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Environmental and Social Dimensions of Engineering Research

Introduction

This module addresses ethical issues associated with engineering research from a macroethical, societal perspective. Its central focus is on the engineer's ethical requirement to hold paramount the safety, health and welfare of the public. A key aspect of this mandate is to provide our clients and the public with sustainable designs.

Engineering research requires attention to both microethical and macroethical perspectives. The microethical perspectives are covered in detail in the modules in this series. These are the steps that must be taken by the individual researcher to ensure that his or her results are sound and that the process to achieve these results is ethical. These steps include assurances to respect human subjects, including proper adherence to institutional review board requirements (e.g. obtaining informed consent), respect for intellectual property, and respect for scientific integrity (e.g. avoiding inappropriate manipulation of data).

Macroethical issues are the domain of the entire profession of engineering. Such issues are "concerned with the collective, social responsibility of the engineering profession and societal decisions about technology."[1] Both micro and macroethical perspectives must be part of any engineering researchers protocol, although the type and area of research dictates the actual mix. For example, researchers engaged in nanotechnologies, neurotechnologies and other emergent areas may venture into macroethical issues more directly than those engaged in more traditional areas. However, even traditional engineering research often has macroethical issues, such as when an exiting approach is not the most sustainable (e.g. heavily dependent on animal studies, when *in silico* models could provide the same information), or when the collective effect of existing technologies has a profoundly negative impact on society (e.g. technologies that produce greenhouse gases at a higher rate than alternative approaches)

Learning Objectives

This module has five objectives:

1. To view the engineering profession's social responsibility within the contexts of our codes of ethics;
2. To inform the engineer of the importance of scale in ethical decision making, including an ability to differentiate between micro and macroethical issues;
3. To enhance the engineer's knowledge of green engineering, sustainable design, and environmental ethical principles and paradigms;
4. To increase the engineer's awareness and appreciation of direct and indirect impacts of research, especially macroethical issues.
5. To improve the engineer's ability to differentiate risk-based from precautionary-based decision making.

Perspectives on Obligations to the Environment

Micro versus Macroethical Perspectives

Anthropocentric versus biocentric versus ecocentric ethics

Instrumental vs. intrinsic viewpoint

Receptors: Human health; ecosystems; welfare

Sustainability; future peoples; distant peoples; future environments

Risk versus precautionary decision-making

Environmental and Social Metrics

Measures of success

1. Risk and reliability
2. Justice
3. Sustainability

Both engineering practice and engineering research share a common feature; they call for balance. Society demands that the state-of-the-science be advanced as rapidly as possible *and* that no dangerous side effects ensue. Most engineers have an appreciation for the value of pushing the envelopes of research. They are also adept at optimizing among numerous variables for the best design outcomes. However, emergent areas are associated with some degree of peril. A recent query of top scientists[2] addressed this very issue. Its focus was on those biotechnologies needed to help developing countries. Thus, the study included both the societal and technological areas of greatest potential value (See Table 1). Each of these international experts was asked the following questions about the specific technologies:

- Impact. How much difference will the technology make in improving health?
- Appropriateness. Will it be affordable, robust and adjustable to health care settings in developing countries, and will it be socially, culturally and politically acceptable?
- Burden. Will it address the most pressing health needs?
- Feasibility. Can it realistically be developed and deployed in a time frame of 5–10 years?
- Knowledge gap. Does the technology advance health by creating new knowledge?
- Indirect benefits. Does it address issues such as environmental improvement and income generation that have indirect, positive effects on health?

Table 1. Ranking by global health experts of top ten biotechnologies needed to improve health in developing countries. Data from survey conducted in: A.S. Daar, H. Thorsteinsdóttir, D.K. Martin, A.C. Smith, S. Nast, and P.A. Singer, 2002, “Top Ten

Biotechnologies for Improving Health in Developing Countries," *Nature Genetics,* 32, pp.229-232.

Final ranking	Biotechnology
1	Modified molecular technologies for affordable, simple diagnosis of infectious diseases
2	Recombinant technologies to develop vaccines against infectious diseases
3	Technologies for more efficient drug and vaccine delivery systems
4	Technologies for environmental improvement (sanitation, clean water, bioremediation)
5	Sequencing pathogen genomes to understand their biology and to identify new antimicrobials
6	Female-controlled protection against sexually transmitted diseases, both with and without contraceptive effect
7	Bioinformatics to identify drug targets and to examine pathogen–host interactions
8	Genetically modified crops with increased nutrients to counter specific deficiencies
9	Recombinant technology to make therapeutic products (for

	example, insulin, interferons) more affordable
10	Combinatorial chemistry for drug discovery

The top three areas require major advances in biomedical engineering. The fourth area is within the domain of environmental and civil engineering. The fifth is a challenge for genetic and tissue engineers. The sixth technology falls within biomedical engineering research and clinical engineering. The seventh combines the work of computer engineers and biomedical engineers, while the eighth is a blend of agricultural and biomedical engineering with food sciences. The ninth areas will require advances in biomedical, clinical, and tissue engineering, and the tenth will call on computational pharmacological modeling (e.g. compartmental models), material sciences, biomedical engineering and chemical engineering.

Thus, engineers as agents of technological progress are at a pivotal position. Technology will continue to play an exponentially increasingly important role in the future. The concomitant societal challenges require that every engineer fully understand the implications and possible drawbacks of these technological breakthroughs. Key among them will be biotechnical advances at smaller scales, well below the cell and approaching the molecular level. Technological processes at these scales require that engineers improve their grasp of the potential ethical implications. The essence of life processes are at stake.

Microethical and Macroethical Engineering Perspectives

> "The ultimate measure of a man is not where he stands in moments of comfort and convenience, but where he stands at times of challenge and controversy."
>
> Martin Luther King, Jr. (1963)[3]

Engineers are quite familiar with scale. In fact, we often characterize phenomena by their dimensions and by when they occur, that is, by their respective *spatial* and *temporal* scales. Engineers are comfortable with dimensional analysis by which we measure and describe physical, chemical and biological attributes of what we design. But, can we "measure" ethics in a similar way? King's advice is that we *can* measure ethics, especially in our behavior during worst cases. How well can we stick to our principles and duties when things get tough? Philosophers and teachers of philosophy at the university level frequently subscribe to one classical theory or another for the most part, but most concede the value of other models. They all agree, however, that ethics is a rational and reflective process of deciding how we ought to treat each other.

Approaches to ethics can differ by scale. For example, the *engineering profession* has a moral responsibility to society to ensure that designs and technologies are in society's best interest. In addition, the *individual engineer* has a specific set of moral obligations to the public and the client. The moral obligations of the profession as a whole are greater than the sum of the individual engineers' obligations. The profession certainly needs to ensure that each of its members adheres to a defined set of ethical expectations. This is a necessary, but insufficient, condition for the *ethos* of engineering. The “bottom-up” approach of ensuring an ethical engineering population does not completely ensure that many societal ills will be addressed.

Political theorist, Langdon Winner has succinctly characterized the two-fold engineering moral imperative:

> Ethical responsibility … involves more than leading a decent, honest, truthful life, as important as such lives certainly remain. And it involves something much more than making wise choices when such choices suddenly, unexpectedly present themselves. Our moral obligations must … include a willingness to engage others in the difficult work of defining what the crucial choices are that confront technological society and how intelligently to confront them.[4]

This engagement necessitates both the bottom-up and the top-down approaches.

Most professional ethics texts, including those addressing engineering ethics, are concerned with what has come to known as *microethics*, which is “concerned with individuals and the internal relations of the engineering profession.”[5] This is distinguished from *macroethics,* which is “concerned with the collective, social responsibility of the engineering profession and societal decisions about technology.”[6]

Engineers are concerned with outcomes. Ideas and designs must come to fruition. When we start a project, we say, “This is what my client wants (the ends), so this is how I will make it happen (the means). Sometimes in the course of meeting our objectives, we may cause some harm; the famous problem of using our ends to justify our means. As applied to professional situations, the famous philosopher Immanuel Kant's prescription for moral behavior is often referred to as *duty ethics.* Kant proposed a solution to the problem with his categorical imperative.[7] This states that to see if something is ethical, one should consider what would happen if that act were a law adopted by everyone. If the law helps humankind, the act is moral; if it hurts others on the whole, the act is immoral. While Kant's categorical imperative is a societal antidote to this problem, it may well not be followed by a sufficient number of individuals to preserve and sustain a resource.

Elizabeth Kiss, who directs the Kenan Center for Ethics at Duke University, likes to explain Immanuel Kant's categorical imperative maxim in contemporary terms. She labels her version as the "Six O'clock News" imperative.[8] Basically, if you are pondering whether something is ethical or not, consider how your friends and family would feel if they heard about all of its details on tonight's TV news. Put colloquially, "What would your Mama think?" That may cause one to consider fully the possible consequences of one's decision.

Kant used the categorical imperative to underpin duty ethics (also known as "deontology") with empathetic scrutiny. However, empathy is not the exclusive domain of duty ethics. In teleological ethics, empathy is one of the palliative approaches to deal with the problem of "ends justifying the means." Other philosophers also incorporated the empathic viewpoint into their frameworks. In fact, John Stuart Mill's utilitarianism's axiom of "greatest good for the greatest number of people" is moderated by his "harm principle" which, at its heart, is empathetic. That is, even though an act can be good for the majority, it may still be unethical if it causes undue harm to even one person. Empathy also comes into play in contractarianism, as articulated by Thomas Hobbes as social contract theory. For example, John Rawls has moderated the social contract with the “veil of ignorance” as a way to consider the perspective of the weakest, one might say “most disenfranchised,” members of society.[9] Finally, the rationalist frameworks incorporate empathy into all ethical decisions when they ask the guiding question of “what is going on here?” In other words, what benefit or harm, based on reason, can I expect from actions brought about by the decision I am about to make? One calculus of this harm or benefit is to be empathetic to all others, particularly the weakest members of society, those with little of no “voice.”

As professionals, engineers strive for excellence. This is articulated in the codes of ethics, which extend the mandate beyond avoiding actions that are clearly wrong, and move us to strive for engineering accomplishments that advance human endeavors. The engineering profession pushes us to seek ways to do what is right. Part of the formula for ethical behavior is to know who is affected by what we do. But for whom do we strive to do what is right? Certainly, the company, agency, or holders of contracts are our clients, but our actions must not simply solve immediate problems for a specific client. Rather, they must be viewed as to how they will play out in the larger public and for future generations.

All design decisions are uncertain to some degree. Thus, we are not always certain about the extent of influence of our ethical decisions, so we may need to make them conservatively, following a “precautionary principle” which states that if the consequences of an action, such as the application of a new technology, are unknown but the possible scenario is sufficiently devastating, then it is prudent avoid the action. However, the precautionary approach must also be balanced against opportunity risks. In other words, by our extreme caution are we missing opportunities that would better serve the public and future generations? Are the risks of a new technology acceptable in light of possible benefits? The key is the full and accurate characterization of risks and benefits. Unfortunately, design decisions are often not fully understood until after the fact (and viewed the prism of lawsuits and media frenzies).

Ethical Principles

Ethical principles are "general norms that leave considerable room for judgment."[10] Such principles are codified formally into professional codes of practice. They are also stipulated informally by societal norming, such as by religious, educational and community standards. In fact, most principles of professional practice are derivative from a small core of moral principles[11], such as:

1. Respect for autonomy – Allowance for meaningful choices to be made. Autonomous actions generally should be taken intentionally, with understanding and without controlling influences or duress;
2. Beneficence – Promotion of good for others and contribution to

their welfare.

3. Nonmaleficence – Affirmation of doing no harm or evil;
4. Justice – The fair and equal treatment of people.

Justice: The Key to Sustainability

Cardinal virtues are virtues on which morality hinges (Latin: *cardo*, hinge): justice; prudence; temperance; and fortitude. Among them, justice is the key to sustainability. This is the empathic view and is basic to many faith traditions, notably the Christian's "Golden Rule" and the Native American's and Eastern monks' axiom to "walk a mile in another's shoes." Actually, one of commonalities among the great faith traditions is that they share the empathetic precept; for example:[12]

- Judaism, Shabbat 31a, Rabbi Hillel: "Do not do to others what you would not want them to do to you."
- Christianity, Matthew 7, 12: "Whatever you want people to do to you, do also to them."
- Hinduism, Mahabharata XII 114, 8: "One should not behave towards others in a way which is unpleasant for oneself; that is the essence of morality."
- Buddhism, Samyutta Nikaya V: "A state which is not pleasant or enjoyable for me will also not be so for him; and how can I impose on another a state that is not pleasant or enjoyable for me?"

