the *Grand Challenges* addressed these discriminatory conditions of expertise (for a summary of this scholarship see Brown et al., 2009).

We should draw no simple equivalence between such current exclusionary habits and those of earlier generations. We no longer traffic in crudely racialized presumptions about the innate technical talents of different groups, as that evident in the 1927 magazine profile of Gerard Swope, mentioned above. In that piece, Swope was said to be identifiable as the perfect "idealistic engineer" in part because he possessed "thin lips often pursed in thought when in repose" and "sharp clean-cut features," both traits invoked in opposition to the facial features thought to signal non-white genetic heritage (Adams, 1923). However, we do use unexamined criteria (standardized tests, adherence to certain curricular experiences) to judge the talent of aspiring engineering students, and those criteria reassert lines of racial and class differences (Purdy & Wasburn, 2005). And, while we would assuredly not propose today, as did an engineering textbook of 1916, that the engineer must not only be male but also be committed to a "normal family life," homophobia persists in engineering (Cech & Waidzun, 2011; Pawley & Tonso, 2010; Slaton, 2001). Identity constrains opportunity in engineering in many ways. In its claims of definitive knowledge about what constitutes human welfare (the "grand" of "grand challenges" perhaps), uninflected by such issues of identity and inclusion, the NAE's document reifies socially constructed and socially impactful definitions of expertise and "forward edge" technological practice.

Relatedly, despite what I must presume to be sincere concern with the well-being of all who live with the products of engineering, the interests of many non-expert communities are set largely out of view in the very formulation of the fourteen Grand Challenges. They are simply not part of the "story line" of engineering here (Martin, Scott, & Strout, 1995). For example, consider the recommendation that engineering fields make it a priority to "Engineer new medicines." We learn in the NAE document that personalized medicine, building on genetic and genomic techniques, can increasingly base patient treatment on individual biology. This implies an unprecedented precision in medical practice, but in declaring that precision and customization to be the primary goals of bioengineering, this Grand Challenge also empowers researchers' inattention to the collective social

conditions that in part determine our health. Variable nutrition, exposure to pollutants, and workplace risks among different communities and similar socially conditioned factors in human health are hidden. Individuals, cast by the *Grand Challenges* authors as fortunate consumers of medical and pharmaceutical innovation, are not authentically empowered by these developments because they are not given the option of choosing effective preventive strategies.

Again, I don't deny the tremendous benefits to be derived from the development of new medicines. But a "glass-half-full-or-half-empty" framing of these matters forecloses constructive conversation, and those benefits will be limited if we ignore the larger social world in which pharmaceutical and bioengineering innovation occurs. The totalizing claims of the document overall for the beneficial impacts of engineering discourage such a heterogeneous intellectual project. Not least worrisome is the elision in this Grand Challenge, however inadvertent, of engineering's role in causing illness. For example, agricultural engineering and food processing techniques of recent decades have introduced contaminants into diets that are now understood to produce cumulative exposure and serious risks (Santi, 2010). Science and bioengineering reveal those dangers, but these dangers remain offstage in the *Grand Challenges*, rendered irrelevant in the contemplation of hopeful portrayals of the field.

The idea that bioengineering might bring mixed blessings for humanity, visible when its impacts are viewed through the largest lens, is not a recent development. Even in 1942, V. B. Sullam could write concernedly of Ehrlich's pharmaceutical discoveries in light of globalization:

A world free from syphilis, from meningitis, from pneumonia . . . What else could we dream of? But, with tropical diseases held in check new frontiers would be open in Asia, in Africa, in South America, and agriculture would become unprofitable in the OLD World; new and tremendous problems would arise. (p. 393)

Sullam stresses the interdependency of global markets to convey the mixed impacts that a scientific "advance" might have on different populations, rather than assert some falsely unified if familiar picture of human welfare. But such concerns about technical enterprise are almost always developed and shared *outside* of engineering disciplines themselves, or compartmentalized within engineering as humanistic or policy *aspects* of technical work, rather than as reflecting conditions that might be generative of engineering work itself (here Riley, 2008, is extremely helpful).

