THESIS

SEEING BEYOND DESIGN: EXPLORING NON-ENGINEERING FUNCTIONS OF TECHNOLOGY IN ENGINEERING ETHICS

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ABSTRACT

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The purpose of this paper is to draw a distinction between the function of technology in engineering contexts and non-engineering contexts. The first two sections identify and elaborate this distinction; the final portion of the paper demonstrates why engineers should be aware of non-engineering functions of technology in light of this distinction. Both engineering (or design-based) and non-engineering evaluations of technology can be categorized within the genus of engineering ethics. However, I do not intend to provide a commentary on how engineers might improve the design process. Rather, my goal is to provide an argument as to why it is important for engineers to understand the limitations of the design method of evaluation. In order to do so, I will outline various non-engineering evaluations of conventional nuclear technology and the correlations between non-engineering evaluations and advanced nuclear designs of today. In closing, I will distinguish engineering as a method, a metaphysical concept, from engineering as a profession, an ethical concept. I will conclude by demonstrating that understanding the limitations of the design method is an essential feature of professional engineering. Through introducing the limitations of the design method it will be clear why engineers should learn to see beyond the design.

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Chapter 1 -- Metaphysical Reform and the Function of Technology from the Design Perspective

In this chapter, I introduce the metaphysical framework that supports my primary argument that if engineers are to assume responsibility within a society, they must understand the limitations of the engineering discipline with respect to other systems of knowledge. The limitations of an engineering conception of technology are illuminated through an analysis of the functions of technology from a variety of perspectives.

I introduce R.G. Collingwood's epistemological reform of metaphysics, which identifies absolute presuppositions as the basis of any form of knowledge. Collingwood argued for the replacement of traditional metaphysics, or the study of *being* as such, with a metaphysic solely concerned with identifying the fundamental assumptions, or absolute presuppositions, that define the systems of knowledge used to understand human experience. I apply Collingwood's reconceptualization of metaphysics to technology. In doing so, I reject any absolute ontological conception of technology with a metaphysical conception of technology based on practical method. Fundamental presuppositions are discovered through the critical inspection of questions that give rise to particular disciplines or sciences. Collingwood's metaphysical reform enables a plurality of sciences to evaluate the same phenomena without establishing ontological priority among them.

I begin this chapter with an outline of the engineering or design-based method used by engineers to evaluate technology. The design-based method is generally teleological in the sense that technology is evaluated based on a prescribed purpose established by the designer or engineer. In other words, design assessments of technology are established entirely on the fulfillment of design parameters. Any evaluation of technology that takes advantage of methods beyond design are, therefore, external to the engineering process.

Coordination between disciplines is difficult. There is a popular Indian parable that is a useful metaphor for understanding why. The story involves a group of blind men in a squabble regarding the nature of an elephant. Eventually they come across an elephant and decide to settle the matter, but since they cannot see the animal, they observe the creature by touch. After their individual investigations, they return to the group to share their experience. Each one of the men is disgruntled by his comrades' account of the elephant, because none of the accounts matches up. One man, having felt the elephant's trunk, claims the elephant resembles a rope; another feels the creature's sturdy belly and likens it to a wall. The men argue for hours, unable to reach a consensus until a wise bystander fills them in on a secret: elephants are very large creatures--each man, in his search for understanding, misidentified his limited experience as reflecting the entirety of the animal. In philosophical terms, the subject-matter and method of a discipline are confined within specific epistemological boundaries. These boundaries are hard to identify and even harder to cross over. As a result, communication becomes difficult--people talk past one another like blind men describing the different parts of the same elephant.

For our purposes, the elephant is technology. The purpose of this paper is to understand technology from an engineering design perspective. In order to do so, however, we must explore a variety of perspectives distinct from design. I argue that if engineers are to assume responsibility within society, they must understand the limitations of the engineering discipline with respect to other systems of knowledge. Through the process of understanding, they will come to realize that the rest of the world does not evaluate technology based on design standards--that is the job of the engineer. Rather, other disciplines evaluate technology in accordance with their own unique methods and purposes. Understanding the boundaries between engineering and non-engineering methods would enable the coordination necessary to solve complex societal problems in the coming decades. The sooner engineers see themselves as an integral perspective in a collective understanding of technology, the sooner technology will progress rather than merely change. A more efficient machine does not necessarily mean that it is a better machine.

When I entered engineering school, I had a simple understanding of technology. I considered technology to be a tool, gadget, or system brought into existence by a designer in order to perform a specific task. I assumed, years ago, that someone invented the hammer for driving and removing nails; the bicycle was made because someone was tired of walking; the Wright brothers invented the airplane to feel what it is like to fly. When we speak about a technology being *for* something, we are usually referring to its *purpose*, and when we think of a technology's purpose, we think of the idea held in the mind of the designer when the technology was first conceived. This purpose acts as a *reason* for the creation of a technology. For instance, if you were to ask a carpenter why he crafted a bookshelf, he might point you in the direction of a messy pile of books.

An object has instrumental value if it exists for the sake of something else. My early understanding of technology, thus, was instrumental. Technology exists in order to increase productivity, effectiveness, social mobility, communication, and creativity. Each time we want to get to work, communicate with a friend, or fly across the country, we take advantage of the instrumental value inherent in technology.

The purpose of the machine, structure, or artifact acts as an explanation--a reason for the technology's design and physical manifestation. This type of explanation, articulated clearly in Aristotle's metaphysics but also in his ethical and political thought, uses a prescribed purpose or end to explain phenomena. In Aristotle's metaphysic, natural objects, like vegetation and animals, are embedded with purpose. For instance, the acorn, driven by its internal telos, reaches maturity as an oak tree. By contrast, non-natural objects, like artifacts, are given a purpose by an external source. The purpose of an artifact is determined by its creator--a rational agent and in most cases, a human being. Bronze is shaped by the hand of a craftsman into a statue for purposes of worship, protection, and as an offering to the gods. Under Aristotle's conception of an artifact, these purposes, or *final causes*, provide an explanation for the existence of an artifact--a reason for being.

The typical understanding of technology is, in many ways, teleological; most people interpret a technology's telos not in regard to its designer's intention but in terms of how they interact with it. The citizens believe the reason for high-speed rail is to take those who live in the suburbs into the city so that they may work and earn an income for their families. They subscribe to this reasoning even if the mayor might see the rail line as the fulfillment of a campaign promise--a way to gain political power. Though the common understanding of a technology’s purpose is derived from how a person interacts with the technology, I intend telos to refer only to the deliberate intention of a designer.

By the time they finish an undergraduate degree, engineers have learned to evaluate technology from a different, but related, perspective. Engineering programs introduce a new dimension of technology through exposure to mathematics, theoretical sciences, design methods, and other practical tools necessary for completing complex designs. The introduction to theoretical and applied systems of knowledge and tools is intended to build up a student's technical understanding so that any future problem is met with a sufficient dose of “know-how.” This “know-how” is the essence of engineering (Mitcham 1994, 220). Individuals inside and outside the engineering profession conceptualize engineers as the collective facilitators and deliverers of know-how--the providers of technical expertise and judgment. Know-how is knowledge required to find the precious metal, remove it from the earth and shape it into something society values. Simply put, know-how is the *design* of an artifact--the knowledge of the final form an artifact must take in order to fulfill its intended purpose. Aristotle called this explanation, the design of an artifact, the artifact’s *formal cause.*

When engineers graduate, they become doers, designers, movers of earth, or, generally, agents who bring technology into a physical manifestation. As agents they publish their research, pass on their designs, and monitor their solutions carried out by builders, contractors, and technicians. The engineer acts and, as a result of his action, the plans and conceptions that he formalized are made concrete. Aristotle called the being that manipulates material into an artifact an *efficient cause*. The professional engineer, in her submission of designs, drawings, and procedures, is the initial efficient agent that jumpstarts the physical manifestation of a particular technology.

Aristotle’s aforementioned causes provide the metaphysical basis behind the engineering or design-based understanding of technology; technology is an object designed and crafted for the fulfillment of a purpose determined and manifested by its creators. When newly graduated engineers begin their careers, they are setting out on a career in which they act as the final, formal, and efficient cause of artifacts consumed by the rest of society.

Within the last century, the teleological conception of technology has come under scrutiny, particularly from non-engineers--most notably, scientists, political theorists, economists, and philosophers. Those outside the design process have identified unforeseen consequences of technology and criticized the enormity of its environmental impact and influence on political and social action. To them, technology appeared to function in ways *other than fulfilling its intended purpose*. Coal, for example, provided the energy needed to fuel a technological revolution that had far-reaching political, economic, and social consequences. It powered steam engines, heated homes, and generated the power to manufacture the artifacts of two world wars. From an engineering methodology, the technologies that supported the coal industry functioned as its designers intended. If the function of a technology strayed from its intended purpose or failed to fulfill its purpose in an effective manner, the design process was altered to accommodate an improvement. Yet, in the second half of the twentieth century, closer inspections of the use and consequences of coal consumption led to a significant change in the future of energy production, societal values, and, eventually, political discourse. From the perspective of a non-engineering person, coal has functioned as a global pollutant.

In light of criticisms regarding fossil fuels, those maintaining a teleological conception of technology--that is, most people working within the engineering design process--have found ways to mitigate pollutants by altering the design constraints of particular technologies. By adhering to values like sustainability, the non-technical values are integrated within the design process in the form of specific parameters. In the wake of the environmental movement, more environmental scientists have found seats at the engineering design table, and environmental engineering courses have sprouted in engineering schools around the country. The integration of environmental science into engineering design indicates that the purpose of technology from an engineering perspective (expressed in design parameters) has become more complex. For instance, the design criteria of the modern automobile have expanded beyond their initial purpose of merely providing a mode of transport. Today, a car must get people to where they need to go while maintaining a specific gas mileage, meeting strict emission standards, and, of course, pleasing consumers aesthetically. Thus, in some way or another, the problems introduced by non-engineers in the early part of the 19th and 20th centuries have been addressed within the modern design process.