- Islam, Forty Hadith of an-Nawawi, 13: “None of you is a believer as long as he does not wish his brother what he wishes himself.”
- Confucianism, Sayings 15:23: “What you yourself do not want, do not do to another person.”

Our competence can take us in the right direction. We must excel in what we know and how well we do our technical work. This is a necessary requirement of the engineering experience, but it is not the only part. Engineering schools have increasingly recognized that engineers need to be both competent and socially aware. The ancient Greeks referred to this as *ethike arêtai* (“skills of character”). The competence of the professional engineer is inherently linked to character.

Evolution of Responsible Conduct

Educational psychologists argue that moral development takes a predictable and stepwise progression. The development is the result of social interactions over time. For example, Kohlberg[13] identified six stages in three levels, wherein every person must pass through the preceding step before advancing to the next. Thus, a person first behaves according to authority (Stages 1 and 2), then according to approval (Stages 3 and 4), before finally maturing to the point where they are genuinely interested in the welfare of others. My experience has been gratifying in that most engineering students in my course have indicated moral development well within the post-conventional level.

We can apply the Kohlberg model directly to the engineering profession (See Figure 1). The most basic (bottom tier) actions are pre-conditional. That is, engineering decisions are made solely to stay out of trouble. While proscriptions against unethical behavior at this level are effective, the training, mentorship and other opportunities for professional growth push the engineer to higher ethical expectations. This is the normative aspect of professionalism. In other words, with experience as guided by observing and emulating ethical role models, the engineer moves to conventional stages. The engineering practice *is* the convention, as articulated in our codes of ethics.

Above the conventional stages, the truly ethical engineer makes decisions based on the greater good of society, even at personal costs. In fact, the “payoff” for the engineer in these cases is usually for people she well never meet and may occur in a future she will not share personally. The payoff does provide benefits to the profession as a whole, notably that we as a profession can be trusted. This top-down benefit has incremental value for every engineer. Two common sayings come to mind about top-down benefits. Financial analysts often say about the effect of a growing economy on individual companies: “A rising tide lifts all ships.” Likewise, environmentalists ask us: “To think globally, but to act locally.” In this sense, the individual engineer is an emissary of the profession.

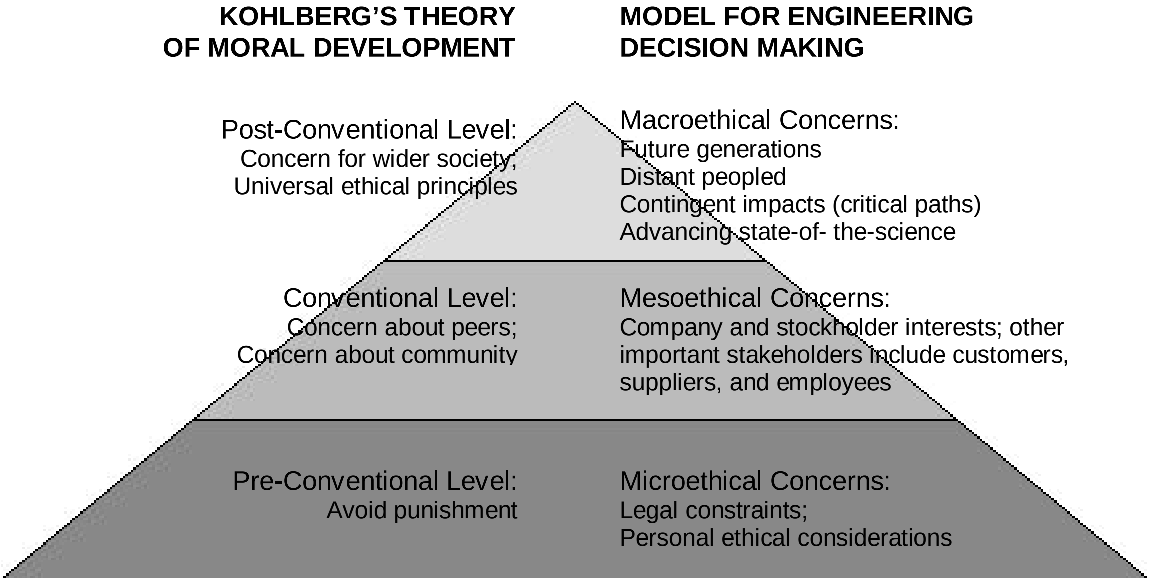


Figure 1. Adaptation of Kohlberg's stages of moral development to the ethical expectations and growth in the engineering profession. Source: D.A. Vallero. 2007. *Biomedical Ethics for Engineers: Ethics and Decision Making in Biosystem and Biomedical Engineering.* Burlington, Massachusetts: Academic Press.

Research introduces a number of challenges that must be approached at all three ethical levels. At the most basic, micro-ethical level, laws, rules, regulations and policies dictate certain behaviors. For example, cloning and blastocyst research, especially that which receives federal funding, is controlled by rules overseen by federal and state agencies. Such rules are often proscriptive, that is, they tell you what *not to do*, but are less clear on what actually *to do.*

At the next level, beyond legal considerations, the engineer is charged with being a loyal and faithful agent to the clients. Researchers are beholding to their respective universities and institutions. Engineers working in companies and agencies are required to follow mandates to employees (although never in conflict with their obligations to the engineering profession). Thus, engineers must stay within budget, use appropriate materials, and follow best practices as they concern their respective designs. For example, if an engineer is engaged in work that would benefit from collaborating with another company working with similar genetic material, the engineer must take precautionary steps to avoid breeches in confidentiality, such as trade secrets and intellectual property.

The highest level, the macroethical perspective, has a number of aspects. Many of the research and development projects address areas that could greatly benefit society, but may lead to unforeseen costs. The engineer is called to consider possible contingencies. For example, if an engineer is designing *nano-machinery* at the subcellular level, is there a possibility that self-replication mechanisms in the cell could be modified to lead to potential adverse effects, such as generating mutant pathological cells, toxic byproducts, or changes in genetic structure not previously expected? Thus, this highest level of professional development is often where *risk tradeoffs* must be considered. In the case of our example, the risk of adverse genetic outcomes must be weighed against the loss of advancing the state of medical science (e.g. finding nano-machines that manufacture and deliver tumor-destroying drugs efficiently).

Ongoing cutting-edge research (such as the efficient manufacturing of chemicals at the cellular scale, the development of cybernetic storage and data transfer systems using biological or biologically-inspired processes, etc.) will create new solutions to perennial human problems by designing more effective devices and improving computational methodologies. Nonetheless, in our zeal to push the envelopes of science, we must not ignore some of the larger, societal repercussions of our research; that is, we must employ new paradigms of “Macroethics.”

William A. Wulf, president of the National Academy of Engineering, introduced the term Macroethics, defining it as a societal behavior that increases the intellectual pressure "to do the right thing" for the long-term improvement of society. Balancing the potential benefits to society of advances in nanotechnology while also avoiding negative societal consequences is a type of macroethical dilemma.[14] Macroethics asks us to consider the broad societal impact of science in shaping research agendas and priorities. At the same time, “Micro-ethics” is needed to ensure that researchers and practitioners act in accordance with scientific and professional norms, as dictated by standards of practice, community standards of excellence, and codes of ethics.[15] The engineering profession and engineering education standards require attention to both the macro and micro dimensions of ethics. Criterion 3, “Program Outcomes and Assessment” of the Accreditation Board for Engineering and Technology, Inc. (ABET) includes a basic micro-ethical requirement for engineering education programs, identified as “(f) an understanding of professional and ethical responsibility,” along with macroethical requirements that graduates of these programs should have “(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context” and “(j) a knowledge of contemporary issues.”[16]

Green Engineering and Sustainable Design

Engineers are successful when their designs are implemented so that the desired results are achieved. In recent decades, engineers have increasingly been asked to design buildings, devices and systems that are sustainable. That is, they provide the benefits not only to the present users, but do so in a way that future people will not be harmed by present benefits. This is at the heart of green engineering.

Green Engineering: A Primer

> It is our aspiration that engineers will continue to be leaders in the movement toward the use of wise, informed, and economical sustainable development. This should begin in our educational institutions and be founded in the basic tenets of the engineering profession and its actions.
>
> National Academy of Engineering (2004)[17]

The terms “green engineering” and “sustainable design” are often linked in the literature. While it makes much sense to treat the areas together, they are actually very different concepts.

Environmental conscientiousness evolved in the twentieth century from a peculiar interest of a few design professionals to an integral part of every engineering disciple. In fact, one of the most important macroethical challenges for engineers is to provide sustainable designs. The U.S. Environmental Protection Agency defines *green engineering* as:

> *…* the design, commercialization and use of processes and products that are feasible and economical while reducing the generation of pollution at the source and minimizing the risk to human health and the environment.[18]

Green engineering asks the designer to incorporate "environmentally conscious attitudes, values, and principles, combined with science, technology, and engineering practice, all directed toward improving local and global environmental quality."[19] However, the design must also be feasible and must adhere to the first canon of engineering practice; holding paramount the safety, health and welfare of the public. One of the principles of "green engineering" is the recognition of the importance of *sustainability*.

Sense of Place

Design professions have gone through numerous transitions over the past two centuries. In the West, these have tracked with changes in societal norms and expectations. A large change has occurred in how we perceive the world around us. The green perspective has evolved in other design professions besides engineering. For example, *green architecture* has been defined as the means of allowing:

> … people to become more in touch with the environment in which they live. It incorporates natural landscapes into the buildings design, which gives people a better connection to the land. It also takes into account all the environmental effects, which a building will have on a place. Green design is based out of creating buildings that fit into their natural surrounds and give the people who use them a sense of place, as opposed to conventional architecture, which pushes people away from the natural environment. Many of the key components of green design involve in-depth knowledge about a place. Green buildings must account for sun intensities, temperature variation, precipitation and many other environmentally driven aspects. Without knowledge of local environments, green buildings cannot plan for variations and they will not be as energy efficient.[20]

So-called green buildings incorporate given site characteristics and conditions, such as microclimate, light exposure, vegetation, and urban factors (e.g. noise and amenities) into the design. Thus, the building is seen as an entity that goes beyond mere shelter to become a "selective filter" against outside interferences and admitting desirable qualities (e.g. incoming solar radiation in the winter, daylight, and air exchanges.[21]

Thus, green design embodies a sense of place that differs from that of the “endless frontier of the eighteenth, nineteenth and much of the twentieth centuries, where individualism and conquest led to buildings the optimized isolation *from* the environment, rather than optimization *of* the environment. In the former sense of place, the environment was easily viewed as inexhaustible and ever resilient. Whereas green architecture often starts with the view of the potential building, the canvas of the environment is the real starting point. Using the common art analogy, the building site canvas is certainly not empty as many earlier designers perceived the site to be. It is actually quite full, and any change must account for the effect that a building or planned community will have on this environment. One of the first to articulate this new sense of place was Aldo Leopold.

Case Study: Pruitt Igoe Housing Development and the Land Ethic

Environmental ethics is the set of morals, those actions held to be right and wrong, in how people interact with the environment. Three ethical viewpoints dominate environmental ethics: anthropocentrism; biocentrism; and ecocentrism (See Figure 2). Anthropocentrism is the philosophy or decision framework based human beings. It is the view that all and only humans have moral value. Nonhuman species and abiotic resources have value only in respect to that associated with human values (known as instrumental value). Conversely, biocentrism is a systematic and comprehensive account of moral relationships between humans and other living things. The biocentric view requires an acceptance that all living things have inherent moral value, so that respect for nature is the ultimate moral attitude. By extension of the biocentric view, ecocentrism is based on the whole ecosystem rather than a single species.