We might consider the Grand Challenge to "Prevent nuclear terror" to embody this pattern. The document articulates the staggering dangers of nuclear technology falling into the hands of terrorists, but then completely disaggregates that misapplication of nuclear knowledge from the institutional and intellectual developments that give rise to legitimate incarnations of nuclear energy. That is, the Grand Challenges initiative fails to acknowledge that legitimate activities in this case are a precondition for illegitimate activities. American policy makers are currently advocating for the expansion of nuclear power production on the presumption that security is a surmountable matter; we are not attempting to solve the security problems before proceeding. The *Grand Challenges'* authors acknowledge that, "Ensuring that a nation using nuclear power for energy does not extract plutonium for bomb building is not easy," but the larger framing of how such high-risk situations arise in part through the participation of engineers is not an element of the Grand Challenge discussion. While the discussion of another Grand Challenge, "Securing cyberspace," gives much more attention to shortcomings in technological realms ("The problems are currently more obvious than the potential solutions"), the occupational, institutional, and market forces that have brought about that situation and *that may impede its improvement* are not addressed.

THE AGENCY OF ENGINEERS

It seems reasonable to conclude that if leaders of the American engineering professions, such as the NAE, put such forces at the center of their analyses and recommendations, the work of engineers might begin to include inquiry about the social origins and impacts of that work. Defining engineering problems in light of such up- and downstream conditions would require a concerted shift in the field; in no engineering job description that I know of appear the words, "Determine the broadest social and political conditions in which you perform your technological tasks and act accordingly." Such a work requirement sounds absurd to our ears, but that sense of absurdity in fact arises from a culturally specific idea of engineering which can be challenged. Similarly, it is easy to picture how engaging in that kind of institutional contextualization could lead to arguments against the necessity of one's own employment; without some newly imagined sort of job security the risks to engineers who participate in such self-critique are immense. But some if not all engineers historically involved in humanistic reforms surely have had just such profound recalibrations in mind, despite such impediments as the entrenched instrumentality of the field, so powerfully described by Seron and Silbey (2009). We might take this opportunity to draw a sharp line between a new sort of social agency for engineers and that customary instrumentality.

The somewhat passive or reactive character ascribed to engineers in the *Grand Challenges* might discourage the uptake of social and political responsibility by engineers. Despite the authors' repeated appeals to engineers' social values and proactive impulses, in many ways the text conveys that the status quo is acceptable. Consider the *Grand Challenges* authors' endorsement of engineering work on sustainable energy sources:

Anticipating the continued use of fossil fuels, engineers have explored technological methods of capturing the carbon dioxide produced from fuel burning and sequestering it underground. (NAE, 2008, p. 3)

Since one of the fourteen challenges is to "Make solar energy economical," we should not assume that by "anticipating the continued use of fossil fuels" the authors really mean "accepting" that use. And yet, economic context is nonetheless presumed by the authors of the *Grand Challenges* to determine the value of engineers' research, and thus appropriately to direct that research:

Engineering solutions for both solar power and nuclear fusion must be feasible not only technologically but also economically when compared with the ongoing use of fossil fuels. (NAE, 2008, p. 3)

This phrasing posits the relative affordability of technologies as a standard for meritorious engineering research, but historically, affordability has been judged in industrial societies through the lens of corporate profit. Cost saving and profit are notoriously conservative forces in capitalistic economic systems, leaving patterns of material privilege (and disadvantage) intact. As MacKenzie and Wajcman put it, "economic shaping is social shaping" (1999, p. 13). The Grand Challenge authors acknowledge that "engineers' earlier projects have . . . unexpected or negative impacts," but offer all such caveats with so little contextual analysis that these qualifications lose their power to shape the future of engineering.