To a large extent, a teleological understanding of technology is maintained in engineering schools today because it is foundational to the concept of engineering design. As Aristotle instructed, in order to create an artifact, the purpose or final cause of that artifact must be clearly conceptualized within the mind of the craftsman. Thus, according to the Aristotelian conception of artifacts, teleology is integral to the design process and always will be.

Louis Bucciarelli, a seasoned engineer, consultant, and author on the design process has written at length about the ambiguous and complex nature of design in such a way that might make the Aristotelian conception of an artifact seem like a caricature (Bucciarelli 1994). No design team, according to Bucciarelli, fully comprehends the design parameters at the beginning of a design process because, more often than not, practical complications and even specific desired outputs arise throughout the development of a design. Rather, engineering design is a social process, changing as users' expectations, technological methods, and R&D teams combine to create a cohesive, or sometimes not-so-cohesive, end product.

Although it may be true that the complex nature of modern design makes ancient conceptions of artifacts appear overtly primitive, it would be a mistake to claim that modern technology is different in kind rather than degree. Despite the fact that the final cause of modern technology might require more time, coordination, and expertise to discern and integrate an intention into the design parameters, the finished design must nonetheless articulate a purpose for the technology. Without intention, without a final cause, an artifact is nothing more than a random assembly of material--an object rather than a tool, a stone in rather than a hammer. Thus, as long as constraints are properly integrated into a design, an engineer can modify the purpose of a technology and establish a prescribed end, a final cause. Therefore, from the perspective of a designer, the *function* of technology has largely remained the same--to fulfill the purpose established by its designers--even if the values that influence the purpose have changed. Through the eyes of the designer, the political, economic, and environmental constraints within the design process are simply additional spokes added to a wheel of parameters to consider in the design process. Adding spokes does not alter the nature of the wheel--it just makes the wheel stronger.

The Metaphysics of Technology without Ontology

I did not realize what troubled me about the designer conception of technology until I left the university to work as an engineer in training (EIT). As it so happens, during my stint as an EIT, I took my first philosophy class remotely. The time spent working alongside professional engineers in tandem with the critical reflection I practiced in my introduction to philosophy course led me to be inclined to believe that engineering education was lacking a critical element. It was not until I discovered R.G. Collingwood's restructuring of metaphysics without ontology that I realized the shortcoming was epistemologically and metaphysically linked. I will briefly summarize Collingwood's metaphysical project and provide a discussion of its relevance to the designer's conception of technology.

Collingwood argues that all knowledge is derived from experience, and our understanding of the world takes its shape based on how we express, formulate, and organize practical experiences. Furthermore, the ways we have come to interact with the world determine our conceptions of reality. The sixteenth century whale-hunter, for example, thought about his world in ways we might consider simple, practical, or based firmly in common sense; the ocean is an unforgiving and dangerous place; the reef knot is useful for furling sails; years on a boat make a man yearn for the return trip to dry land and his family. By contrast, Isaac Newton understood reality in a more theoretical manner. Instead of relying on his senses to navigate through the world, Newton opted for a theoretical reality, hidden from the senses, that, in many ways, defied commonsense understanding. The world acted according to unseen laws of nature, and any explanation of nature that exempted natural laws was a bastardized description of an objective reality. The sailor might tell you why the anchor sinks, but his explanations did not depend on Newton's laws of motion. Rather, according to the seaman (and Aristotle), the anchor sinks simply because anchors are heavy objects made of iron.

According to Collingwood, the boatman's qualitative reality fundamentally differs from Newton's quantitative reality because of the nature of his work as a sailor. It was never necessary for the boatman to venture beyond the common sense understanding of the world because a common sense understanding is all he needed to sail a ship. Likewise, Newton, as a part of the English aristocracy, willingly retreated from the world of common sense, passed beyond the realm of perception, and pioneered theoretical science as we know it. Similar to the sailor, Newton's methods of understanding were a function of his work. Being a natural philosopher demanded quantitative understanding.

Returning to Collingwood's metaphysic, the activities necessary for action are possible only through the adoption of "absolute presuppositions." Without the presupposition that "reality is fundamentally quantifiable," neither Newton, nor any other modern natural philosopher, could ever have developed a mathematical understanding of physical processes. The realization of absolute presuppositions in all forms of knowledge led Collingwood to the conviction that presuppositionless knowledge or knowledge of pure being is incoherent. Thus, there is no sense in claiming knowledge of any objective reality or a reality beyond a specific method of understanding. Later in his career, Collingwood called for a reformulation of metaphysics away from ontology. In his *Essay on Metaphysics*, he argues for the replacement of traditional metaphysics, or the study of *being* as such, with a metaphysic solely concerned with identifying the fundamental assumptions, or absolute presuppositions, that define the systems of knowledge used to understand human experience (Collingwood 1940, 34-48). I will explain in the following chapter how these systems of knowledge are distinct in subject-matter and methodology.

Collingwood's metaphysical project attempts to illuminate the various presuppositions that lie behind different forms of inquiry. An easy way to understand Collingwood's metaphysical approach is through analyzing the meanings behind commonplace terms and concepts used or assumed in practice. Inspecting the meaning of these terms helps to identify the absolute presuppositions that govern different disciplines (D'oro 2002, 16-19). Collingwood thought that if we can better understand what is meant by concepts like *being, cause*, and *action* in different contexts, we will have a better understanding of the fundamental assumptions that undergird our various methods of understanding.

For instance, the concept *cause* does not carry the same meaning in every science.[1] When a physician uses the word "cause," her intended meaning is different than that of the molecular biologist whose meaning, in turn, differs from that of the historian. If a historian was asked to explain a statement like, "The attack on Pearl Harbor caused the United States to enter World War II," she would spend much of her time explaining *thoughts*. These thoughts might be reasons, motives, or the intentions of government actors who contributed to the decision to enter the war. Thus, to understand the meaning of *cause* in the historical sense means to attribute reasons, motives, and intentions to relevant actors. The subject-matter of historical explanations is mental or rational objects--occurrences *in the mind* of thinking persons. In Collingwood's words regarding mentalistic causation, "that which is caused is the free and deliberate act of a conscious and responsible agent, and causing him to do it means affording him a motive for so doing" (Collingwood 1940, 285). Put more simply, "to cause" in the historical sense is to think or, perhaps, re-think.

When the technician, doctor, or engineer speaks of causes, he is primarily referring to an event *in nature,* that is, an event not occurring within the mind but one external to it. He does not explicitly refer to reasons, motives, or intentions of actors like the historian. Of course, in the practical sciences, an event in nature has occurred by mental activity to some extent--for example, the design process, the prescription of medicine, or the intentional pull of a lever. However, the technician is primarily concerned with how these plans are executed and how they affect the physical world. For example, following the Aberfan coal mine collapse in the 1960s, the British government ordered an investigation into the causes of the collapse. Engineers responsible for the structural integrity of the coal mine tips (deposits of waste material collected near the opening of mines) were obligated to provide a mechanistic explanation for the tip's failure, which included concepts like soil saturation, coefficient of friction, and bearing capacity of soil

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[1] Here, I am not using the word "science" to mean natural science--the science promoted and used by Galileo, Bacon, and Newton--as we do today. Rather, by "science," I refer to its original meaning, namely, "a body of systematic or orderly thinking about a determinate subject-matter" (Collingwood, 1940, 4). This meaning is more in line with the Latin word *sciencia*, or discipline. I will use the word science in this general sense unless specified otherwise.

materials. These engineers were not responsible for providing thoughts, reasons, or motives for keeping the mine open against the advice of regulators. Such explanations were not part of their purview. Rather, their obligation as engineers was relieved after they gave a physical or mechanistic explanation of the event. Thus, the subject-matter of the technician's explanation is a non-mentalistic *event*.

Even further removed from the mental or internal sense of causation are the explanations found in modern and post-modern theoretical sciences. All events within the physicist's explanation are removed from any instantiation of purpose, intention, motive, or reason. That is to say, the physicist's explanation operates within a strictly mechanical and determined universe. If she uses verbs like "wants," "tries," or "likes," she uses them metaphorically or as a short-hand method to refer to an otherwise determined event. Like the technician, but to an even greater degree, the subject-matter of the physicist's explanation is completely external to the mind.

The historian qua historian does not construct theories and predictive principles of behavior as does the theoretical scientist because formulating theories and predictions is not what the historian does. Moreover, the weapons designer is not concerned with how his weapons are used because he is neither a military strategist nor an international diplomat, and the theoretical physicist has no room in her laboratory for the poet in her quantifiable, determined universe.

Within Collingwood's metaphysical understanding, the distinguishing factor between sciences is the absolute presuppositions which provide the boundaries of a science's subject-matter and method. Since subject and method are largely a function of the practical nature of a science, no subject-matter or method carries ontological priority over another. For instance, the theoretical physicist has no justification to support her claim that natural *events* are more real, in an absolute sense, than *thoughts* or events of the mind. Similarly, the methods of natural science are not epistemologically superior to the method of historical reconstruction. The truths delivered by a particular science--be they in the form of laws, predictions, reasons, motives, or mathematical principles--are restricted within the universe of discourse particular to that science. Due to its separation from ontology, Collingwood's metaphysical reform enables a plurality of sciences to evaluate the same phenomena without establishing ontological priority among them. For example, Collingwood considered the controversy over the mind-body distinction to be the result of a misunderstanding of method and presuppositions.