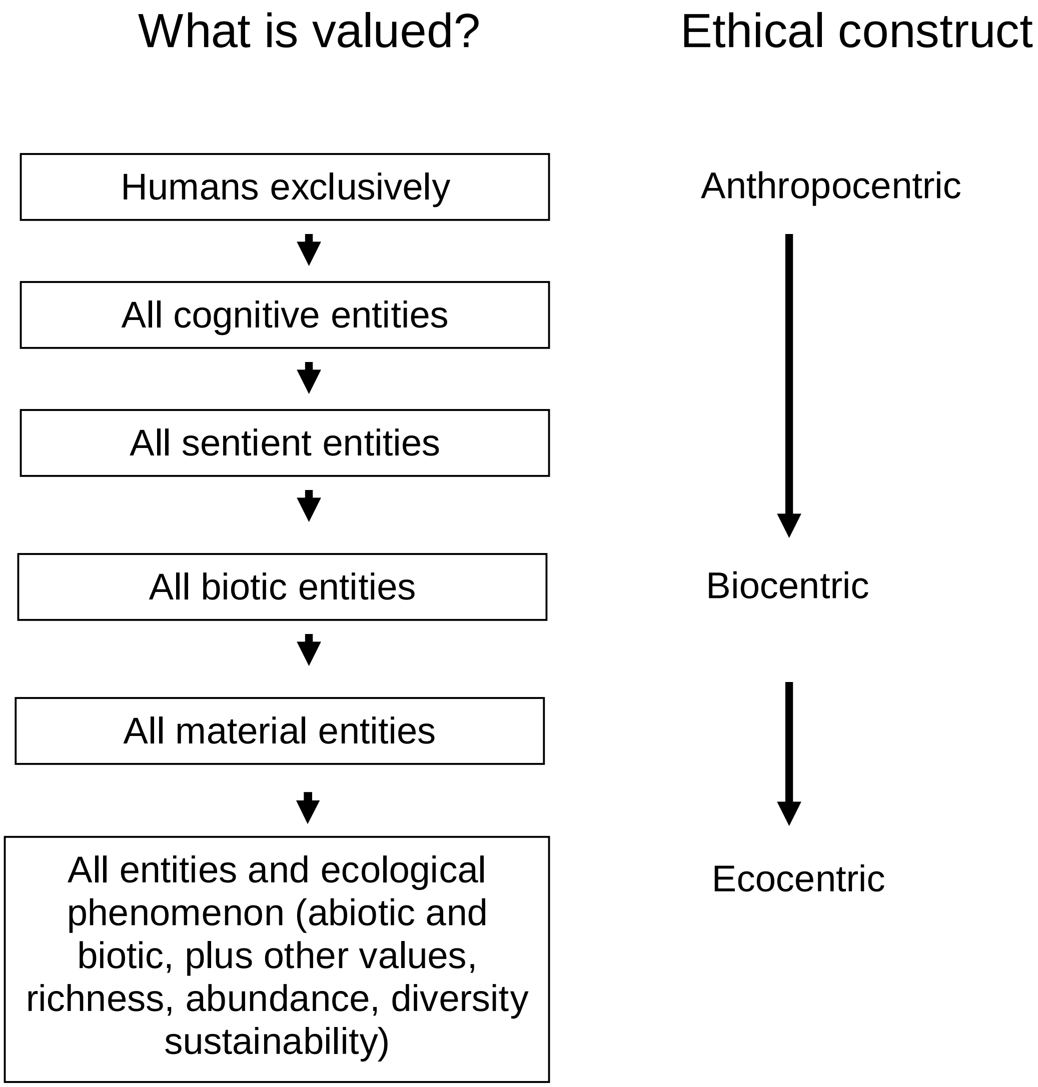


Figure 2. Continuum of ethical viewpoints. Adapted from R.B. Meyers. 2003. Environmental Values, Ethics and Support for Environmental Policy: A Heuristic, and Psychometric Instruments to Measure their Prevalence and Relationships. International Conference on Civic Education Research. November 16-18, 2003 New Orleans, Louisiana.

Thus, anthropocentrists may strong disagree with biocentrists on the loss of animal habitat from the standpoint of perceived value. The anthropocentrist may hold that the elimination of a stand of trees is necessary so they provide less perceived monetary worth (instrumental value) than the project in need of the clear-cutting, whereas the biocentrist sees the same stand of trees has having sufficient inherent value to prevent the clear-cutting. Few hold any of these viewpoints exclusively, but apply them selectively. For example, a politician holding a strong anthropocentric viewpoint on medical research or land development may love animals as pets.

In his seminal journal *A Sand County Almanac* (1949) Aldo Leopold took the ecocentric view and established the “land ethic.” It was a dramatic shift in thinking from that which was dominated during the first half of the twentieth century. Leopold held that this new ethic “reflects the existence of an ecological conscience, and this in turn reflects a conviction of individual responsibility for the health of land” This is a precursor to ecocentrism.

The ecocentric view asked the designer to perceive undeveloped land or existing structures as more than a “blank slate” and standing building stock as more than mere three-dimensional structures ready to be built, changed, or demolished as means to engineering ends. In fact, land and structures are human enterprises that will affect people’s lives directly. The Pruitt-Igoe public housing project in St. Louis, Missouri is a tragic and telling example of an engineering failure by one of the great contemporary architects that resulted from a lack of insights into the in sense of place.

Thus “failure” in design can go beyond the textbook cases and those shared by our mentors and passed on from our predecessors. Minoru Yamasaki, by most accounts, was a highly successful designer and a prominent figure in the modernist architectural movement of the mid-twentieth century. Tragically and ironically, Yamasaki may be best remembered for two of his projects that failed. Yamasaki and Antonio Brittiochi designed the World Trade Center towers that were to become emblems of Western capitalism. Certainly, Yamasaki cannot be blamed, but the towers failed. In fact, the failure of architects for buildings is seldom structural and often aesthetic or operational (e.g. ugly or an inefficient flow of people). Yamasaki strived to present an aesthetically pleasing structure. One may argue that his architectural success in creating a structure so representative of contemporary America was a factor in its failure, making it a prime target of terrorists.

Most post-collapse assessments have agreed that the structural integrity of the towers was sufficient well beyond the expected contingencies. However, if engineers do not learn the lessons from this tragedy, they can rightfully be blamed. And the failure will be less a failure of applying of physical sciences (withstanding unforeseen stresses and strains) than a failure of imagination. Engineers have been trained to use imagination to envision a better way. Unfortunately, now we must imagine things that were unthinkable before September 11, 2001. Success depends on engaging the social sciences in our planning, design, construction and maintenance of our projects. This will help to inform us of contingencies not apparent when exclusively applying the physical and natural sciences.

The Pruitt Igoe housing development was a very different type of failure. The buildings, like the Manhattan towers, were another modernist monument. Rather than a monument to capitalism, Pruit Igoe was supposed to be emblematic of advances in fair housing and progress in the war on poverty. Regrettably, the development was to become an icon of failure of imagination, especially insights into the land ethic.

Contemporary understanding of environmental quality is often associated with physical, chemical, and biological contaminants, but in the formative years of the environmental movement, aesthetics and other "quality of life" considerations were essential parts of environmental quality. Most environmental impact statements addressed cultural and social factors in determining whether a federal project would have a significant effect on the environment. These included historic preservation, economics, psychology (e.g. open space, green areas, and crowding), aesthetics, urban renewal, and the land ethic:

> A thing is right when it tends to preserve the integrity, stability and beauty of the biotic community. It is wrong when it tends otherwise.[22]

The land ethic was articulated about a decade after Pruitt Igoe project was built, so the designers did not benefit from the insights of Leopold and his contemporaries. However, the problems that led to the premature demolition of this costly housing experiment may have been anticipated intuitively if the designers had taken the time to understand what people expected. There is plenty of culpability to go around. Some blame the inability of the modern architectural style to create livable environments for people living in poverty, largely because they “are not the nuanced and sophisticated ‘readers’ of architectural space the educated architects were.”[23] This is a telling observation and an important lesson for engineers. We need to make sure that the use and operation of whatever is designed is sufficiently understood by those living with it.

Other sources of failure have been proposed. Design incompatibility was almost inevitable for high-rise buildings and families with children. However, most large cities have large populations of families with children living in such environments. In fact, St. Louis had successful luxury townhomes not too far from Pruitt Igoe. Another identified culprit was the generalized discrimination and segregation of the era. Actually, when originally inhabited the Pruitt section was for blacks and Igoe was for whites.

Costs always become a factor. The building contractors’ bids were increased to a level where the project construction costs in St. Louis exceeded the national average by 60%. The response to the local housing authority’s refusal to raise unit cost ceilings to accommodate the elevated bids was to reduce room sizes, eliminate amenities, and raise densities.[24] As originally designed, the buildings were to become "vertical neighborhoods" with nearby playgrounds, open-air hallways, porches, laundries, and storage areas. The compromises eliminated these features. And, some of the removal of “amenities” led to dangerous situations. Elevators were undersized and stopped only every third floor and lighting was inadequate in the stairwells. So, another lesson must be to know the difference between desirable and essential design elements. No selfrespecting structural engineer involved in the building design would have short cut the factors of safety built into load bearing. Conversely, human elements essential to a vibrant community were eliminated without much if any accommodation.[25]

Finally, the project was mismatched to the people who would live there. Many came from single-family residences. They were moved to a very large, imposing project with 2,800 units and almost 11,000 people living there. This was quadrupled the size of the next largest project of the time.

When the failure of the project became overwhelmingly clear, the only reasonable decision was to demolish it, and this spectacular implosion became a lesson in failure for planners, architects, and engineers. In Yamasaki’s own words,

> I never thought people were that destructive. As an architect, I doubt if I would think about it now. I suppose we should have quit the job. It's a job I wish I hadn't done.[26]

Engineering is not only applied natural sciences but many engineers, especially when they advance to leadership positions in engineering, find themselves in professional situations where the social sciences, particularly ethics, would be the more valuable set of skills that would dictate their success as engineers. Teaching our students first to recognize and then to think through ethical problems is like providing a viewing port in the professional cargo door to see of the ethical mechanism is properly locked and “over center.” We often overlook “teachable moments.” For example, we repeatedly miss opportunities to relate engineering and social science lessons from even the most life and society changing events like the fall of the World Trade Center towers.[27]

Thinking of engineering as “applied social science” redefines engineering from a profession that builds things, to a profession that helps people. The extension of this conclusion should encourage educators to re-evaluate what it is we teach our engineering students. We believe that all engineers should include in their educational quiver at least some arrows that will help them make the difficult ethical and social decisions faced by all professional engineers.

Risk, Reliability and Ethics

Environmental challenges force engineers and scientists to consider the physicochemical characteristics of the pollutants and match these with the biogeochemical characteristics of the media where these pollutants are found. We had to increase our understanding of myriad ways that these characteristics would influence the time that these chemicals would remain in the environment, their likelihood to be accumulated in the food chain and how toxic they would be to humans and other organisms. Those contaminants that have all three of these characteristics worry us the most. In fact, such contaminants have come to be known as “PBTs”, i.e. persistent, bioaccumulating toxicants.

The problems at Love Canal, Times Beach, Valley of the Drums and the many environmental disasters that followed them pushed regulators to approach pollutants from the perspective of risk. The principal value added by environmental professionals is the skill to improve the quality of human health and ecosystems. Thus, the change in risk is one of the best ways to measure the success of engineers. By extension, reliability lets us know how well we are preventing pollution, reducing exposures to pollutants, protecting ecosystems and even protecting the public welfare (e.g. buildings exposed to low pH precipitation).

Risk, as it is generally understood, is the chance that some unwelcome event will occur. The operation of an automobile, for example, introduces the driver and passengers to the risk of a crash that can causes damage, injuries and even death. The hazardous waste cases emphasized the need to somehow quantify and manage risks.

The understanding of the factors that lead to a risk is known as *risk analysis.* The reduction of this risk (for example, by wearing seat belts in the driving example) is *risk management.* Risk management is often differentiated from *risk assessment*, which is comprised of the scientific considerations of a risk. Risk management includes the policies, laws, and other societal aspects of risk.

Designers must consider the interrelationships among factors that put people at risk, suggesting that we are risk analysts. Designs must be based on the sound application of the physical sciences. Sound science must be the foundation of risk assessments. Engineers control things and, as such, are risk managers. Engineers are held responsible for designing safe products and processes, and the public holds us accountable for its health, safety and welfare. Likewise, architects must provide designs that are sustained in the best interests of their clients. The public expects designers to "give results, not excuses,"[28] and risk and reliability are accountability measures of their success. Engineers design systems to reduce risk and look for ways to enhance the reliability of these systems. Thus, green design deals directly or indirectly with risk and reliability.

Both risk and reliability are probabilities. People living near industries and waste sites, at least intuitively, assessed the risks and, when presented solutions by engineers, made decisions about the reliability of the designs. They, for good reason, want to be assured that they would be "safe." But, safety is a relative term. Calling something "safe" integrates a value judgment that is invariably accompanied by uncertainties. The safety of a product or process can be described in objective and quantitative terms. Factors of safety are a part of every design. Most of the time, environmental safety is usually expressed by its opposite term, risk.