This orientation towards social and political neutrality seems, to me, to be incompatible with critical assessment of engineering and thus with genuinely democratic practice. Social scientists have demonstrated that patronage (sponsorship of innovation and production) is strongly determinative of the impacts of technology (Croissant & Smith-Doerr, 2008; Mackenzie & Wajcman, 1999; Moore, Kleinman, Hess, & Frickel, 2011; Newfield, 2008). Yet, that element of American

engineering is rendered almost entirely opaque in this document. The bald, celebratory rhetoric of pro-capitalist voices in earlier decades simply attributed our quality of life to corporations. In 1944, economist Ludwig von Mises editorialized that the techniques and products of "Big Business," from "noodles, soap, [and] cigarettes" to "railroads" and "rayon" are characterized by "... an unceasing tend towards improvement" (p. 3). But no such associations, either laudatory or critical, are exposed in the *Grand Challenges*, as engineering appears in the text to be a service-oriented yet oddly autonomous body of knowledge work. Without some frank discussion of the structures of patronage, how can the NAE's aim of fairly and deliberately distributing engineering's benefits possibly be enacted, on either a national or global stage?

A number of historians and social scientists have lately honed in on the idea that engineers are too often cast, even in their own promotional rhetoric, as "problem solvers" rather than "problem definers." In this way, engineering has limited not only its professional status relative to policy and science fields, but also discouraged its practitioners and publics from seeing technological expertise as potentially a politically progressive instrument (Croissant & Smith-Doerr, 2008; Downey, 2005; Slaton, 2010; Wisnioski, 2009). However, even that sort of critical analysis may not offset one of the most powerfully conservative features of the *Grand Challenges* and similar prescriptive projects: the foreclosure of the possibility that engineering may not be the answer to a social or material problem.

It is the patent function of the *Grand Challenges* to show the role of engineering in meeting the needs of current and future human societies, but the document's logic is totalizing in claiming that those needs "await engineering solutions." Andrew Abbott has shown that professions routinely undertake such self-justifying activities to persuade their audiences of their particular utility (Abbott, 1988). But unlike professions with narrower claims to societal benefit, such as accounting, or with humanistic claims confined to a single area of human experience (however grandiose), such as medicine, engineering often articulates an especially diverse social utility. I do not suggest that we assess the relative contributions of different expert groups to human welfare or even the validity of such claims, both ridiculous exercises that would land us in an infinite regress of criteria-setting and evidence-choosing. Rather, if we are concerned with the impact of knowledge production systems on human welfare, we might learn a great deal by studying the precise means by which bodies of expertise attain their credibility. Historically, observers from Thoreau onward have interrogated the universalizing and self-perpetuating logic of industrialization, by which expectations of economic growth demand technological innovation, which in turn begets more economic growth. Engineering demands more engineering, as Mumford made clear. Again, while engineering has surely improved the quality of life for countless individuals in industrialized societies, obscuring this self-perpetuating logic cannot be consistent with thoroughly progressive social ideologies; hence the problem with setting "engineering challenges" in the first place ... they are predetermined to necessitate more engineering.

Consider in this regard the NAE Grand Challenge centered most clearly on America's built environment, a call to "Restore and improve urban infrastructure." Happily, in articulating this challenge, the authors do not uncritically call for the replacement of existing structures. Instead, they highlight the creation of new facilities, such as "hubs" that may support the addition of mass transit, bikes, or walking to existing road systems. Yet the document stops short of casting roads as part of the problem so that we might entertain the possibility that fewer built structures in these settings would be better. Certainly, the authors introduce no larger point about the sometimes unsustainable or undemocratic nature of American civil engineering projects. Nowhere do they ask us to think about the legal and policy structures that continue to facilitate the construction of, say, new roadways and suburban developments, long after the ill effects of such sprawl, on both the

environment and urban communities left behind, came to light. Pro-automobile, pro-development, and even pro-business ideologies that balk in principle at limiting any private enterprise in this country will militate against engineering work on such "hubs" even at the funding and design stage, let alone at the technical research and construction stages. As in many portions of the document, mention of "various policies and political barriers" to changes in the aims of engineers is confined here to a single sentence included after and apart from other points, rather than treated as integral, pervasive forces in the built environment (see Nieusma & Tang, this issue). "Political forces" must be marshaled in order for engineers to work effectively, we read, but engineering itself is cast by extension as something other than a political force.