The human being, understood from the perspective of a mental scientist (like a historian), is a mental object. Thus, to explain a person's behavior is to explain a person's thoughts. Conversely, the same human being, understood from the standpoint of a natural scientist, is a physical object. To explain a person's behavior as a natural scientist is to describe its bodily motions mechanistically in terms of muscle contractions and electro-neurological firings. The explanations presented by the historian will be different than those of the natural scientist because the two understand the human being in ways that are methodologically distinct.

Collingwood's reform of metaphysics provides an alternative perspective on the metaphysical and ethical understanding of technology. As I mentioned previously, from an engineering perspective, a technology's function is evaluated based on how well or ill the function fulfills its prescribed purpose outlined by its design parameters. If a battery does not retain a charge, the battery is evaluated poorly by the engineer--some chemical reaction was not triggered; perhaps the operative temperature fell below what was specified. However, the teleological evaluation of technology from the design perspective is not necessarily the only relevant evaluation of technology. Sciences which evaluate technology independently of a prescribed purpose are on equal ontological footing. There is no justifiable ontological priority between an engineering evaluation and a mentalistic, e.g., political, evaluation of technology. The function of a technology is also not ontologically fixed. Rather, the function of a technology depends on the method used to evaluate it. The Hoover Dam functions differently to the engineer than it does to the politician, economist, ecologist, or tourist.

If different sciences generate different evaluations of technology, why should it matter to the engineer? How will non-technical evaluations of technology affect the design process? To some extent, engineering design will not change at all. The engineering evaluation of technology will remain teleological--concerned primarily with fulfilling a prescribed end. However, as Bucciarelli argues, engineer design is a complex social process, and the design parameters of a technology are not established concretely until the final design is complete (Bucciarelli, 1994, 195). Thus, in some sense modern, engineers have room to adjust design parameters in order to account for evaluations from other sciences.

Regardless as to how this approach affects the design process, important ethical questions arise from a metaphysical understanding of technology free of an absolute ontological framework. Should engineers be concerned with the function of technology not accounted for by their design parameters? Should an engineer's understanding of a technology never venture beyond the design-method-evaluation? How are engineers to make sense of criticisms that evaluate technology irrespective of a technology's purpose? Do engineers share public responsibility in the use, effects, and unforeseen consequences of their designs? Philosophers, political theorists, and engineers have written about these questions (Winner 1980; Son 2008; Mitcham 2010). If any of these questions is answered in the affirmative, a further investigation into the various functions of technology is necessary. After all, most technologies criticized by scientists, political theorists, economists, and philosophers are not critiques of the prescribed purposes of technology but rather of a technology's function evaluated from outside the design process.

Outlining distinct methods of evaluation will be the subject matter of the next section of this paper. For the purpose of illustration, I will focus primarily on the political, ethical, and environmental evaluations of nuclear energy production. Despite the fact that these methods often overlap in practice, I will argue that they offer metaphysically distinct approaches for evaluating the functions of nuclear energy production.

The discussion of evaluative methods in the following section will provide a foundation for the final section in which I argue for the reconceptualization of engineering ethics in terms of responsible understanding. In my conclusion I will argue that if a responsible engineer is to engage in the design and implementation of a specific technology, she must also participate in evaluations of technology from aplurality of metaphysically distinct methods, i.e., engineers must know how to evaluate the function of a technology based on methods other than engineering design. They must be able to "see beyond design."

Chapter 2 -- Four Evaluations of Nuclear Energy Production

My principle aim for this chapter is to demonstrate how sciences are distinct in their presuppositions, methods, and, by extension, evaluations of specific technologies. In this chapter, I outline four methods used to evaluate technology: engineering design method, political method, economic method, and environmental method. The subject matter of political and economic assessment is rational *thought*. That is, political and economic evaluations seek to understand the thought process of political and economic agents who influence or are influenced by technology. Design and environmental analyses assess technology through empirical methods. Thus, the subject-matter of the design and environmental method are *events* that occur outside the mind of engineers or environmental scientist. The metaphysical distinctions between sciences are applied in four evaluations of nuclear power reactors based on the respective methodologies. After the political, economic, and environmental analyses are complete, I outline various ways in which the design method has accounted for non-engineering assessments of conventional light-water nuclear reactors (LWR) through the designs of advanced nuclear technologies (ANR).

The shift in nuclear reactor design from LWRs to ANRs illustrates how changes in design are responses to non-engineering assessments of technology. However, further reflection on the historical analyses of technology suggests that, even if ANRs account for the critical assessments from non-engineering sources, criticism of nuclear technology will persist from non-engineering disciplines. Thus, engineering design will continually be incommensurate with evaluations of technology from external sources. The perpetual criticism from non-engineering methods does not indicate a flaw in the design method. Rather, non-engineering criticism indicates that the design method of analyzing technology is limited in its capacity to account for non-engineering evaluations.

Before I expand on different methods of evaluation, I will briefly summarize the various presuppositions of the different sciences I will use. I will evaluate nuclear technology[2] based on three distinct but related sciences--namely, political science, economic science, and environmental science.[3] Note that these evaluations will not belong to a specific school or tradition within a science--I will not give, for example, a Marxist evaluation of nuclear technology, although such evaluation is certainly possible. Rather, in my evaluations I intend to make explicit the methodology of political thought in general.

In order to delineate the various methods, I will outline the ways in which different sciences conceptualize a specified subject-matter. I do not wish to belabor questions regarding the nature of political thought because the point I wish to make does not necessarily depend on a specific formulation of method. All that I intend to demonstrate is that the methods used to evaluate technology have distinct presuppositions.

I will close this section with a discussion of how these evaluations have influenced the development of advanced nuclear technology in the United States. I will accomplish two things in this chapter. The first is to illustrate that any understanding of a technology's function is dependent upon the discipline conducting the analysis. For example, political evaluations of technology will illuminate a *political* function of technology, and an environmental evaluation of the same technology will articulate an *environmental* function. In other words, my first aim is to show that a single technology has multiple, distinct functions. My second goal is to explicitly demonstrate how engineering design is confined within

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[2] When I refer to nuclear technology, I mean nuclear energy production unless specified otherwise.

[3] Here, I am not referring to political science and economics as they are often thought of under the umbrella of "social science," which is primarily based on empirical methods. I am borrowing a distinction from R.G. Collingwood, who differentiates mentalistic or philosophical sciences from empirical sciences based on subject-matter. (Collingwood 1940, 285) I will refer to political and economic sciences as mentalistic sciences--meaning their subject-matter is *thoughts* rather than *events*.

a universe of discourse particular to the design method despite the fact that design criteria are often shaped by disciplines outside engineering design.

To be clear, my intention is not to present an argument for or against further investment in or production of nuclear technology. I have intentionally identified common evaluations of nuclear energy production. Some of them are deployed to bolster arguments for more research and development of nuclear power; others are used to deter further investment in the industry. My aim is to show how sciences are distinct in their presuppositions, methods, and, by extension, evaluations of specific technologies.

Design Evaluation and Method

To review, engineers predominantly evaluate technology teleologically, i.e., based on a predetermined purpose outlined by design standards. Thus, according to the engineer, a technology's function is always understood relative to a specific end. If a technology underperforms or fails to accomplish its prescribed purpose, one of two assertions can follow. First, something might have run amok in the design process--the relation between the prescribed purpose and the design parameters was faulty. Perhaps a misestimation occurred in the research prior to design, or a miscalculation might have been overlooked within the design itself. For instance, if someone were to design a guitar to be strung with spaghetti instead of nylon strings, he might end up with an engaging craft for a toddler, but he will not be making any music. The second type of failure might involve a flaw in the application of the design. For example, the NASA Challenger exposition failed due to a misapplication of the rocket design, not the design itself. An O-ring was used outside its design parameters[4] resulting in a fuel leak and explosion. Had NASA's management decided to launch during conditions within the specified design parameters, the launch would have likely transported the astronauts safely into orbit. Generally speaking, if design

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[4] The ambient temperature was too low at the time of the launch.

parameters are adequately researched, calculated, and adhered to during manufacturing and application, a technology will be positively evaluated based on design method standards.

The necessity of research and calculation is indicative of the prominent presupposition regarding the method of engineering evaluations, namely that technology is evaluated through induction. Understanding whether a technology has fulfilled its purpose is achieved through observation and careful measurement in order to detect alignment or deviance from design parameters. If the engineer's measurements do not match what was expected by design standards, then the technology did not function in accordance with its prescribed purpose. Thus, measurement and empirical verification are the methodological tools by which the engineer evaluates a technology, and design-based evaluations necessarily presuppose empirical methods. As I mentioned in Chapter 1, the subject-matter of engineering evaluations is an external event as opposed to an internal thinking process. Engineers are not expected to comment on the thoughts of other people. Rather, the job of the engineer is to give mechanistic explanations of events regarding technology and the effects of technology.

Political Evaluation and Method

Political evaluations of technology consider how a technology might influence patterns of social power and authority within a group of people. More precisely, political analyses are reconstructions of the thinking of political actors. In a democracy, the political actors are the public; in a republic, the actors are elected representatives; the head of state is the primary actor in an authoritarian government. Although political evaluations of technology are often understood in the context of governance, political evaluations of technology are also applicable in more refined contexts such as in business, academia, or the family.