Success or failure as environmental practitioners is in large measure determined by what we do compared to what our profession “expects” us to do. Safety is a fundamental facet of our duties. Thus, we need a set of criteria that tells us when are designs and projects are sufficiently safe. Four safety criteria are applied to test engineering safety:[29]

1. The design must comply with applicable laws.
2. The design must adhere to “acceptable engineering practice.”
3. Alternative designs must be sought to see if there are safer practices.
4. Possible misuse of the product or process must be foreseen.

These four provisions are the starting point for sustainable design.

Sustainability

Their recognition of an impending and assured global disaster led the World Commission on Environment and Development, sponsored by the United Nations, to conduct a study of the world's resources. Also known as the Brundtland Commission, their 1987 report, *Our Common Future,* introduced the term *sustainable development* and defined it as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”[30] The United

Nations Conference on Environment and Development (UNCED), i.e. the Earth Summit held in Rio de Janeiro in 1992 communicated the idea that sustainable development is both a scientific concept and a philosophical ideal. The document, *Agenda 21*, was endorsed by 178 governments (not including the United States) and hailed as a blueprint for sustainable development. In 2002, the World Summit on Sustainable Development (WSSD) identified five major areas that are considered key for moving sustainable development plans forward.

The underlying purpose of sustainable development is to help developing nations manage their resources, such as rain forests, without depleting these resources and making them unusable for future generations. In short, the objective is to prevent the collapse of the global ecosystems. The *Brundtland Report* presumes that we have a core ethic of intergenerational equity, and that future generations should have an equal opportunity to achieve a high quality of life. The report is silent, however, on just why we should embrace the ideal of intergenerational equity, or why one should be concerned about the survival of the human species. The goal is a sustainable global ecologic and economic system, achieved in part by the wise use of available resources.

We are creatures that have different needs. Maslow[31] articulated this as a hierarchy of needs consists of two classes of needs: basic and growth (See Figure 3). The basic needs must first be satisfied before a person can progress toward higher-level growth needs. Within the basic needs classification, Maslow separated the most basic physiological needs, such as water, food, and oxygen, from the need for safety. Therefore, one must first avoid starvation and thirst, satisfying minimum caloric and water intake, before being concerned about the quality of the air, food, and water. The latter is the province of environmental protection. The most basic of needs must first be satisfied before we can strive for more advanced needs. Thus, we need to ensure adequate quantities and certain ranges of quality of air, water, and food. Providing food requires ranges of soil and water quality for agriculture. Thus, any person and any culture that is unable to satisfy these most basic needs cannot be expected to “advance” toward higher-order values, such as free markets and peaceful societies. In fact, the inability to provide basic needs militates against peace. This means that when basic needs go unmet, societies are frustrated even if they strive toward freedom and peace. And, even those that begin may enter into vicious cycles wherein any progress is undone by episodes of scarcity. We generally think of peace and justice as the province of religion and theology, but engineers will increasingly be called upon to “build a better world.”

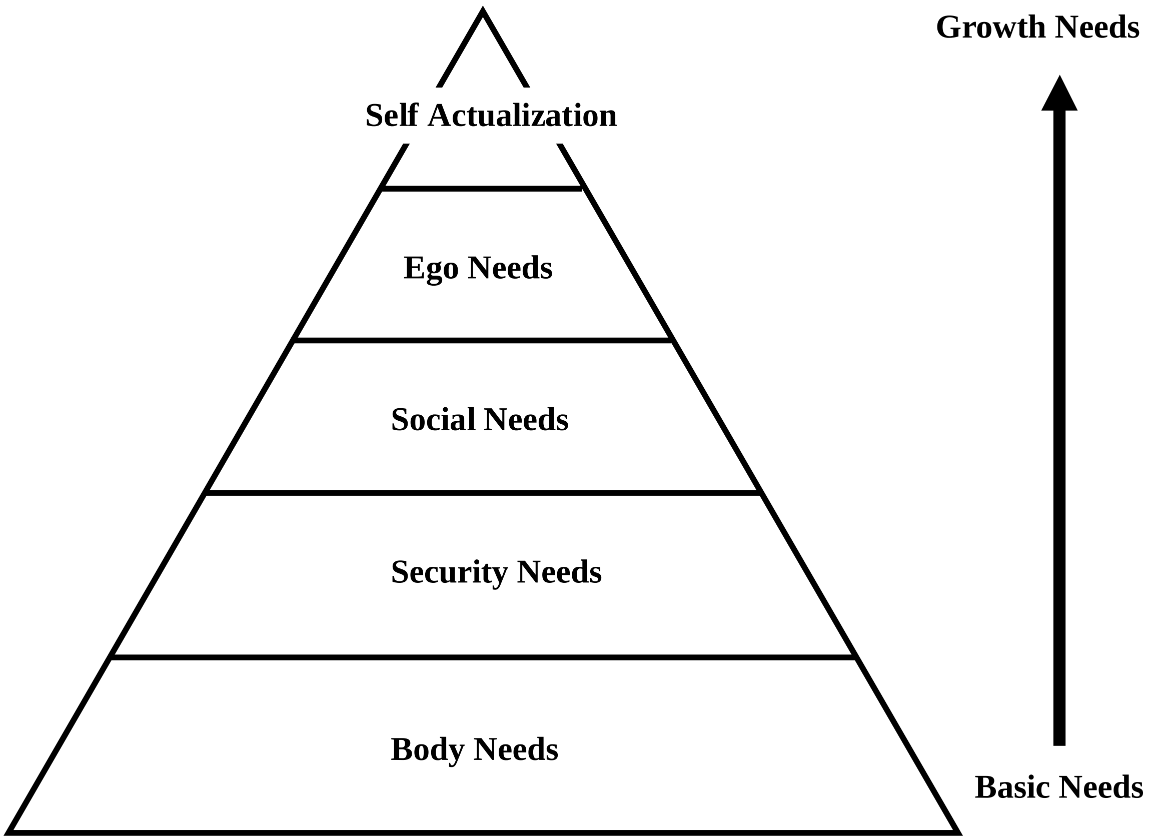


Figure 3. Maslow's hierarchy of needs. The lower part of the hierarchy (i.e. basic needs) must first be satisfied before a person can advance to the next growth levels.

Even mechanical engineers, whom we may at first blush think of as being mainly concerned about non-living things, are embracing sustainable design in a large way. In fact, in many ways the mechanical engineering profession is out in front on sustainable design. For example, the ASME website draws a systematic example from ecology:

> To an engineer, a sustainable system is one that is in equilibrium or changing at a tolerably slow rate. In the food chain, for example, plants are fed by sunlight, moisture and nutrients, and then become food

> themselves for insects and herbivores, which in turn act as food for larger animals. The waste from these animals replenishes the soil, which nourishes plants, and the cycle begins again.[32]

Sustainability is, therefore, as systematic phenomenon so it is not surprising that engineers have embraced the concept of “sustainable design.” At the largest scale, manufacturing, transportation, commerce and other human activities that promote high consumption and wastefulness of finite resources cannot be sustained. At the individual designer scale, the products and processes that engineers design must be considered for their entire lifetimes and beyond.

Case Study: The Tragedy of the Commons

Since sustainability requires knowing what is important, it requires a sense of what the client, which is ultimately the public, values. In addition, such thinking requires some forecast of what will be valued in the future, which means we need a way to divvy up the values among the disparate groups that comprise the present and future stakeholders. Garrett Hardin (1915-2003) postulated a means of doing this. Hardin was a biologist by training and an ethicist by reputation. In 1968 he wrote a hugely influential article entitled "The Tragedy of the Commons" which has become a “must-read” in every ecology course and increasingly in ethics courses. In this article Hardin imagines an English village with a common area where everyone's cow may graze. The common is able to sustain the cows and village life is stable, until one of the villagers figures out that if he gets two cows instead of one, the cost of the extra cow will be shared by everyone, while the profit will be his alone. So he gets two cows and prospers, but others see this and similarly want two cows. If two, why not three -- and so on -- until the village common is no longer able to support the large number of cows, and everyone suffers.

This concept can be extended intellectually to finite resources and the carrying capacity of ecosystems. A similar argument can be made for the use of non-renewable resources. If we treat diminishing resources such as oil and minerals as capital gains we will soon find ourselves in the “common” difficulty of having too many people and not enough resources.

A thread running all through Hardin's books is that ethics has to be based on rational argument and not on emotion. His most interesting book is *Stalking the Wild Taboo* in which he takes on any number of social conceptions that demand rational reasoning. However, like many of those aggressively advocating scientism, his views approach rationalism in a manner that only that which can be measured can be said to exist.

This view when taken to the extreme, can exclude human qualities such as happiness or the human soul. It can also lead to an extreme form of biocentrism or ecocentrocism, known as deep ecology. This is actually a modern form of utilitarianism, holding that nature and the natural order should be valued over individual human happiness, which has even spawned views that the worth of certain human beings (e.g. newborns, elderly, and infirm) are of less worth than sentient animals. Consider this quote by the ecocentrist, Peter Singer:

> In our book, *Should the Baby Live?,* my colleague Helga Kuhse and I suggested that a period of twenty-eight days after birth might be allowed before an infant is accepted as having the same right to life as others.[33]

Such views are counter to the engineer’s first canon, which is to hold paramount the safety, health and welfare of the public. In fact, the socially responsible engineer has an ethical obligation to the most vulnerable members of society. Most of our plans cannot be targeted for the healthiest or strongest, but for those that are sensitive. For example, air pollution controls need to protect infants, the elderly, asthmatics, and others sensitive to airborne contaminants. Similarly, food and water supplies must meet standards to protect the more vulnerable members of society (e.g. those with allergies and young children). Thus, the life cycle extends beyond a single point in time and space.

Hardin’s parable demonstrates that even though the individual sees the utility of preservation (no new cows) in a collective sense, the ethical egoistic view may well push the decision toward the immediate gratification of the individual at the expense of the collective good. Ironically, this view can result in large scale harm (e.g. artifacts of pollution, waste of resources, legacies of diseases, and exhaustion of resources).

The Green Categorical Imperative

Let us venture more deeply into the realm of ethics. After all, ethics is intricately tied to sustainability. Ultimately, ethics tells us what we *ought to do.* It informs us of how we need to think about ourselves and others. These others can be near or distant, present and future. Thus, as mentioned, ethics has dimensions in space and time.

Virtue ethics is the ethical theory that emphasizes the virtues, or moral character, in ethical decision making. It focuses on what makes a good person, rather than what makes a good action. People who devote their lives to doing the right thing are said to behave virtuously. Aristotle tried to clarify the dichotomy of good and evil by devising lists of virtues and vices, which amount to a taxonomy of good and evil. One of the many achievements of Aristotle was his keen insight as to the similarities of various kinds of living things. He categorized organisms into two kingdoms, plants and animals. Others no doubt made such observations, but Aristotle documented them. He formalized and systematized this taxonomy. Such a taxonomic perspective also found its way into Aristotle's moral philosophy.

The classical works of Aristotle, Thomas Aquinas, *et al.*, make the case for life being a mix of virtues and vices available to humans. Virtue can be defined as the power to do good or a habit of doing good. In fact, one of Aristotle's most memorable lines is that "Excellence is habit." If we do good, we are more likely, according to Aristotle, to keep doing good. Conversely, vice is the power and habit of doing evil. The subjectivity or relational nature of good and evil, however, causes discomfort among engineers. We place great import on certainty and consistency of definition.

We all will not all agree on which of the virtues and vices are best or even whether something is a virtue or a vice (for example, loyalty), but one concept does seem to come to the fore in most major religions and moral philosophies: empathy. Putting oneself in another's situation is a good metric for virtuous acts.

A different ethical view is that of consequentialism, which holds that the value of an action derives solely from the value of its consequences.

Consequentialists believe that the consequences of a particular action form the basis for any valid moral judgment about that action, so that a morally right action is an action that produces good consequences. One type of consequentialism is that of utilitarianism, which measures the ethical value in terms of greatest good for the greatest number. The Tragedy of the Commons points the problem of consequentialism and utilitarianism in the absence of sustainability. That is, if people view values exclusively in terms of their present and personal needs, collective costs will likely be incurred. For example, if present energy needs of this generation is the sole target of the “greatest good,” future generations may be left with enormous costs (e.g. global climate change, loss of habitat, exposure to persistent pollutants).