CONCLUSIONS

As neoliberal ideologies gaining credence among American policy makers and politicians tighten their grasp and market forces play an increasing role in Americans' determinations of what counts as worthwhile technological inquiry, it may become more difficult to draw attention to possibly harmful effects of engineers' labor (Brown, 2006). There is a Sputnik-era sense of urgency surrounding Western scientific innovation in 2012, for its promise of both economic and national security applications, and amidst fears of an ostensible "skills gap," an accompanying illogic to doubting the national need for more engineers and engineering (Slaton, 2012). At the same time, since this discussion has raised doubts about the efficacy of what is clearly a well intentioned project, it is worth repeating that on every page of the *Grand Challenges*, welcome developments in health, shelter, mobility, labor saving devices, and national security as well as directions for further such improvements are instantly recognizable to the engineers, educators, employers or policy makers who are the likely readers of the document.

The suggestive point here, however, might be in those last words: ". . . *the likely readers of the document.*" How would people of other nations or cultures, outside the usual audiences for NAE recommendations, read this document? Or, persons living in economically disadvantaged American communities that have historically borne the costs, rather than benefits, of the nation's industrial or infrastructural development? The universalizing tone of the *Grand Challenges*, implying that there are better and worse material projects in which humans might engage but that all humans share the same material interests, supports historical patterns of material privilege and injustice. Technological developments that enhance aspects of my life can have costs for others: my inexpensive household heating comes from the use of coal obtained through mountaintop-removal mining, a process that has caused incalculable environmental and community harm in parts of Appalachia. My ability to purchase inexpensive household appliances derives not only from the genius of inventors, materials experts, and process engineers, but from the low wages of factory workers in other parts of the globe.

The alternative to relentless positivity is not negativity, but criticality, or openness of inquiry. The selective outlook of the *Grand Challenges'* authors could be recognized as such. The categorization of certain problems as engineering problems might be shifted in helpful ways here. If the Grand Challenges project advocates for the control of chemical weapons, for example, it might also ask what is *not* remedied when chemical warfare is indeed foiled by nano-engineered detection devices—the sources of geopolitical conflict that give rise to the weapons in the first place. With such a wide lens, defense spending might be reconfigured to include economic development in troubled nations, perhaps through U.S.-led innovation in health and water distribution technologies, say. Or, we might ask, "what is not fixed when American cars run on renewable fuels?" The answer: The economic system that deprives those who do not own cars of proximity to jobs, healthy food, and pleasant communities, and the reification of that system in a road-based

infrastructure. "Why roads at all?" we might ask anew. We need to put the work of engineers (and our expectations of their work) on the broadest possible stage to assess its meaning for human society; flattery gets us nowhere, literally.

These reorganizations of "problems" and "solutions" involve taxonomic change, questions about where engineering begins and ends. These are being asked by historians, sociologists, and policy makers working in the loosely defined field of Science and Technology Studies, but also by those who write about economic equity, environmental history, labor history, and many other subject areas in which engineered structures and systems have had an impact. Activists, as noted above, have also asked these questions as they contend with perceived challenges to health, sustainability, and quality of life in the U.S. and global settings. This paper emerges not from a belief that the authors of the *Grand Challenges* hold some particular ideological position about health, sustainability, energy production, or any of the geopolitical matters surrounding these areas of human enterprise. Rather, it derives from a powerful sense that the well intentioned authors and promoters of these 21st Century *Grand Challenges* are operating at a distance from the critical scholarship in which those non- or extra-engineering fields engage (Sismondo, 2008). The document fails to engage with the important historical finding that technical knowledge is *necessary* in order for technical expertise to improve human welfare, but *not sufficient*, as historian of urban technology Scott Gabriel Knowles has put it (2011). The Grand Challenges help us set priorities; some projects are more worthwhile than others, without organizing our work we cannot make headway. But questioning the definition of what counts as headway may be the most important challenge of all.

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