In his essay, “Do Artifacts have Politics?” Langdon Winner makes two assertions regarding the political nature of technology (Winner 1980). The first suggests simply that some features of a technology are capable of altering the distribution of political power within a group of people. In Winner’s words, “we noticed ways in which specific features in the design or arrangement of a device or system could provide a convenient means of establishing patterns of power and authority in a given setting” (Winner

1980, 134). Particular features of a technology might be wielded in favor of particular political ends. Some features of technologies are used as a means of fulfilling the desires of political actors. In such cases the purposes of the technology are malleable--able to be adjusted based on the political outcomes desired by those in power. Winner states that technologies that act as political tools retain some technical flexibility within their design constraints and material form. This type of political artifact is exemplified most clearly in the deployment of military weapons to accomplish a task with specific political ends, such as the Union's positioning of military ships to block essential imports from England to the Confederacy in the Civil War.

However, some technologies, according to Winner, result in shifts in political power without intention. For example, the widespread use of agricultural harvesting machines in California in the 1960s and 70s was a result of the complex relationship between agricultural research institutions, primarily the University of California, and corporate interests. Although capital gains were clearly a motivation of corporate investors, the social and political consequences of the technology were not necessarily the result of a predetermined plot. Behavioral scientists who studied the lawsuit between farm worker activists and the University of California specifically argued against there having been any intentional political motive in the design and implementation of the technology (Barton, Friedland 1976, 42). However, in the end, the installation of the machines reconfigured the balance between the social and political actors in rural agricultural communities. As a result of the machine, power in the industry shifted to favor large corporations who had vested interests in industrializing agricultural markets. Small-operation farms that depended predominantly on immigrant and low-wage workers for labor struggled to match the production and revenue norms of industrialized farms, which made use of the new technology.

As a result of corporate technological investment in coordination with publicly funded research institutions, small farmers struggled to compete for a place in the domestic and international agricultural markets after the introduction of the technology. The harvester machines led to a decrease in the number of tomato farms from around four thousand farms in the early 1960s to around six hundred farms in the late 1970s. By the start of the 1970s, nearly 100 percent of the tomatoes grown in California were harvested by the machine. (Barton, Friedland 1976, 35). Similar political and social observations are applicable to many other cases in which automation has displaced workers and revolutionized an industry.

Winner is convinced that the invention of the tomato harvester is likely not an example of a technology invented deliberately to control social and political dynamics. However, it would be a mistake to say that the institutions that brought about these social and political shifts were not political actors--that is, that they were not aware, to some degree, of the political ramifications of their new technology. A more appropriate claim is that the institutions that introduced the tomato machine were not acting maliciously toward rural farming communities. In other words, the researchers and inventors behind the machine did not consider the *moral* implications of their creation. However, moral forethought is not an essential quality of political agents, especially when opportunities to benefit politically or financially from a new technology are involved.

The second assertion by Winner is a much stronger claim. Winner suggests that some technologies might confine a society to a particular form of political structure. In Winner's words, "In the second instance we examined ways in which the intractable properties of certain kinds of technology are strongly, perhaps unavoidably, linked to particular institutionalized patterns of power and authority" (Winner 1980, 134). In such cases, the flexibility to adjust the desired constraints and material form of a technology is lost. Once the technology is implemented, the political consequences are fixed and no amount of creative ingenuity or political resourcefulness could "change the intractability of the entity or significantly alter the quality of its political effects" (Winner 1980, 134). Thus, according to Winner's second assertion, technology, once put in place, ossifies the political framework of a society and, again, functions independently--removed from any political actor's desires or prescribed purposes.

An example of the second type of political evaluation of technology is presented by Winner in his discussion of the political rigidness of conventional nuclear technology. Winner argues that the instantiation of nuclear energy necessitates a highly centralized form of management due to the complexity of waste disposal--in particular, the risk of the propagation of nuclear waste for the construction of military weapons. According to Winner, the threat to national security would require a heavy-handed type of governance once nuclear power plants were in operation.

To some extent, Winner's observation of the political nature of nuclear energy has been proven accurate in the last four decades. The US Nuclear Regulatory Commission maintains strict licensing procedures for new nuclear plant proposals that heavily regulate safety, waste management plans, and environmental protections. Moreover, it seems reasonable to conclude that further investment in nuclear technology might lead to an increase in centralized control over the energy market. However, investment in nuclear energy did not materialize in the industry as nuclear enthusiasts had envisioned in the 1970s. Moreover, the future of nuclear energy production might not restrict the political landscape as much as Winner anticipated. Later, I will offer some evidence that appears to run contrary to Winner's analysis in light of recent developments in nuclear technology; specifically, advanced nuclear technologies might provide some of the technological flexibility that Winner argued was an impossible characteristic of nuclear energy.

The subject-matter of political thought is rational or mentalistic phenomena. Thus, political evaluations involve thinking in two forms: reconstructing the thoughts of political agents--the wielders of political power; and reconstructing thoughts regarding political theory--thoughts belonging to those who have systematized different means of distributing power throughout a society. For our purposes, political evaluations are mentalistic explanations including theories, reasons, and motives behind the development and application of technology. This holds true in both instances of Winner's analysis of political technologies.

It would be foolish to ignore empirical methods in political evaluations of technology. Quantification can be a useful tool for analyzing political events. However, if politics refers to the philosophical science of understanding political *action*, i.e., the free and intentional attempt to acquire power, empiricism can only act as *evidence* of thought.[5] The contemporary political scientist who treats political action purely as an object of empirical investigation, e.g., an event, substance, or thing, does not recognize the mental activity to which I refer here.

In its first form, a political evaluation of technology involves reconstructing the thought process of rational political actors. To consider our previous example, the individuals responsible for the deployment of the tomato harvester knew that the machine would increase the productivity and profit margins in such a way that would make it more difficult for traditional farms to compete. The desire and opportunity to revolutionize the tomato industry made the investment in, research into, and development of the tomato harvester a *rational* choice. (Note that I am not claiming that it was the morally appropriate choice. I am only claiming that the decision to invest in the technology is consistent with their desire to change the tomato production industry.) Rethinking this decision is a political evaluation in the first sense.

In the second form, political evaluation requires the application of political thinking to a specific context. The instantiation of nuclear technology, as Winner argues, fixes the distribution of power in favor of a centralized entity. In this proposition, Winner takes advantage of his understanding of different forms of governance, e.g., authoritarian vs. democratic, and critically applies them to a specific technology. This is an example of the second form of political evaluation.

Economic Evaluation and Method

Both political and design-based evaluations of technology have economic components to them. For instance, a governor will have a hard time convincing his constituency to vote for a twenty-two-billion-dollar infrastructure plan if the economic demands require a hike in taxes. Similarly, an

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[5] Empiricism acting as evidence of thought is analyzed by R.G. Collingwood in his *Idea of History*; Collingwood argues that “exact sciences,” i.e., sciences that identify thought as their subject, attempt to understand the problems facing particular individuals in particular circumstances. Thus, the methods and findings of the empirical scientist are *useful* to the political (in the mentalistic sense) scientist insofar as her empirical findings are understood within the appropriate context.

engineering consulting firm will justifiably discontinue their design of a proposed highway expansion if the department of transportation asks for a nonviable financial budget. Despite the overlap with other sciences, the economist has a method of evaluation of technology different from that of the politician or the engineer. Namely, the economist is concerned with decisions regarding matters of utility--how a technology would influence the distribution of resources, e.g., water, manpower, capital, and wealth, that could be used for other purposes within a society.

The engineer thinks in terms of utility, usually in the form of expediency or efficiency specified by design parameters. However, the question of whether or not the interstate is paved with concrete as opposed to asphalt does not concern the economist until the values of the materials have been converted into economic terms. The politician also concerns himself with utility as he seeks the acquisition of power. However, the economist pays no attention to whether party X has a seat on a regulatory committee unless changes in policy result in changes in utilities, such as federal investment. The economist is concerned with decisions that influence how people are employed by the highway construction project, how the increased capacity in traffic flow will affect the number of city-dwellers who move to the suburbs, and how the expanded highway will financially impact the tourism industry. The economist evaluates the utility of a technology in terms of how it might satisfy the motivations of people who intentionally control the distribution of resources transferred through society.

As noted in the previous example regarding the tomato harvesting machine, economic activity often plays a pivotal role in political thought. The critical distinction between economic and political action is that economic action is inherently instrumental. Economic thought is an action taken to fulfill some ulterior end, such as the acquisition of political power. Thus, a politician can utilize economic thought.

Like political evaluations, economic evaluations of technology are rational reconstructions of the *thoughts* of economic agents. They take the form, “do X so that Y.” Although the empirical methods and quantification of values is often a necessary step in measuring economic development (especially in universities where economics is considered an empirical social science), economic action is rationally rather than empirically based. As is so in politics, thought is the subject-matter of economic science. The fundamental presupposition of all economic action is the intent to maximize gains--to "buy cheap and to sell dear" (Collingwood 1926, 170). Thus, the motivations for performing a specific economic action are best explained not empirically but rationally, from an adequate understanding of contextual, often quantifiable, elements.

Environmental Evaluation and Method

The final science I wish to discuss evaluates a technology based on its environmental impact. The environmental scientist, ecologist, or conservationist considers how a technology might alter, obstruct, or compromise a pre-existing object or system in nature. The definition of nature is controversial. However, the work of the environmental scientist necessitates that she determine a specific condition of nature to act as the basis for evaluation--be it a non-anthropocentric state existing before the introduction of human influence on nature (even if this state is an approximation or based on modeling) or simply an arbitrarily established "natural condition." Having established a condition of normalcy, the environmental scientist evaluates technology based on the degree and kind of influence a technology has on a predetermined state in nature.

Generally, environmental evaluations of technology are inductive and empirical--based on the measurable effects that a technology has on the natural environment. Although a natural condition might be described in qualitative terms like beauty, health, or balance, the environmental scientist must refer to the condition of the environment in empirical terms, i.e., quantifications, generalizations, and predictions. Otherwise, her function ceases to be scientific and resembles the aesthetic. Thus, like the engineer, the environmentalist evaluates the function of technology through empirical methods, and the subject-matter for environmental investigation is *events* in nature.