The third principal ethical theory is deontology, or duty-based ethics. As mentioned in the introduction, Immanuel Kant is recognized as the principal advocate of this school of thought. Duty can be summed up as the “categorical imperative.” With apologies to Kant, the categorical imperative is when deciding whether to act in a certain way, ask if your action (or inaction) will make for a better world if all others in your situation acted in the same way. In other words, should your action be universalized? If so, it is your duty to take that action. If not, it is your duty to avoid that action.

Whether an individual action is right or wrong is comprehensive. It is not whether one should pour a few milligrams of a toxic substance down the drain, it is whether everyone with this amount of toxic substances should do likewise. The life cycle dictates whether the action is right or wrong. The benefits and risks to the environment may cause one to rethink a process in the life cycle. Thus, the life cycle illustrates what we might call the “green categorical imperative.

Green design is not the exclusive domain of duty ethics. In consequentialism, the life cycle viewpoint is one of the palliative approaches to deal with the problem of “ends justifying the means.” In fact, Mill’s utilitarianism’s axiom of “greatest good for the greatest number of people” is moderated by his “harm principle” which, at its heart, takes into account the potential impact of an action on others now and in the future. That is, even though an act can be good for the majority, it may still be unethical if it causes undue harm to even one person.

The life cycle also comes into play in contractarianism, as articulated by Thomas Hobbes as social contract theory. For example, Rawls has moderated the social contract with the “veil of ignorance” as a way to consider the perspective of the weakest, one might say “most disenfranchised,” members of society. Finally, the rational-relationship frameworks incorporate empathy into all ethical decisions when they ask the guiding question of “what is going on here?” In other words, what benefit or harm, based on reason, can I expect from actions brought about by the decision I am about to make? One calculus of this harm or benefit is to be empathetic to all others, particularly the weakest members of society, those with little of no “voice.” Thus, the design professional must keep in mind these members of society in spite of the loud voices of the politicians, investors and others who would dictate less than green design decisions.

Implementing Sustainable Designs

Sustainability requires adopting new and better means of using materials and energy. The operationalizing of the quest for sustainability is defined as *green engineering,* a term that recognizes that engineers are central to the practical application of the principles sustainability to everyday life. The relationship between sustainable development, sustainability, and green engineering is progressive:

Sustainable Development **à** Green Architecture and Engineering **à** Sustainability **à** Sustainable Design

Sustainable development is an ideal that can lead to sustainability, but this can only be done through green engineering.

Green architecture and engineering[34] treat environmental quality as an end in itself. The U.S. EPA amplifies the importance of the interrelationships of feasibility, environmental quality, public health, and welfare:

> … the design, commercialization, and use of processes and products, which are feasible and economical while minimizing 1) generation of pollution at the source and 2) risk to human health and the environment. The discipline embraces the concept that decisions to protect human health and the environment can have the greatest impact and cost effectiveness when applied early to the design and development phase of a process or product.[35]

Green engineering approaches are continuously being integrated into engineering guidelines. This is being made easier with improved computational abilities (See Table 2) and other tools that were not available at the outset of the environmental movement. Increasingly, companies have come to recognize that improved efficiencies save time, money, and other resources in the long run. Hence, companies are thinking systematically about the entire product stream in numerous ways:

- applying sustainable development concepts, including the framework and foundations of “green” design and engineering models;
- applying the design process within the context of a sustainable framework: including considerations of commercial and institutional influences;
- considering practical problems and solutions from a comprehensive standpoint to achieve sustainable products and processes;
- characterizing waste streams resulting from designs;
- understanding how first principles of science, including thermodynamics, must be integral to sustainable designs in terms of mass and energy relationships, including reactors, heat exchangers, and separation processes; and
- applying creativity and originality in group product and building design projects.

Table 2. Principles of Green Programs. First two columns, except "Nano-materials" adapted from: U.S. Environmental Protection Agency, 2005, "Green Chemistry": http://www.epa.gov/greenchemistry/principles.html; accessed April 12, 2005. Other information from discussions with Michael Hays, U.S. EPA, National Risk Management Research Laboratory, April 28, 2005.

Principle	Description	Example	Computational and Other Engineering Tools
Waste Prevention	Design chemical syntheses and select processes to prevent waste, leaving no waste to treat or clean up.	Use a water-based process instead of an organic solvent-based process.	Bioinformatics and data mining can provide candidate syntheses and processes.
Safe Design	Design products to be fully effective, yet have little or no toxicity.	Using microstructures, instead of toxic pigments, to give color to products. Microstructures bend, reflect and absorb light in ways that allow for a full range of colors.	Systems biology and "omics" technologies (i.e. genomics, proteomics, metabanonics) can support predictions of cumulative risk from products used in

			various scenarios.
Low Hazard Chemical Synthesis	Design syntheses to use and generate substances with little or no toxicity to humans and the environment.	Select chemical synthesis with toxicity of the reagents in mind upfront. If a reagent ordinarily required in the synthesis is acutely or chronically toxic, find another reagent or new reaction with less toxic reagents.	Computational chemistry can help predict unintended product formation and reaction rates of optional reactions.
Renewable Material Use	Use raw materials and feedstocks that are renewable rather than those that deplete nonrenewable natural resources. Renewable feedstocks are often made from agricultural products or are the	Construction materials can be from renewable and depleting sources. Linoleum flooring, for example, is highly durable, can be maintained with non-toxic cleaning products, and is manufactured from renewable resources amenable to being	Systems biology, informatics, and “omics” technologies can provide insights into the possible chemical reactions and toxicity of the compounds produced when switching from depleting to renewable materials.

	wastes of other processes; depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or that must be extracted by mining.	recycled. Upon demolition or re-flooring, the linoleum can be composted.	
Catalysis	Minimize waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once.	The Brookhaven National Laboratory recently reported that it has found a “green catalyst” that works by removing one stage of the reaction, eliminating the need to use solvents in the process by which many organic compounds are synthesized. The	Computation chemistry can help to compare rates of chemical reactions using various catalysts.

		catalyst dissolves into the reactants. Also, the catalyst has the unique ability of being easily removed and recycled because, at the end of the reaction, the catalyst precipitates out of products as a solid material, allowing it to be separated from the products without using additional chemical solvents.[36]	
Avoiding Chemical Derivatives	Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate	Derivativization is a common analytical method in environmental chemistry, i.e. forming new compounds that can be detected by chromatography. However, chemists	Computational methods and natural products chemistry can help scientists start with a better synthetic framework.

	waste.	must be aware of possible toxic compounds formed, including left over reagents that are inherently dangerous.	
Atom Economy	Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.	Single atomic and molecular scale logic used to develop electronic devices that incorporate design for disassembly, design for recycling and design for safe and environmentally optimized use.	The same amount of value, e.g. information storage and application, is available on a much smaller scale. Thus, devices are smarter and smaller, and more economical in the long-term. Computational toxicology enhances the ability to make product decisions with better predictions of possible adverse effects, based on the logic.

Nano-materials	Tailor made materials and processes for specific designs and intent at the nanometer scale (≤ 100 nm).	Emissions, effluent, and other environmental controls; design for extremely long life cycles. Limits and provides better control of production and avoids over-production (i.e. “throwaway economy”).	Improved, systematic catalysis in emission reductions, e.g. large sources like power plants and small sources like automobile exhaust systems. Zeolite and other sorbing materials used in hazardous waste and emergency response situations can be better designed by taking advantage of surface effects; this decreases the volume of material used.
Selection of Safer Solvents and Reaction Conditions	Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are	Supercritical chemistry and physics, especially that of carbon dioxide and other safer alternatives to halogenated solvents	To date, most of the progress as been the result of wet chemistry and bench research. Computational methods will

	necessary, use innocuous chemicals.	are finding their way into the more mainstream processes, most notably dry cleaning.	streamline the process, including quicker "scale-up."
Improved Energy Efficiencies	Run chemical reactions and other processes at ambient temperature and pressure whenever possible.	To date, chemical engineering and other reactor-based systems have relied on "cheap" fuels and, thus, have optimized on the basis of thermodynamics. Other factors, e.g. pressure, catalysis, photovoltaics and fusion, should also be emphasized in reactor optimization protocols.	Heat will always be important in reactions, but computational methods can help with relative economies of scale. Computational models can test feasibility of new energy efficient systems, including intrinsic and extrinsic hazards, e.g. to test certain scale-ups of hydrogen and other economies. Energy behaviors are scale-dependent. For example, recent

			measurements of H_2SO_4 bubbles when reacting with water have temperatures in range of those found the surface of the sun.[37]
Design for Degradation	Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.	Biopolymers, e.g. starch-based polymers can replace styrene and other halogen-based polymers in many uses. Geopolymers, e.g. silane-based polymers, can provide inorganic alternatives to organic polymers in pigments, paints, etc. These substances, when returned to the environment, become their original parent	Computation approaches can simulate the degradation of substances as they enter various components of the environment. Computational science can be used to calculate the interplanar spaces within the polymer framework. This will help to predict persistence and to

		form.	build environmentally friendly products, e.g. those where space is adequate for microbes to fit and biodegrade the substances.
Real-time Analysis to Prevent Pollution and Concurrent Engineering	Include in-process real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.	Remote sensing and satellite techniques can provide be linked to real-time data repositories to determine problems. The application to terrorism using nano-scale sensors is promising.	Real-time environmental mass spectrometry can be used to analyze whole products, obviating the need for any further sample preparation and analytical steps. Transgenic species, while controversial, can also serve as biological sentries, e.g. fish that change colors in the presence of toxic substances.
Accident Prevention	Design processes using chemicals	Scenarios that increase probability of	Rather than waiting for an accident to occur

	and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.	accidents can be tested.	and conducting failure analyses, computational methods can be applied in prospective and predictive mode; that is, the conditions conducive to an accident can be characterized computationally.

There are numerous industrial, commercial, and governmental green initiatives, including Design for the Environment (DFE), Design for Disassembly (DFD), and Design for Recycling (DFR).[38] These are replacing or at least changing pollution control paradigms. For example, concept of a “cap and trade” has been tested and works well for some pollutants. This is a system where companies are allowed to place a “bubble” over a whole manufacturing complex or trade pollution credits with other companies in their industry instead of a “stack-by-stack” and “pipe-by-pipe” approach, i.e. the so-called “command and control” approach. Such policy and regulatory innovations call for some improved technology based approaches as well as better quality-based approaches, such as leveling out the pollutant loadings and using less expensive technologies to remove the first large bulk of pollutants, followed by higher operation and maintenance (O&M) technologies for the more difficult to treat stacks and pipes. But, the net effect can be a greater reduction of pollutant emissions and effluents than treating each stack or pipe as an independent entity. This is a foundation for most sustainable design approaches, i.e. conducting a life-cycle analysis, prioritizing the most important problems, and matching the technologies and operations to address them. The problems will vary by size (e.g. pollutant loading), difficulty in treating, and feasibility. The easiest ones are the big ones that are easy to treat (so-called “low hanging fruit). You can do these first with immediate gratification! However, the most intractable problems are often those that are small but very expensive and difficult to treat, i.e. less feasible. Of course, as with all paradigm shifts, expectations must be managed from both a technical and an operational perspective. Not the least, the expectations of the client, the government, and those of the individual engineer must be realistic in how rapidly the new approaches can be incorporated.

Historically, environmental considerations have been approached by engineers as constraints on their designs. For example, hazardous substances generated by a manufacturing process were dealt with as a waste stream that must be contained and treated. The hazardous waste production had to be constrained by selecting certain manufacturing types, increasing waste handling facilities, and if these did not entirely do the job, limiting rates of production. Green engineering emphasizes the fact that these processes are often inefficient economically and environmentally, calling for a comprehensive, systematic life cycle approach. Green engineering attempts to achieve four goals:

1. Waste reduction;
2. Materials management;
3. Pollution prevention; and,
4. Product enhancement.

Optimizing for Sustainable Design: Life Cycle Assessment

Green engineering encompasses numerous ways to improve processes and products to make them more efficient from an environmental standpoint. Every one of these approaches depends on viewing possible impacts in space and time. Engineering and architecture have always been concerned with space. Architects consider the sense of place. Engineers view the site map as a set of fluxes across the boundary. Time is a bit more difficult. The design must consider short and long-term impacts. Sometimes these impacts are on futures beyond us.