To summarize, political and economic evaluations of technology deploy rational methods that seek to bring an understanding of technology on the basis of reconstructed reasons, motives, and desires of political and economic agents. As for the sciences that provide *empirical* evaluations of technology, I will offer evidence of the influenced design alterations and environmental mitigation techniques in nuclear energy production. After a brief introduction to the development of nuclear energy in the United States, I will apply the aforementioned sciences and formulate evaluations of nuclear energy production based on each evaluative method and subject-matter.

Nuclear Energy in the United States

There are many variations of nuclear technology. However, generally speaking, nuclear power is generated by a chain of controlled fission reactions that emit heat. Heat from fission is then converted into steam that, when pressurized, rotates a turbine. The mechanical energy from the turbine is converted into electricity, which is distributed to utilities, stored in batteries, or consumed on-site.

After the discovery of a controlled fission reaction and the invention of the atomic bomb in the first half of the twentieth century, the nuclear energy industry in the United States benefited from heavy public and private investment. In 1954, Lewis Strauss, chairman of the U.S. Atomic Energy Commission, infamously projected that one day nuclear electricity would be “too cheap to meter.” The first nuclear reactors were designed to power submarines, which used ocean water as the principal source for cooling the reactors. This system was called the light-water reactor (LWR) design. Most existing nuclear reactors in the world have been constructed using LWR designs, and every operative nuclear power plant in the United States is a version of the light-water reactor.

Construction of nuclear facilities peaked in the 1970s and 80s due in large part to its promise of cheap energy and as an alternative to an increasingly powerful fossil fuel industry. Public optimism followed technological innovations that resulted in nuclear-generated electricity powering utility grids across the country by the late 1970s. During the next ten years, two major nuclear meltdowns--at Five Mile Island (1979) and Chernobyl (1987)--drove nuclear production and investment into relative stagnation. However, despite investment and production pullbacks, global nuclear energy production peaked in 2006 and has remained relatively consistent over the past two decades (WNA 2020). According to the US Energy Information Administration, in 2019, ninety-six operating nuclear reactors provided twenty percent of domestic energy production, trailing only coal and natural gas as sources of energy. Globally, nuclear power plants account for roughly ten percent of energy production.

The 2012 nuclear meltdown in Fukushima, Japan was another highly publicized event that undermined public trust in the industry. However, new technological innovations have revived interest in investment in advanced nuclear technologies, and new nuclear production has reemerged as a relevant subject in technological, political, economic, and environmental discourse.

Future nuclear energy technologies look very different from the light-water reactors of the last century. New innovations in advanced nuclear production have been designed to mitigate the costs, security, and safety risks of conventional pressurized water-reactor designs. The changing tide within the nuclear industry is a result of a multitude of political, economic, and environmental drivers. In many ways these non-engineering forces have directed the design goals of advanced nuclear technology that are in development today. However, as previously mentioned, design-based evaluations of technology use a method unique to the engineering discipline. Design changes in advanced nuclear technologies enable new evaluations of nuclear technology based on societal values and previous criticisms of the nuclear industry. However, while these new assessments use updated criteria, they are still based on design criteria; that fundamental issue has not changed. Any resultant understanding from the design-based method must, therefore, be confined to the epistemic boundaries established by design parameters.

Political Evaluations of Nuclear Energy

Nuclear technology has been subject to political criticism since its inception. The optimism that followed the initial investment in nuclear energy production in the 1970s has been dampened by mishaps made public throughout the last fifty years. Within this time frame, discontent with nuclear energy production has come from political agents such as environmental advocacy groups, Native American tribes, and the general public. In spite of recent efforts to shift public perception of nuclear technology to a more favorable position, the negative reputation of nuclear power largely persists. Thus, the widespread disapproval of nuclear energy production is one of the most significant political hurdles for advocates of the industry today. I will outline a few objections to the nuclear energy production process that drive public skepticism in the United States.

There are several objections to nuclear energy production. Foremost, images of nuclear meltdowns are hard to forget. The destruction that resulted from the aforementioned nuclear disasters has engendered strong suspicion regarding the safety of nuclear reactors. The light-water reactors currently generating nuclear power need an abundant supply of water to maintain the system's cooling mechanism. If any problem occurs that prevents the cooling system from functioning, meltdowns occur. Thus, nuclear reactors must be able to withstand unprecedented circumstances including natural disasters like tsunamis, hurricanes, and tornadoes. Reactors located in coastal regions exposed to extreme weather events, like the plant in Fukushima, Japan, are especially susceptible to damage that might result in a catastrophe. Although alternative cooling mechanisms are being explored in advanced nuclear designs, the salience of any large scale devastation will likely influence the public perception of all forms of nuclear technology.

Furthermore, concerns over the disposal of nuclear waste exacerbate political issues with nuclear technology. The controversy regarding Yucca Mountain, a proposed long-term waste depository just east of the California-Nevada border, has publicized mounting conflict between utility companies and the federal government regarding the long-term disposal of spent nuclear fuel. The State of Nevada has successfully led attempts to block funding and execution for the depository, citing environmental concerns over leaking nuclear waste and the lack of consent from Nevada residents and the Western Shoshone Indian Nation, whose reservation is in close proximity to the cite. The enormity of the problems inherent in back-end energy disposal has contributed to the political battle for the industry being an uphill one since its conception.

Additional public discontent followed mishaps involving uranium mining and milling practices necessary for the nuclear fuel supply. Uranium mines and mills, if handled improperly, can be detrimental to environmental systems and human health. Sparked by the World Uranium Hearing in 1992, large antinuclear advocacy movements have brought uranium mining under increased scrutiny especially by native tribes in the United States, Australia, and Canada. Evidence that mismanaged uranium mines caused increased rates of lung cancer and kidney disease in Navajo communities in Arizona has been documented (Arnold 2014, A47). Such findings have contributed to the argument that mismanaged uranium mining disproportionately affects the health and safety of underrepresented communities like the Navajo.

Aside from nuclear energy's negative public perception, further criticism of the political nature of nuclear technology involves the rigid managerial and regulatory demands that are required by the technology. As I mentioned previously, Winner argues that nuclear technologies do not function with the technical and material elasticity necessary for decentralized management--especially in comparison to renewable sources like solar energy. The inflexibility of the industry stems largely from issues related to waste proliferation. Production of nuclear waste is a concern for any government's oversight of nuclear technology for civilian purposes. The possibility of plutonium-rich waste being appropriated by enemies of the state--foreign or domestic--presents too great a danger to national security to rely on self-regulation of the industry. The risks to national security and public health posed by back-end fuel disposal alone practically mandate strong governmental oversight over the disposal process. Thus, a vote for nuclear energy is a vote for heavily regulated energy production.

Moreover, due to the large price tag of conventional nuclear power plants, past and future political evaluations of nuclear power generation are particularly important for the continued existence of the nuclear industry. Although private investment in advanced nuclear technology has increased, the financial resources needed to bolster a nuclear energy revival will require support from federal and state governments if nuclear technologies are to compete with fossil fuels and popular renewables.

Economic Evaluations of Nuclear Energy

All economic evaluations are used to inform economic action--that is, decisions intended to maximize the value of resources. Economic evaluations of nuclear energy are primarily utilized to make informed comparisons between nuclear energy and other forms of energy. These comparisons are useful to an assortment of institutions--e.g., private investors, government agencies, environmental advocates, and microeconomists--seeking a better understanding of the technology's influence on systems like energy markets or public policy.

Economic analyses of operating nuclear power plants generally focus on production and expenses. Production is the output capacity of the plant, measured in watt-hours. Expenses are the costs necessary for production. A general economic unit of productivity divides the total output capacity of the plant by the expenses resulting in an average generating cost of electricity. Generating costs of conventional nuclear plants are divided into three categories: capital expenditures (which include up-front building costs and regulatory management), operational expenditures (which cover engineering fees and on-site management), and fuel expenditures (NEI 2019).

Nuclear power plants are notorious for requiring enormous initial investment--sometimes orders of magnitude higher than their renewable competitors like solar and wind. However, conventional nuclear reactors are among the best sources for consistent long-term energy production or base-load energy, comparable only to fossil fuels, such as natural gas and coal. As a result, nuclear is positioned in a unique place in the energy market. The up-front cost of building nuclear power plants is steeper than most alternatives; however, once in operation, nuclear power provides a steady source of low carbon-emitting energy.

In the United States, nine nuclear power plants have prematurely closed since 2013, and five additional plants have announced plans to shut their doors in the coming decades (NEI 2019). The reasons for premature plant closures are primarily the result of two common pressures--market forces and policy. Market pressures are mostly driven by the increasingly falling price of American domestic natural gas production. The production of natural gas has steadily increased from 2005 to 2018 (EIA 2019). The increase in natural gas production has driven down natural gas prices to such a degree that changes in the gas market greatly impact the financial viability of other domestic sources of energy. As a result, natural gas, a base-load energy option, is a dominant force in the domestic base-load market. According to the Nuclear Energy Institute, the low price of natural gas will continue to suppress the wholesale energy market, making it difficult for conventional nuclear power plants to produce a competitive product (NEI 2019).

Another predominant, albeit indirect, economic stressor on nuclear energy production comes from federal and state energy policy. More than two-thirds of states have proposed renewable energy standards that mandate utility companies purchase a certain percentage of renewable energies in the wholesale market. Nuclear energy is not included as a viable source of renewable energy because of its reliance on fuel that is non-renewable. Thus, nuclear energy is often excluded from many environmental policy initiatives. In some cases, the exclusion of nuclear from environmental policy initiatives has driven nuclear energy prices into negative pricing (NEI 2019).

Although economic analysis of technology is intimately related to political, environmental, and technological factors, the function of nuclear technology can be uniquely evaluated in economic terms. Economic actors understand nuclear technology with respect to its generating costs, consumption of resources, and impact on markets. Analyzing the movement of resources, especially movement related to policy and market pressures, is a necessary evaluation if engineers are to understand the economic function of conventional and future nuclear technologies.

Environmental Evaluations of Nuclear Energy

From an environmental perspective, no form of energy extraction, from harvesting corn to constructing wind farms to mining coal, is free from inflicting consequences on the environment. In an energy production context, the environmental scientist gathers evidence regarding the ecological impact of the various sources of energy. She does this in order to understand and, if possible, minimize the negative consequences of a technology on an established state of the natural environment. That is, the environmental scientist collects data and makes predictions in order to evaluate the function of technology in relation to an established state of normalcy, health, and balance. This determined state is the basis for an environmental evaluation of technology.

For example, paleoclimatologists seek an understanding of trends in the earth's climate from thousands of years prior to the onslaught of significant human influence (Hansen, Sato 2012, 1). For the work of the paleoclimatologist, immediate data is unavailable; thus, she must utilize simulations of prior events, which are constructed from indirect but accessible data sources. Tasks like determining the temperature of Earth's climate thousands of years ago require physical imprints of past climate conditions. These imprints or proxies draw evidence from objects like ice cores from Antarctica, measurements of changes in sedimentary layers of rock formations, and analyses of evidence embedded in long-living organisms like coral reefs (Hansen, Sato 2005 pp.1). Thus, this state of normalcy arrived at by data extrapolation and simulation is used as a basis for comparison for climate researchers seeking an understanding of post-industrial climate trends.

Awareness of human impact on Earth's climate has gained significant scientific attention since the start of the environmental movement in the 1960s. Investment into climate research has culminated in a consensus among climate and environmental scientists that human-related greenhouse gas emissions are contributing to a significant and perhaps dangerous spike in global temperatures. Information stored in ice cores from Antarctica indicates that CO_2 levels have steadily increased since the industrial revolution. Moreover, additional modelling generated across various scientific disciplines suggests that this increase in CO_2 is, in part, due to emissions from technologies developed during and after the industrial age (NASA 2020).

Perhaps more than any other industry, domestic and international energy production has the potential to be impacted by climate-related concerns in the future. The 2015 Paris Climate Agreement includes 189 nations committed to maintaining the rise in average global temperature in the twenty-first century below two degrees Celsius. In the United States, over two-thirds of states have legislated renewable energy standards that reserve a place in the wholesale utility market for renewable sources of energy. Similar environmental proposals and regulations likely will influence the development of the energy production regulation at the local, state, federal, and international levels in the decades to come.

One of the justifications for regulating energy production rests on the claim that reducing global energy dependence on fossil fuels will contribute to a decrease in the rate at which the planet warms and to an eventual stabilization of global temperatures. In order to prevent the negative consequences of rising global temperatures, national governments are being asked by the Intergovernmental Panel on Climate Change to dramatically cut fossil fuel consumption by 2050 (IPCC 2018, 14). According to the US Energy Information Administration, fossil fuels including coal, natural gas, and petroleum accounted for approximately sixty-three percent of the total energy produced domestically in 2019 (US EIA 2019). Consequently, a large gap in domestic energy supply will result if measures are taken to significantly reduce fossil fuel consumption in the coming decades. Although nuclear energy is not considered renewable, its advocates argue that investment in nuclear energy production is a viable low-carbon alternative to fossil-fuel production (O'Regan 2020). Advocates argue that nuclear investment is a necessary step toward supplementing renewable energy sources and mitigating the loss in energy production from fossil fuels in the coming decades.

Nuclear reactors do not create carbon emissions while operating. Thus, if a society is interested in reducing carbon emissions relatively quickly, it seems reasonable to sew nuclear power into the energy fabric of the future. However, other ecological evaluations of nuclear technology, especially the mining and disposing of uranium, present environmental concerns that have been the object of scrutiny for decades from environmental advocates. Some of the environmental concerns involving the front- and back-end energy cycle of uranium are described next.

Uranium mines and mills are regulated in order to prevent exposure to radioactive contaminants at mine and mill sites. The processes by which uranium is mined and condensed into "yellowcake"--the substance that is transformed into the fuel source for many light-water reactors--are beyond the scope of this discussion. However, as I mentioned previously, regulatory malfeasance at mines and mills during the creation of yellowcake is an environmental safety hazard (Arnold 2019, A46). Oversight of mining and mill operations is a split responsibility in the United States. Depending on the type of uranium extraction used, the Office of Surface Mining, the U.S. the Department of the Interior, the U.S. Nuclear Regulatory Commission, and individual states share regulatory responsibilities (NRC 2019).

Aside from a meltdown at a nuclear plant, disposal of spent fuel is perhaps the most significant environmental concern of the nuclear power generation process. More radioactive than uranium ore found in the ground, spent uranium must be disposed of in designated areas or recycled into fuel to be used in the future. However, in order to accomplish either of these solutions, the proper infrastructure must be in place in the form of recycling operations or permanent disposal sites. As previously mentioned, Yucca Mountain Repository in Nevada has been the proposed permanent disposal site for nuclear waste in the United States, but progress in the disposal process has been perennially hampered by political, environmental, and legal resistance.

According to the World Nuclear Association, uranium recycling technology is a promising avenue for back-end waste disposal despite its slow development. While efforts to permanently dispose of nuclear waste have led to setbacks and delays in the United States, Japan and countries in Europe have successfully generated electricity from recycled plutonium (Euratom 2018). Fuel recycling technology is an important potential step toward back-end energy cycle mitigation in the United States. As depicted in the 2017 documentary *The New Fire*, the promise of fuel recycling technology has enthralled a number of American start-up companies seeking to fortify nuclear energy in the energy market.

Nuclear power plants are among many other technologies attempting to provide low-carbon energy across the globe. From the point of view of an environmental scientist, all sources of energy function as impediments to a state of nature free of human technological impact. However, fossil fuel energy sources have received increasing scrutiny from environmental scientists for their relative high output of CO_2 and contribution to rising global temperatures. Although nuclear technology poses a number of serious environmental risks, some groups of environmental scientists have taken the position that nuclear reactors are a necessary form of energy production in the coming decades. The environmental risks posed by nuclear energy production might pale in comparison to other energy sources like fossil fuels, especially if climate change is as serious a threat as is suggested by the scientific community.

Design Solutions to Conventional Nuclear Energy

Design evaluations of technology depend on the fulfillment of design parameters. A technology receives a positive evaluation when it fulfills its prescribed purpose set forth by designers and a negative grade when it fails to do so. Historical reflections on conventional nuclear technology result in mixed reviews from a design perspective. Many nuclear reactors have operated as designed for decades and together continue to supply nearly a fifth of domestic power in the United States. However, sometimes--most notably in cases like Three Mile Island, Chernobyl, and Fukushima--nuclear technology fails to fulfill its intended purpose. In such cases, it is reasonable to conclude that some conventional nuclear reactors deserve a failing grade from a design perspective.

Rather than expand on the detail of specific design failures, I will move on to a discussion regarding how engineering design has accounted for some of the criticisms of conventional nuclear power production from political, economic, and environmental perspectives. The example of advanced nuclear technology will illustrate how engineering design is capable of shifting design parameters to accommodate changes in non-engineering assessments of technology. Nonetheless, changes in design parameters do not alter the design-based method of evaluation. Providing an overview of advanced nuclear design solutions to the aforementioned evaluations of technology will reinforce epistemological boundaries of design-based evaluations.

A resurgence of nuclear power research is underway in the United States. A significant portion of that research is focused on developing advanced nuclear reactors (ANR), sometimes called generation IV reactors. Designs for ANR have been altered from the conventional light-water reactor (LWR) designs that have operated as the industry standard around the world since the nuclear industry's conception in the 1960s. In the spring of 2018, the United States Committee on Energy and Natural Resources recommended an amendment to the 2005 Energy Policy Act that directs the Secretary of Energy to carry out research and development projects related to advanced nuclear technology. The bill, entitled the Advanced Nuclear Energy Technology Act (ANETA), outlines twelve ANR design goals, most of which are, in some fashion, responses to the criticisms identified in the political, economic, and environmental evaluations of conventional LWR technology (ANETA 2018).

For instance, political concerns regarding public perception of nuclear production are addressed in goals aimed at incorporating inherent safety features into ANR research, e.g., walk-away-safe or passive safety designs. One such proposal reintroduces a design from the 1960s that uses liquid salt as the cooling source instead of water. Molten salt, having a boiling temperature well above water at atmospheric pressure, does not need to be pressurized to prevent evaporation. As a result, many of the dangers related to a pressurized cooling system are mitigated with a molten salt cooling system. Moreover, some molten-salt reactor designs have uranium fuel intermixed within the molten salt as opposed to being fabricated into solid fuel rods, which contributes to higher cost and safety issues in LWR designs. In case of an emergency, molten-salt ANRs are designed to drain the radioactive fuel into highly insulated emergency storage containers without the need for human intervention. As a result of altered design parameters, molten-salt ANRs provide a safer alternative to LWRs, which leave the deployment of emergency systems up to human discretion. Eliminating the likelihood of human error in an emergency is the intention of this “walk-away-safe” or passive safety design.