The effects may not manifest themselves for decades. In the mid-twentieth century, designers specified the use of what are now known to be hazardous building materials, such as asbestos flooring, pipe wrap and shingles, lead paint and pipes, and even structural and mechanical systems that may have increased the exposure to molds and radon. Those decisions have led to risks to people inhabiting these buildings. It is easy in retrospect to criticize these decisions, but many were made for noble reasons, such as fire prevention and durability of materials. However, it does illustrate that seemingly small impacts when view through the prism of time can be amplified exponentially in their effects.

Sustainable design requires a complete assessment of a design in place and time. We mentioned that the effects can be decades away. In fact, they may be centuries in the future. For example, the extent to which we decide to use nuclear power to generate electricity is a sustainable design decision. The radioactive wastes may have half-lives of hundreds of thousands of years. That is, it will take all these years for half of the radioactive isotopes to decay. Radioactive decay is the spontaneous transformation of one element into another. This occurs by irreversibly changing the number of protons in the nucleus. Thus, sustainable designs of such enterprises must consider highly uncertain futures. For example, even if we properly place warning signs about these hazardous wastes, we do not know if the English language will be understood.

All four goals of green engineering mentioned above are supported by a long-term, life cycle point of view. A life cycle analysis is a holistic approach to consider the entirety of a product, process or activity, encompassing raw materials, manufacturing, transportation, distribution, use, maintenance, recycling, and final disposal. In other words, assessing its *life cycle* should yield a complete picture of the product.

The first step in a life cycle assessment is to gather data on the flow of a material through an identifiable society. Once the quantities of various components of such a flow are known, the important functions and impacts of each step in the production, manufacture, use, and recovery/disposal are estimated. Thus, in *sustainable design,* we must optimize for variables that give us the best performance in temporal senses.

Life cycle assessment (LCA) is an integral part of green engineering. The complexity of LCA ranges from cursory attention paid to inputs and outputs of materials and energy (Figure 4), to multifaceted decision fields extending deeply into time and space. The latter is preferable for decisions involving large scales, such the cumulative build-up of greenhouse gases or the long-range transport of pollutants leading to acid rain or bioaccumulation of toxic substances (e.g. dioxins and polychlorinated biphenyls) in the higher latitudes. Complex LCAs are also favored over cursory models when the effects are extensive, such as externalities and artifacts resulting in geopolitical impacts. The decision to increase the use of ethanol as a fuel additive and a reformulated fuel is such a decision. Thus, the recent proclamation by the United States government to increase ethanol’s share of the refined fuel to 10 percent by the year 2012 provides a case study of the application of LCA, from both design and pedagogical perspectives.

Case Study: Ethanol

Ethanol has been increasingly touted as an alternative to crude oil-based fuels. This interest has been diverse, with coverage in the national media and in professional and research journals. In his 2007 State of the Union Address, U.S. President George W. Bush set a two-part goal:

- Setting a mandatory standard requiring 35 billion gallons of renewable and alternative fuels in the year 2017, which is approximately five times the 2012 target called for in current law. Thus, in 2017, alternative fuels will displace 15 percent of projected annual gasoline use.
- Reforming the corporate average fuel economy (CAFE) standards for cars and extending the present light truck. Thus, in 2017, projected annual gasoline use would be reduced by up to 8.5 billion gallons, a further 5 percent reduction that, in combination with increasing the supply of renewable and alternative fuels, will bring the total reduction in projected annual gasoline use to 20 percent.

These and other alternative fuel standards have met with skepticism and even descent. In particular, the viability of ethanol is being challenged from scientific and policy standpoints. Ethanol is politically popular in corn-growing states. In fact, since the presidential proclamation, dedicated corn crops and ethanol refining facilities in these states have emerged. In other hand, geopolitical impacts, such as food versus fuel dilemmas are being raised. Scientific challenges to any improved efficiencies and actual decreases in the demand for fossil fuels have also been voiced. Some have accused advocates of ethanol fuels of using “junk science” to support the “sustainability” of an ethanol fuel system. Notably, some critics contend that ethanol is not even renewable, since its product life cycle includes a large number of steps that depend on fossil fuels. The metrics of success are often deceptively quantitative. For example, the two goals for increasing ethanol use include firm dates and percentages. However, the means of accountability can be quite subjective. For example, the 2017 *could* be met, but if overall fossil fuel use were to increase dramatically the percentage of total alternative use could be quite small, i.e. not near the 15 percent. Thus, *both* absolute and fractional metrics are needed.

Another accountability challenge is whether losses are included in calculations. From a thermodynamics standpoint, the nation’s increased ethanol use could actually increase demands for fossil fuels, such as the need for crude oil-based infrastructures, including farm chemicals derived from oil, farm vehicle and equipment energy use (planting, cultivation, harvesting, and transport to markets) dependent on gasoline and diesel fuels, and even embedded energy needs in the ethanol processing facility (crude oil-derived chemicals needed for catalysis, purification, fuel mixing, and refining). A comprehensive LCA is a vital tool for ascertaining the actual efficiencies.

The questions surrounding alternative fuels and ethanol, specifically, can be addressed using a three-step methodology. First, the efficiency calculations must conform to the physical laws, especially those of thermodynamics and motion. Second, the “greenness,” as a metric of sustainability and effectiveness can be characterized by life cycle analyses. Third, the policy and geopolitical options and outcomes can be evaluated by decision force field analyses. In fact, these three approaches are sequential. The first must be satisfied before moving to the second. Likewise, the third depends on the first two methods. No matter how political attractive or favorable by society, an alternative fuel must comport with the conservation of mass and energy. Further, each step in the life cycle (e.g. extraction of raw materials, value-added manufacturing, use, and disposal) must be considered in any benefit-cost or risk-benefit analysis. Finally, the societal benefits and risks must be viable for an alternative fuel to be accepted. Thus, even a very efficient and effective fuel may be rejected for societal reasons (e.g. religious, cultural, historical, or ethical).

The challenge of the scientist, engineer and policy maker is to sift through the myriad data and information to ascertain whether ethanol truly presents a viable alternative fuel. Of the misrepresentations being made, some clearly violate the physical laws. Many ignore or do not provide correct weights to certain factors in the life cycle. There is always the risk of mischaracterizing the social good or costs, a common problem with the use of benefit/cost relationships.

First Principles of Efficiency

Biomass-based fuel efficiencies are evaluated in terms of net energy production that is based on thermodynamics (first and second laws). Energy balances can be calculated from the first law of thermodynamics:

Accumulation = creation rate – destruction rate + flow in – flow out (1)

Stated quantitatively as efficiency, Eq (1) is:

$$\mathrm{E}\mathit{fficiency} = \frac{\mathrm{E_{in}} - \mathrm{E_{out}}}{\mathrm{E_{in}}} \times 100 \tag{2}$$

Where, E_{in} = Energy entering a control volume, and

E_{out} = Energy exiting a control volume

The qualifiers in this equation are quite telling. The numerator includes all energy losses. However, these are dictated by the specific control volume. This volume can be of any size from molecular to planetary. To analyze energy losses related to alternative fuels, every control volume of each step of the life cycle must be quantified.

The first two laws of thermodynamics drive this step. First, the conservation of mass and energy requires that every input and output be included. Energy or mass can neither be created nor destroyed, only altered in form. For any system, energy or mass transfer is associated with mass and energy crossing the control boundary within the control volume. If mass does not cross the boundary, but work and/or heat do, the system is a "closed" system. If mass, work and heat do not cross the boundary, the system is an isolated system. Too often, open systems are treated as closed, or closed systems include too small of a control volume (Figure 4). A common error is to assume that the life cycle begins at an arbitrary point conveniently selected to support a benefit/cost ratio. For example, if a life cycle for ethanol fuels begins with the corn arriving at the ethanol processing facility, none of the fossil fuel needs on the farm or in transportation will appear.

The second law is less direct and obvious than the first. In all energy exchanges, if no energy enters or leaves the system, the potential energy of the state will always be less than that of the initial state. The tendency toward disorder, i.e. entropy, requires that external energy is needed to maintain any energy balance in a control volume, such as a heat engine, waterfall, or an ethanol processing facility. Entropy is ever present. Losses must always occur in conversions from one type of energy (e.g. mechanical energy of farm equipment ultimately to chemical energy of the fuel). Thus, Eq (2) is actually a series of efficiency equations for the entire process, with losses at every step.

Utility and the Benefit/Cost Analysis

On the surface, the choice of whether to pursue a substantial increase in ethanol production is a simple matter of benefits versus costs. Is it more or less costly to generate ethanol than other fuels, especially those derived from crude oil? Engineers make much use of the benefit/cost ratio (BCR), owing to a strong affinity for objective measures of successes. Thus, *usefulness* is an engineering measure of success. Such utility is indeed part of any successful engineering enterprise. After all, engineers are expected to provide reasonable and useful products. Two useful engineering definitions of utilitarianism (Latin *utilis*, useful) are imbedded in BCR and LCA:

1. The belief that the value of a thing or an action is determined by its utility.

2. The ethical theory … that all action should be directed toward achieving the greatest happiness for the greatest number of people.

The BCR is an attractive metric due to its simplicity and seeming transparency. To determine whether a project is worthwhile, one need only add up all of the benefits and put them in the numerator and all of the costs (or risks) and put them in the denominator. If the ratio is greater than 1, its benefits exceed its costs.

One obvious problem is that some costs and benefits are much easier to quantify than others. Some, like those associated with quality of life, are nearly impossible to quantify and monetize accurately. Further, the comparison of action versus no-action alternatives cannot always be captured with in a BCR. Opportunity costs and risks are associated with taking no action (e.g. loss of an opportunity to apply an emerging technology may mean delay or nonexistent treatment of diseases). Simply comparing the *status quo* to costs and risks associated with a new technology may be biased toward no action. Costs in time and money are not the only reasons for avoiding action. The greater availability of ethanol may introduce unforeseen risks that, if not managed properly, could interfere with quality of life of distant and future populations, and could add costs to the public (e.g. air pollutants and topsoil loss) with little net benefit. So, it is not simply a matter of benefits versus cost, it is often one risk being traded for another.

Often, addressing contravening risk is a matter of optimization, which is proven analytical tool in engineering. However, the greater the number of contravening risks that are possible, the more complicated that such optimization routines become. The product flows, critical paths, and LCI can become quite complicated for complex issues.

Risk tradeoff is likely to occur in ethanol and biofuel decisions. For example, if the government mandates more ethanol usage, it will also have to enforce new air pollution laws associated with the fuel. These added regulations can be associated with indirect, countervailing risks. For example, the costs of construction of new facilities and the price of feedstock (especially corn) may increase safety risks via “income” and “stock” effects. The income effect results from pulling money away from other fuel ventures to pay the capital costs associated with ethanol, making it more difficult for a company or backers to invest in other services that would have provided improved fuel efficiency. The stock effect results when the capital costs increase to a point where companies have to wait to purchase new facilities, so they are left with substandard manufacturing. Thus, the engineer is frequently asked to optimize for two or more conflicting variables in many situations.

The success of ethanol in displacing fossil fuels depends on the efficiency with which it can be produced and used. Complicating matters, the use of fossil fuels in their production and/or operation is part of ethanol production, as it is for all biofuels. Societal benefits and costs are tied to ethanol’s energy balances.

Teaching Green Engineering

Green engineering is different than most engineering enterprises. It is an application of everything the engineer has learned, but no matter how extensive, the engineer never knows everything about the topic. Thus, green engineering learning objectives are of three types: 1. awareness; 2. understanding; and 3. application.

One of the challenges of environmental policy courses is that so many topics are current that if the instructor tries to address them all, the student will not have an adequate understanding of any issue. At the other extreme, covering one area in too great a detail may mean that the context may be lost on the student. Global climate change, for example, can be covered from myriad perspectives. Students can become aware of the potential problems by viewing videos, such as Al Gore's *An Inconvenient Truth.* They may read newspaper articles and opinion columns. These approaches certainly can raise students' awareness, but are unlikely to provide a complete understanding of the science underpinning the issues. Conversely, we can devote a complete course to the physics of blackbody radiation. The student gains a much more complete understanding of the electromagnetic properties and processes that lead to the greenhouse effect. However, it does not necessarily mean that the student will be able to apply the information and knowledge to whether the U.S. should agree to the Kyoto Accord. In fact, depending on the way the course is taught, the student may not even be able to predict the role of carbon dioxide increases on future ambient temperatures, since so many other factors besides blackbody radiation must be considered in the greenhouse effect.