Other design innovations focus on back-end energy source mitigation. As I mentioned previously, nations around the world are investing in the technologies that consume recycled nuclear waste. In 2019 an American nuclear energy startup company, Oklo, was granted access to use the Idaho National Laboratory’s stockpile of recycled uranium fuel in an ANR prototype. If Oklo’s ANR prototype is actually created, it will be the first reactor in the United States to operate using recycled uranium as its fuel. The implications of Oklo's success are perhaps more significant than the achievement itself--the plant will produce only a small fraction of the energy produced by conventional LWR. However, if successful, the success of a domestic recycled fuel technology would provide reason for continued investment in technologies specifically designed to consume existing nuclear waste.

A technical explanation regarding the way in which ANRs improve fuel efficiency is beyond the scope of this paper. However, it is worth noting that improving fuel performance is an additional attempt to account for political, economic, and environmental evaluations of conventional nuclear power in ANR design. ANRs designed specifically for efficient fuel consumption reduce the amount of back-end waste--one of the darkest clouds hovering over nuclear energy's public perception. Moreover, a reduction in the amount of fuel consumed likely will dissipate pressure and costs associated with back-end disposal and recycling measures. More efficient reactors also improve resistance to waste proliferation for similar reasons. If less fuel is consumed in production, there are fewer opportunities for the fuel to be used for militaristic purposes.[6] Moreover, less fuel consumed in reactors leads to a lower demand for uranium and mining, which is responsible for approximately twenty percent of total generating costs (NEI 2019). Although reducing the amount of mined uranium ore will not immediately reduce the price of wholesale nuclear power, markets likely will see a reduction in the bottom-line price of nuclear energy if more efficient reactors are popularized in the future (NEI 2019).

Perhaps the most impactful design changes in ANR design have to do with revised construction and operational methods. Many ANRs are modular plants designed to be fabricated in a factory and distributed to sites where they will be assembled and put into operation quickly. This quick-build approach reduces the daunting overhead cost of plant construction--one of the most prohibitive economic hurdles for the future of nuclear energy generation. ANETA explicitly states that a design goal of ANRs should be to improve "modular sizes to allow for deployment that correspond with demand for

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[6] Winner's argument regarding the inflexibility of nuclear energy seems to hold less merit if ANR technology dramatically reduces the amount of generated waste product.

electricity" (ANETA 2018). Thus, if carried through into production, the installation flexibility of modular ANRs likely will exceed that of conventional LWRs.

Finally, ANETA calls for ANRs designed with an improved operational base-load flexibility. New ANR designs will be able to respond situationally as a supplement variable energy source when needed. Thus, ANRs will maintain a geographical flexibility so that they might be located in areas in need of a complement to renewables like solar, wind, and hydroelectric. Moreover, if governments respond to the call from climate scientists for a dramatic shift in energy production, renewable energies will have a large gap in the energy market to fill. If domestic dependence on coal and natural gas decreases in the coming decades, ANRs have the potential to greatly reduce generating pressures on variable-load renewables like wind and solar. Simply put, investment in advanced nuclear technology shortens the climb required to meet emission reduction goals.

Despite the fact that new ANRs provide solutions to some non-engineering problems, the design-based assessment of ANRs will be confined to the ANR design parameters. Generally, there is no way in which a design-based evaluation can account for non-engineering assessment beyond prescribed purposes expressed by design parameters. Non-engineering evaluations of technology are metaphysically distinct from design-based assessments because the purpose of the engineer qua engineer is not to consider political, economic, and environmental analysis of technology; the job of the engineer is to design.

The design method is the essence of engineering analyses because the design parameters establish the standard by which engineers evaluate a technology. Although the design method does not change, designs and the purposes behind parameters do change. From our analysis of design adjustments in nuclear technology, we can conclude, consistent with Bucciarelli,[7] that the engineering method can account for evaluations from other sciences. Specifically, within the last decade, technological

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[7] Bucciarelli demonstrates that the engineering design is often influenced by non-engineering forces, e.g., economics, politics, culture (Bucciarelli 1994, 199).

innovations have improved the viability of nuclear energy production from a number of perspectives. ANR are designed to be more efficient, flexible, affordable, reliable, and safe than the conventional LWR designs. The development of ANRs is a testimony to the fluidity and flexibility of engineering design criteria. For instance, molten-salt reactor designs are a response to political and economic assessments of conventional reactors through built-in safety features that reduce construction cost and lower risks of meltdowns. In many ways, advanced nuclear technology has been created to mitigate pressures and concerns voiced from sources *external* to the engineering design method. Thus, from an engineering perspective, changes within the design method are responses to external evaluations of technology.

The ANR is a useful example for understanding the limitations of the design method of assessment and the engineer's understanding of technology in general. Despite the scenario in which ANRs lower waste yields, address some public concerns, increase proliferation resistance, improve fuel performance, and operate flexibly to supplement renewable energy, criticisms of the new form of nuclear energy likely will persist. Thus, it seems that engineering design will continually be incommensurate with evaluations of technology from external sources.

How are we to make sense of two seemingly contradictory relationships between engineering design and non-engineering assessments of technology? As exemplified in the case of ANRs, engineering design has adjusted for non-engineering evaluations of technology. However, perpetual criticism from non-engineering methods indicates that the design method is limited in its capacity to account for non-engineering analyses. Does this observation illuminate an impasse in my primary assertion that engineers should evaluate technology beyond engineering design? The answer to this question is "no," but to understand why, we must complete our understanding of what it means to "see beyond design."

Chapter 3 -- Seeing Beyond Design

This final chapter introduces a new meaning of "engineering." In previous chapters, I have referred to engineering as a *method*. Engineering as method is a metaphysical concept in which design parameters express a prescribed purpose that serves as the basis for assessments of technology. "Engineering" in this chapter refers to engineering as a *profession*. Engineering as a *profession* is primarily a macroethical concept regarding the relationship between engineers and the society within which they work. That is, engineering as a *profession* differs from engineering as a method insofar as professionals perform engineering methods *within a societal context*.

Professional engineering is an ethical concept insofar as ethics is primarily concerned with mental action or *understanding*. That is, ethical action in a professional engineering context involves the mental act of recognizing or becoming aware of multiple functions of technology in accordance with a plurality of methods. In order to clarify the ethical relevance of a pluralistic understanding of technology, I reframe the meaning of "responsibility" to emphasize the need for a broad awareness of different functions of technology. A failure to recognize multiple functions of technology leads to a form of *reductionism* in which a singular evaluative method determines the essence of a technology in an absolute sense. Engineering reductionism, for instance, reduces all evaluations of technology into the design method, and any analyses not represented in the design method are ignored.

Engineers qua engineers, or engineers as defined in the engineering method, do not need to extend their concepts of technology beyond design. However, the lack of a pluralistic understanding of technology acts as a barrier to engineering professionalism. If engineers are to realize their collective responsibility in society, they must understand that engineering design does not occur in isolation and that technology cannot be understood exclusively from design methodology. Engineers must learn to evaluate technology not only as an engineer but as a member of society.

Restricting design evaluations within the limitations of the design method does not contradict my primary assertion that engineers should evaluate technology *beyond* engineering design. A critical distinction lies in the meaning of engineering as a *method* versus engineering as a *profession*. Engineering as a method, or engineering qua engineering, does not consider analyses beyond the design method. There is no reason for engineers, insofar as they are *merely* engineers, to consider an evaluation of technology that is not represented in a design parameter. However, engineers are more than designers--they are professionals. As professionals, engineers do not merely act, but act within a particular societal context. That is, engineering as a *profession* differs from engineering as a method insofar as professionals perform engineering methods *within a societal context*. Engineering as method is an abstraction, divorced from circumstance and void of the context within which all engineering problems exist. However, professional engineering is not isolated from social factors. Rather, the professional is inherently bound to the societal conditions in which she operates. Thus, non-engineering evaluations of technology are relevant to the engineer not because of the nature of the engineering method but because the engineer is an active member of society. The societal component of professionalism highlights an inherent *ethical* component of professional engineering.

Until now, I have been referring to the engineering method as a *metaphysical* concept, and most of the work done in this paper has been dedicated to distinguishing the design-based method from alternatives. The methods of different sciences lead to distinct metaphysical conceptions regarding the function of technology. The previous chapters demonstrate that the different functions of technology are particular to the science used in an evaluation. For example, the evaluations of nuclear technology exemplify three unique methods of understanding the function of nuclear energy production. According to the political method, a technology functions in order to fulfill the political ends of political agents and establish patterns of power and authority. As seen through an economic lens, a technology functions according to the movement of resources and the responses to market demands and public policy. The environmental method measures the technology’s impact on an empirically established environmental condition. Identifying the different functions of technology are *metaphysical* distinctions insofar as they are differentiated based on the presuppositions that undergird method and subject-matter of a science.

This chapter is dedicated to developing the other meaning of engineering, i.e., engineering as a *profession*. The concept of engineering as a profession is fundamentally an *ethical* concept regarding the relationship between engineers and the society within which they work. “Macroethics” is a term used in contemporary engineering ethics scholarship to refer to the relationship between technology and society, such as the collective social responsibility of professional engineers and social decisions regarding technology (Herkert 2005, 374). Macroethics is contrasted with microethics; microethics involves ethical issues at an individual level, such as discerning right actions with reference to codes of conduct or normative theory. Engineering professionalism, thus, should be included under the domain of macroethics.

Engineering professionalism is best articulated in terms of action. Collingwood posited that thought is action in its most primary form (Collingwood 1938, 216). That is, mental activity, thinking, or arriving at a particular understanding, is action in its most fundamental form. For example, within his work on aesthetics, *Principles of Art*, Collingwood claims that the act of becoming aware of one’s emotions--that is, the recognition of one’s emotions as an experience belonging to the self, is the foundation of conscious knowledge (Collingwood 1938, 291). The act of artistic expression is an act of increased awareness to the coming and going of psychical experience. The ability to think or reflect on an emotional state frees the mind from the bondage of the affect. In line with Spinoza’s ethical program, Collingwood asserts that ethical action begins with recognizing the *passions* and, in doing so, converts *passions* into conscious mental *actions*, i.e., thoughts.