Green engineering falls somewhere between these two extremes. That is, a green engineering course must be application-oriented, while increasing the students' awareness of policy issues *and* ensuring they base their applications on sound science. Both an appreciation for the geopolitics and the physics of blackbody radiation must be integrated into the course. Arguably, enhancing geopolitical and policy awareness is particularly important for first-year engineering students, since their pre-college preparation is usually quite quantitative, often limiting the student's exposure to coursework in the humanities and social sciences. However, the problem-solving skills of this group lend itself to interactive learning. Thus, the Socratic Method must be complemented by hands-on activities and quantitative cases. This is enhanced with various LCA software packages, including GREET[39] and SimaPro [40]. A particularly useful system is Building Information Modeling (BIM), one of the emerging tools to help practitioners and students visualize relationships between design decisions and building performance.[41] BIM uses computer technology to create a virtual model of the design and is intended not only as a tool for documentation but also to provide a tool for testing alternative scenarios and measuring each scenario across multiple benchmarks, from material use to energy consumption. The tool transforms the traditional process of the computer as a tool to simply document to one of conducting analysis of all of the building's systems in an integrated fashion. The potential for these models to behave in much more "intelligent" manner provides the design team with the ability to test “what if” scenarios during the design process. With the development of more robust data bases on the characteristics of materials for example, models will be able to more accurately reflect the life cycle implications of the designer’s decisions as the model incorporates the “embodied energy” of alternative materials from the point of extraction, through manufacturing and delivery and finished installation or end use. These information rich models are also able to simulate and analyze alternative scenarios which incorporate project specifics such as local climate that are fundamental to sound sustainable design strategies.

The LCA provides a methodical means of calculating flows of energy and materials through a system, giving the information needed for developing critical paths for a number of options. If the project is still in the planning stages, it can prevent economic and environmental mistakes. If it is part of an environmental management system of an existing project, LCA can point to inefficiencies. LCA is based on systems analysis, with the process chain made up a sequence of sub-systems that exchange inputs and outputs.[42] Interestingly, LCA is a manifestation of the first law of thermodynamics. Figure 4 can be adapted to show the material and energy balances and the relationships between inputs and outputs (Figure 5).

The LCA process is a methodical approach for evaluating ethanol as a suitable, renewable fuel:

1. Defining the goal and scope: This step requires agreement on the functional unit, i.e. the product or service being investigated. The functional unit must be sufficiently clear so that alternatives can be evaluated in terms of efficiency, risks, benefits and economics. The functional unit is also part of the metric for evaluating success or failure of a project after it is initiated.
2. Conducting the life cycle inventory (LCI): The LCI consists of setting the system boundaries. This can take on a thermodynamic flavor, such as looking at losses at each step of product development (e.g. ethanol refining), as well as depicting interactions with others systems (e.g. environmental and economic artifacts). As such, the LCI requires flow diagrams and critical paths, which can be used to find weaknesses and opportunities among the unit processes. Thus resulting inventory table allows students to quantify the material and energy flows associated with each functional unit. This also allows for sensitivity analyses of variables, so that students can begin to assess the value added of each step (e.g. if 75 percent of the energy losses occur in transportation of the raw materials, this may be an opportunity for improved efficiency). There are numerous means of analyzing a system’s environmental “footprint.” An excellent resource of details on the different inventory methodologies has been prepared by the Society of Environmental Toxicology and Chemistry.[43]

3. Assessing the Life Cycle Impact Assessment: The effects of the product and its life cycle are characterized and evaluated. Quantitative information is applied to the inventory to assess environmental impacts, along with ways to eliminate or to mitigate these effects. Students can engage in this effort alone at the beginning, but the real value comes with interactions with fellow students. As such, this may best be a team project.

4. Interpreting the LCA: This step is an analysis of major contributions, sensitivity analysis and assigning uncertainty estimates to each element of the assessment. It is a comprehensive view of the LCA results. Again, this step benefits from synergies on the team.

Revisiting the Harm Principle: Managing Risks

Previously, we mentioned the harm principle espoused by John Stuart Mill. Basically, the principle tells us that even when benefits clearly outweigh costs, we are still morally obliged not to take such action if it causes undo harm to even a few people. This is a difficult concept for those who operate in the quantitative domain, as most engineers and architects do.

The harm principle becomes even more complicated when not taking an action can lead to its own negative consequences. For example, consider a community with substandard housing and in need of demolition of a number of abandoned structures. Further, some of these structures were constructed with asbestos-containing building materials. There are a number of critical paths that could be followed to address the need for better housing, but all of them involve some risk of harm to others. If we decide to demolish the structures there is a potential for exposure to asbestos, but if we decide not to demolish the structures ongoing problems associated with abandoned buildings will persist (fire hazards, crack houses and other criminal activities, aesthetics, and disease vectors, like rats).

Similarly, green and biomedical engineering may seem to compete against different hazards. For example, the choice of using a toxic substance is complex (See Figure 6). Critical paths, PERT charts and other flow charts are commonly used in design and engineering, especially computing and circuit design. They are also useful in life cycle analysis if sequences and contingencies are involved in reaching a decision, or if a series of events and ethical and factual decisions lead to the consequence of interest. Thus, each consequence and the decisions made along the way can be seen and analyzed individually and collectively.[44] Other charts need to be developed for safety training, the need for fail-safe measures, and proper operation and maintenance. Thus, a “master flow chart” can be developed for all of the decisions and sub-consequences that ultimately led to the disaster. Event trees or fault trees allow you to look at possible consequences from each decision.

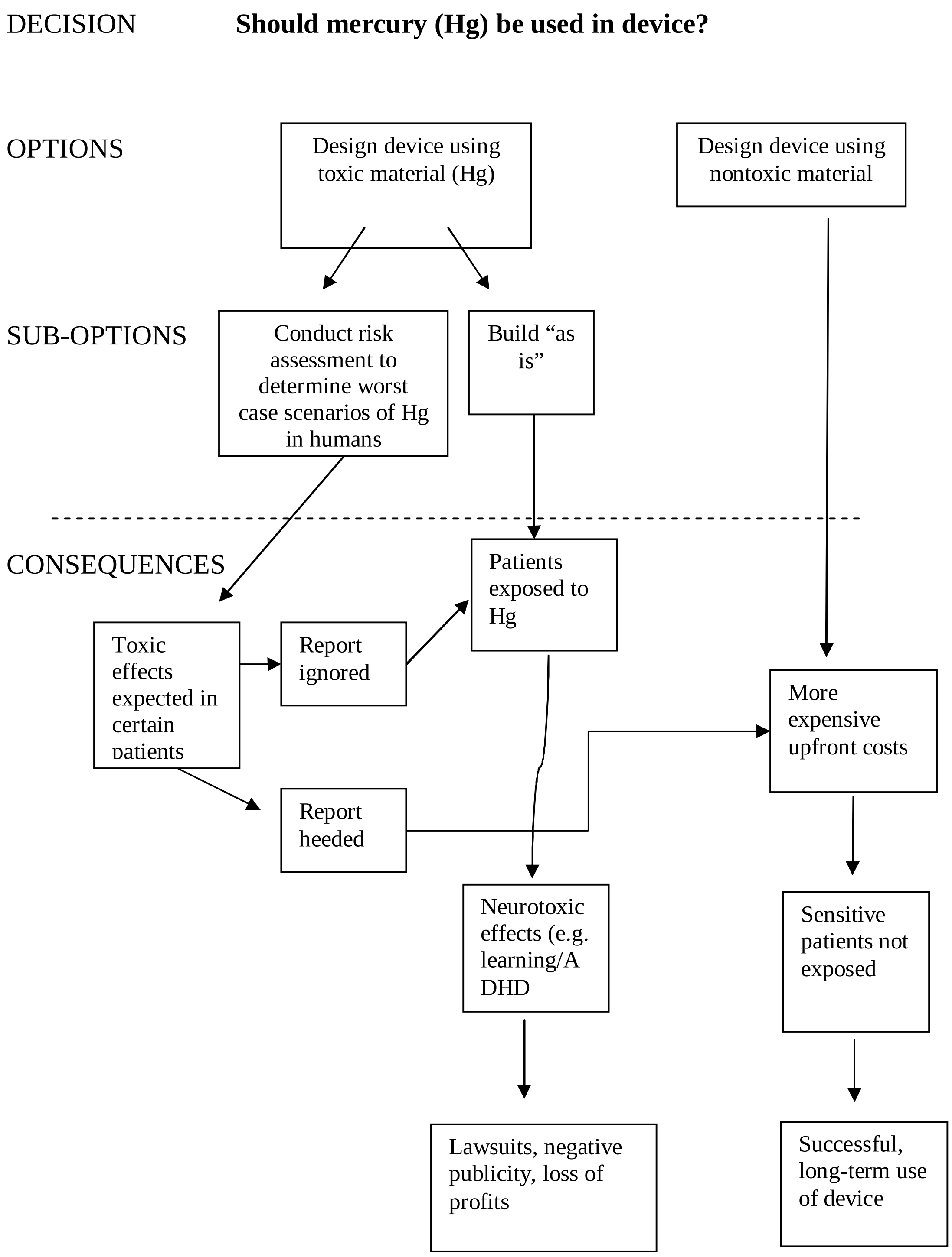


Figure 6. Event tree on whether to use mercury in a medical device.

The design for the environment (DFE) can be very challenging in biomedical engineering. Consider, for example, asthma medication that has been delivered to the lungs using greenhouse gas (GHG) propellant, at first blush the green engineering perspective may forbid it. However, if the total amount of the propellant used in these devices only constitutes 0.0001% of the total GHG used, perhaps the contribution to global warming is considered insignificant. The problem, as illustrated by the Tragedy of the Commons, is that if all of the “insignificant” contributions are ignored, collectively they could cause irreversible damage. When it comes to public health tradeoffs, the significance is determined by medical efficaciousness. For example, if there are alternatives to this particular GHG that are not greenhouse gases and that are just as effective at delivering the medication, then they are preferable from a risk management perspective. For example, some asthma medications are now delivered mechanically. If there are no effective alternatives, the tradeoff with the environmental effects may be justifiable.

Few, if any, design decisions can be made exclusively from a single perspective. We can visualize these design decision as attractions within a force field, where the center of the diagram represents the initial condition with a magnet placed in each sector at points equidistant from the center of the diagram (See Figure 7). If the factors are evenly distributed and weighted, the diagram might appear as that in Figure 8. But, as the differential in magnetic force increases, that factor will progressively drive the decision. So, in our greenhouse gas propellant example, the medical efficacy drives the decision (Figure 9). The stronger the magnet the more the decision that will actually be made will be pulled in that direction. Thus, in greening hospitals, for example, physicians and clinical engineers may drive the decision in one direction; lawyers may pull in another direction; whereas the environmental professionals may pull in a different direction. The net effect is a decision that has been “deformed” in a manner unique for that decision and that must be considered by the designer.

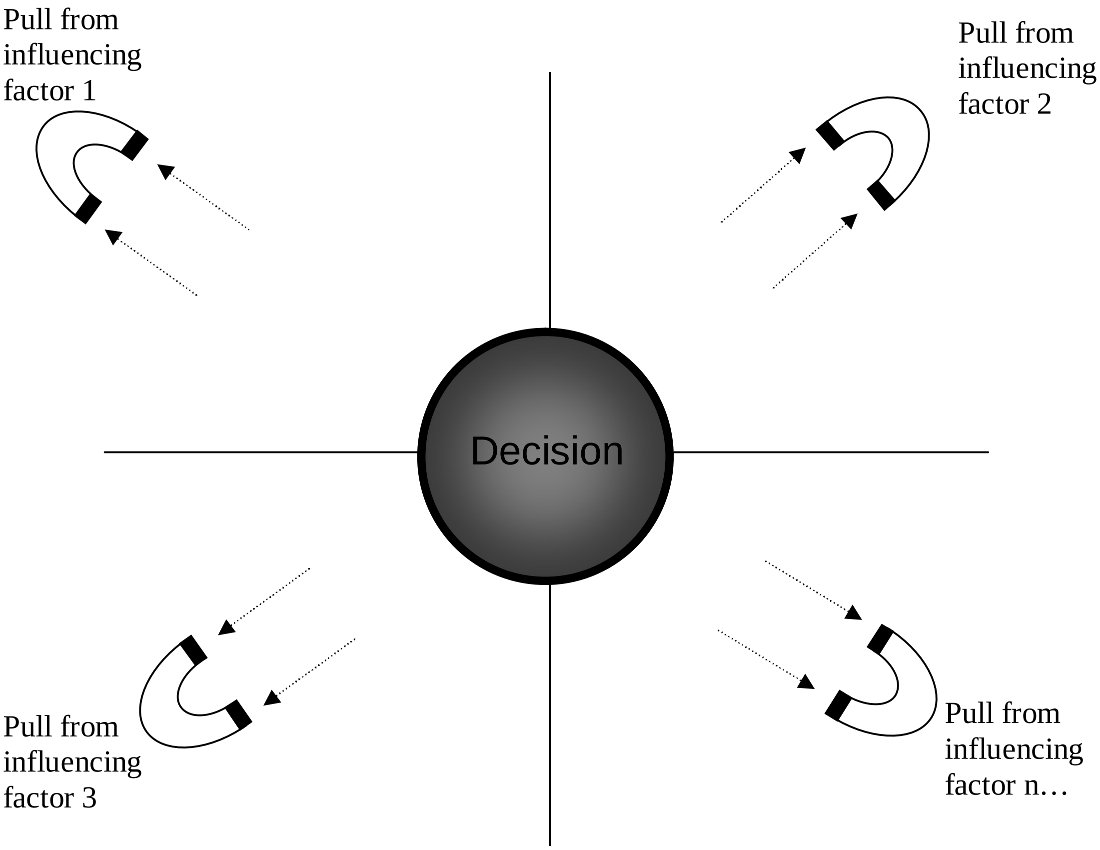


Figure 7. Decision force field. The initial conditions will be driven toward influences. The stronger the influence of a factor, e.g. medical efficacy, the greater the decision will be drawn to that perspective.