Attending to one’s emotional state is similar to ethical action in professional engineering. Ethical action in a professional engineering context involves the mental act of recognizing or becoming aware of multiple functions of technology in accordance with a variety of methods. Furthermore, engineering professionalism entails understanding the nature and limitations of design evaluations of technology with respect to other methods of evaluation in society.

Another term for broadening one's awareness regarding the function of technology in society is "responsibility." Responsibility is a longstanding ethical concept, especially in the ethics of technology. Notably, Hanz Jonas used the term in 1979 to call for a sort of ethical paradigm shift related to the unprecedented power of the technological age (Jonas 1979, 6). He argues that the human ability to annihilate life on earth (via technology) renders ethical concepts like consequentialism and deontology too restricted in their applications to fully account for all ethical obligations (Jonas 1979, 5). Other meanings of "responsibility" are closely associated with professional ethics as outlined in codes and lists of obligations to clients, the environment, and the public at large. More meanings of "responsibility" have been developed in relation to terms like "liability," where an objective to constitute blame or wrongdoing exists (Zandvoort 2000,).

I do not intend to use either of these meanings of responsibility for a number of reasons. I offer a simpler concept of responsibility as an alternative. Questions of responsibility with regard to technology concern how a society, including its engineers, *understand* technology. That is, the best meaning of "responsibility" should involve a consideration of the presuppositions and methods used to understand technology across society.

The concept of responsibility that I would like to employ is perhaps best explained by analogy. If a rancher is responsible for the well-being of a herd of cattle, he must first learn, by way of scrupulous attention, about the behavior of the cattle in various circumstances. The cowboy would observe behaviors that teach him the cattle's grazing patterns, their habits regarding rest, and their demeanor when stressed or fatigued. The responsible stockman would learn as much as he could so as to be able to differentiate his sickly cows from the healthy, the strong from the weak, the panicked from the calm. He would learn when to drive the herd to fresh pastures for grazing and drinking water. The rancher would acquire his awareness through a number of methods: fine-tuning his attention to and observations of his cattle, listening to the advice of other experienced stockmen, and repeatedly attending to the herd when they are in need. This broad understanding is of primary importance if he is to do his job responsibly. Although the engineer comes to know his subject through different processes, the path to understanding also lies in a broad rather than narrow approach. It is through his narrow understanding of technology that he has become specialized, but it is through his broad understanding that he will become a responsible engineer.

Although this definition of responsibility might appear to carry little weight on a practical level, basing our understanding of technology on a plurality of methods and perspectives offers insights otherwise unavailable. Understanding technology in this way enables the discernment of different evaluations of technology without restricting understanding to any presupposition or specific method of intervention.

Engineering professionalism is the way in which an engineer understands the nature and limitations of the engineering method with respect to the rest of society. Thus, aside from contributing to the design process, the professional engineer should evaluate how a technology, presumably the technology she is responsible for designing, functions in society. The professional engineer asks questions like, “How *has* technology X influenced society?”; “How *will* technology X affect society?”; “What does it mean when we say that a technology X has been good for society?”; “What does it mean to say an engineer has engineered well?” These questions have many equally viable answers--all of which offer a part of a pluralistic understanding of technology.

If a person exclusively analyzes a technology using any singular measure, he will inevitably operate under an abstracted conception of technology. As long as there is a plurality of sciences, each of which operates with technology as its object, technology should be understood pluralistically. In light of this plurality, engineers should avoid making evaluations of the nature of technology or how a technology functions best in any absolute, ontological sense. In other words, there are epistemological limitations to claims like “The best technology is the most cost-effective technology”; or “The best technology is the technology that gives us the power to control the market”; or “Good technology is the technology that has the least impact on the natural environment." Most importantly, engineers are not justified in claiming in an absolute sense that the best technology is the technology that fulfills design parameters. Rather, all evaluations of technology are based on metaphysically distinct presuppositions which give rise to a specific method of understanding. Thus, it is a mistake to take one of them as the ideal or essence of technology. The engineer qua engineer is only justified in claiming that a technology is good within a specific engineering context.

The position that any singular method of understanding technology is the only method of understanding technology is a form of *reductionism*. In the first chapter, I established that engineering assessments of technology are essentially teleological. By teleological I meant that the technology's function is understood in terms of a purpose expressed in its design parameters. The design method version of reductionism, or *engineering reductionism*, is the primary target of my criticism. In short, engineering reductionism reduces all evaluations of technology into the design method, and any analyses not represented in the design method are ignored. Harmful consequences of this type of engineering reductionism are evident throughout history, especially in time periods when technological innovation grew rapidly.

Evidence of engineering reductionist thinking exists in technologies that function well according to design parameters but fail to consider evaluations external to it. For example, large hydroelectric dams have served the purpose of providing drinking and irrigation water, flood control, and carbon-free energy to millions of people in nations across the globe. The infrastructure large dams provide has enabled metropolitan areas to flourish in arid climates like those of the United States' southwestern regions. The Hoover and Glen Canyon Dams were positioned on the Colorado River to provide irrigation for agriculture and drinking water for metropolises including Phoenix, Las Vegas, San Diego, and Los Angeles. In accordance with design standards, these dams function generally well. At the time of its construction, the Hoover Dam was considered one of the world's greatest engineering achievements, and the technological advances that enabled the completion of the Hoover Dam were deployed in other large-scale dam projects around the world.

The long-term consequences of large-scale dams are well-documented, and I need not detail the political, economic, or environmental impacts of the structures. However, those familiar with non-engineering assessments of large dams understand that if one were to base his entire understanding of a technology on the fulfillment of design standards, one would walk away with a very limited understanding of the technology. The engineers in charge of completing the design were not required to consider, in the methodological sense, the long-term environmental, political, or economic consequences of the technology. That is, the task of damming the Colorado River did not require understanding the function of the technology beyond its design. After all, engineers qua engineers do not need to extend their understanding of technology beyond design. Similar observations could be made regarding technologies that have had significant social impact such as weapons technology, communication technology, agricultural technology, and medical technology.

What does engineering reductionism have to do with professionalism? Why do professional engineers need to understand assessments of technology beyond their own systems, criteria, and methods of evaluation? Why should a professional engineer care about what the politician, economist, environmentalist, ethicist, poet, or religious authority says about technology, especially if the perspectives of these various types of people have limited impact on what an engineer qua engineer does? To answer this question, we should return to one of Aristotle's types of causation. I mentioned in Chapter 1 that the engineer is the efficient cause of technology. The engineer is society's hands, intentionally manipulating the physical world for some prescribed end. If engineers are to realize their collective responsibility in society, they must understand that engineering does not occur in isolation. Rather, engineers, and the technology they design, influence individuals and systems in ways incomprehensible from any perspective taken alone. Thus, the engineer must understand along with the politician, economist, environmentalist, or individual from any other discipline, that their understanding of technology, taken in isolation, is an artificial abstraction. The abstraction is a result of the organizational methods necessary to make sense of technology. Thus, there is nothing inherently problematic or inappropriate with any coherent method of understanding technology--so long as one recognizes that the method used to analyze a technology does not account for the essence of a technology in an absolute sense. Understanding technology through the design method is necessary in order for the engineer to act as an engineer, but the design method of understanding is only one way of making sense of technology.

Engineers should strive to have as broad an understanding of technology as possible because their design decisions will influence the world in ways that are hidden from the engineering analysis. Exposing students to a broad understanding of technology is an ethical ideal for engineering educators--a good to strive for. In order to understand that the design analysis is merely a piece of a larger understanding of technology, students must be exposed to alternative methods. Introducing students to various evaluations of technology need not be difficult. Ideally, students should be given freedom to choose their own methods of evaluation beyond engineering design. The political, economic, and environmental methods I outlined were arbitrary selections chosen for the sake of simplicity. Methods beyond design are available to engineering students in the humanities, arts, social sciences, and religious contexts.

One macroethical challenge is to further societal conversations regarding the best way to apply technology to social problems. In order to do so, engineers must learn how to bridge the gap between the understanding of technology from an engineering perspective and an understanding of technology from other perspectives represented in society. As I have suggested previously, reasons for this explanatory gap involve the epistemological boundaries that separate different methods of understanding. For instance, other disciplines generally lack the expertise regarding engineering design to comprehend an engineering explanation. Conversely, if a highway engineer never learns to analyze the function of a public highway from a city planner’s perspective, the engineer will be blind to the merits and demerits of his work from the planner’s point of view. Engineering organizations can shrink this gap by conducting technical education opportunities for non-engineers, e.g., public fora that increase exposure of design-based evaluations to the public. Professional engineering groups are well equipped to lead the way in this respect. However, shrinking the gap from the other direction is more complicated. Progress in this direction requires a deliberate shift in *understanding* on behalf of engineers. Engineers must understand the limitations of their own discipline and the societal value of non-engineering assessments of technology.

I suggest shifting toward conceptualizing the relationship informed by a plurality of sciences. In doing so, the concept of technology loses any absolute ontological meaning. However, if a more comprehensive understanding of technology is achieved, what will be gained will outweigh what might be lost. If engineers learn more about how technology functions in other sciences, they will be better able to coordinate with non-engineers.

The fruit of a pluralistic understanding of technology is not a more optimal design per se. Seeking optimization, if not understood within the context of other evaluations of technology, is simply a continuation of engineering reductionism. Rather, the fruit of a more expansive understanding of technology is more responsible engineers; engineers with alertness, awareness, and the discernment of the limitations of the profession--an understanding of what it means to be an engineer **and** of what it means to be a member of society.

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