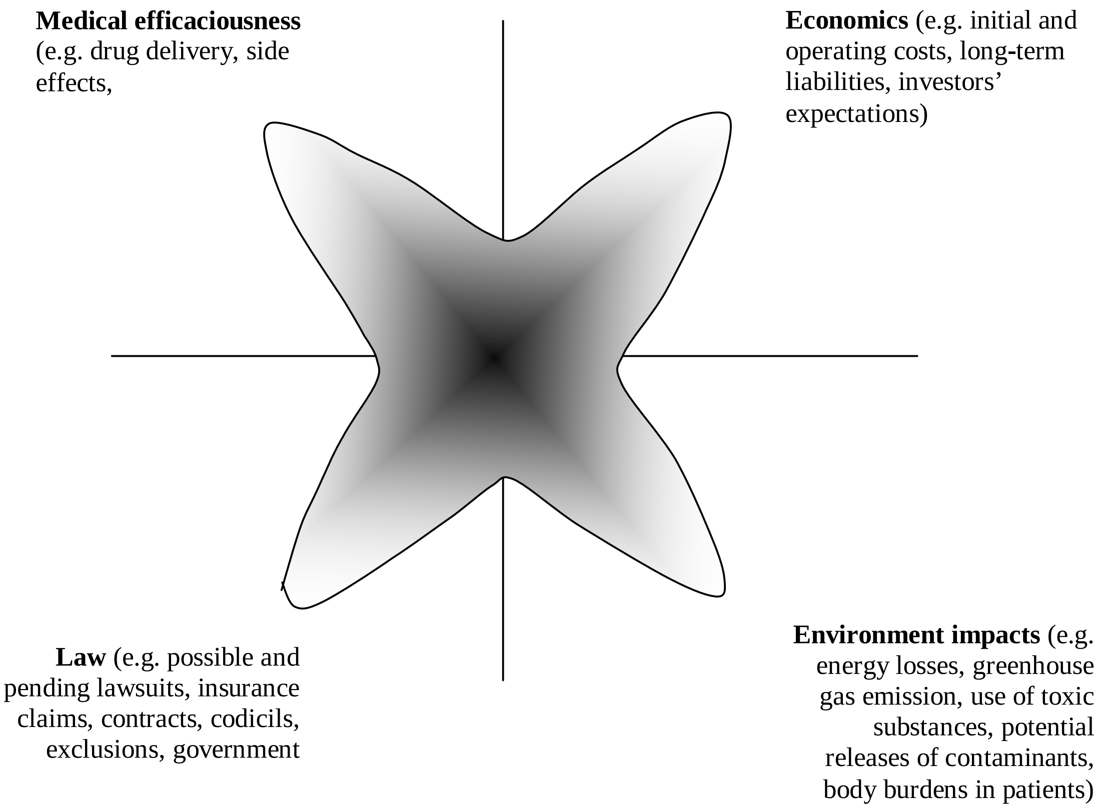
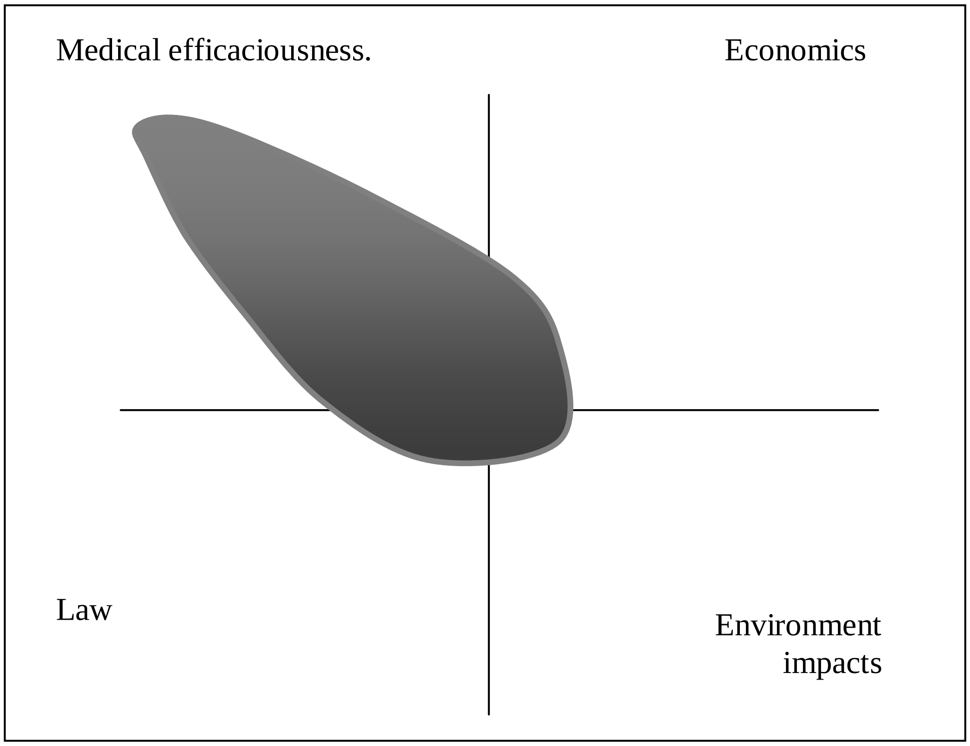


Figure 8. Decision force field where a number of factors have nearly equal weighting in a design decision. For example, if the law is somewhat ambiguous, a number of medical alternatives are available, costs are flexible, and environmental impacts are reversible, the design has a relatively large degree of latitude and elasticity.


Medical efficaciousness.
Economics
Law
Environment impacts

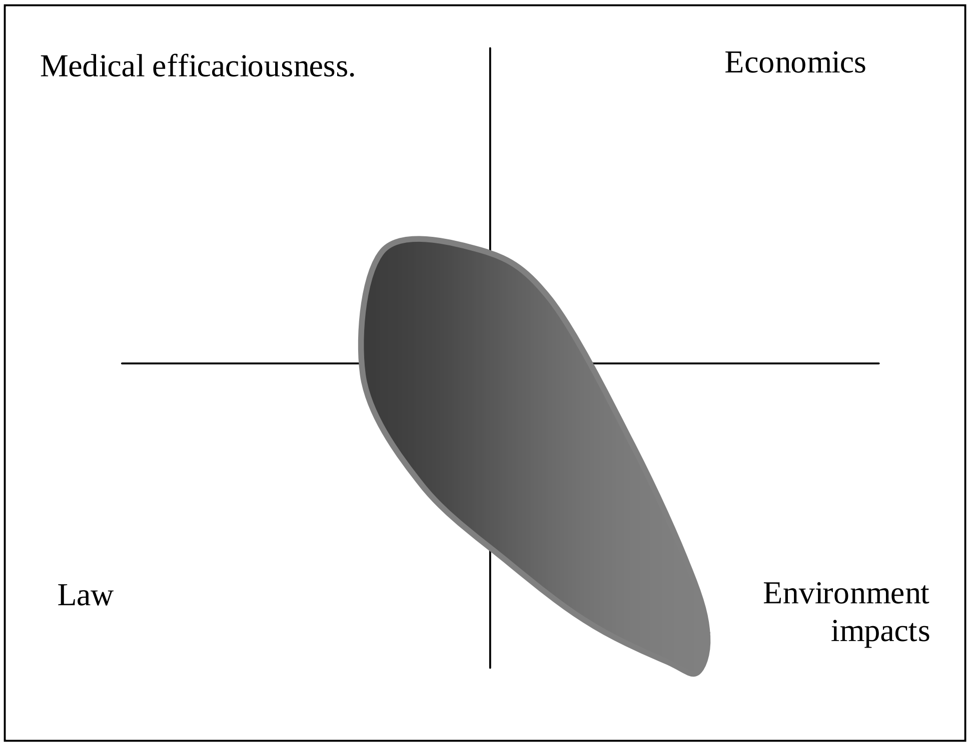

Medical efficaciousness.
Economics
Law
Environment impacts

Figure 9. Decision force field driven predominantly by one or a few factors. For example, if mortality or serious disease will increase, medical efficacy holds primacy over environmental, financial and even legal considerations (A). Legality is complex. At least ideally, the law protects public safety, health and welfare (the three mandates of the engineering profession). Thus, it may embody aspects of the other sectors (e.g. medical beneficence, environmental protection, and cost accountability). If medical efficacy is flexible and can be achieved in a number of ways, but environmental impacts are substantial, irreversible and/or widespread, then the design will be driven to be greener (B). Note that in both diagrams, all of the factors have some force; that is, the factors are important, just not as influential as the stronger factors.

Thus, the harm must be considered comprehensively. Design professionals by their very nature are risk managers. All design decisions are made under risk and uncertainty (that is why factors of safety are a part of every recommendation). The risk management process is informed by the quantitative results of the risk assessment process. The shape and size of the resulting decision force field diagram give an idea of what are the principal driving factors that lead to decisions. Therefore, the force field diagram can be a useful, albeit subjective, tool to visualize initial conditions, boundary conditions, constraints, tradeoffs, and opportunities.

Conclusion

Engineering ethics can be viewed from the perspective of the practicing engineer or individual researcher. This is known as microethics. While the codes of ethics stress these ethics, engineers also have responsibilities to society. These larger issues are the concern of macroethics. Notable among macroethical responsibilities is the engineering profession's obligation to protect the environment. Engineers have a number of tools to ensure that our designs are ethical and responsible, including the life cycle assessment process. These tools can help ensure that the engineering profession continues to grow in its call to socially responsibility.

Quiz Questions:

1) True or False? Ensuring that an engineer has no conflict of interest on bidding a job against a previous employer is a macroethical issue.

2) True or False? Deciding whether research on an implant device receives the appropriate informed consent from subjects is a microethical issue.

3) True of False? Balancing risks and opportunities from nanotechnological research is a macroethical issue.

4) True or False? The categorical imperative is an ethical maxim based on whether an action should be universalized.

5) How can Mill's harm principle be applied to green engineering?

6) All of the following ethical principles apply to research, except for:

5. Respect for autonomy

6. Beneficence
7. Cost effectiveness
8. Nonmaleficence
9. Justice

7) Compare and contrast Hardin’s Tragedy of the Commons with Leopold’s Land Ethic.

8) Give an example of an anthropocentric viewpoint that provides societal benefit and another that provides societal harm.

9) Give an example of an ecocentric viewpoint that provides societal benefit and another that provides societal harm.

10) Requiring industries to recycle 25% of plastics in their manufacturing process is an example of:

A. Risk assessment
B. Risk management
C. Risk perception
D. Risk communication

11) Engineering safety can be tested with all of the following criteria except:

A. The design must comply with applicable laws.
B. The design must adhere to “acceptable engineering practice.”
C. Alternative designs must be sought to see if there are safer practices.

D. The engineer has determined that the public’s welfare would be better served by a less safe design.
E. Possible misuse of the product or process must be foreseen.

12) Green engineering encompasses all of the following except:

A. Waste reduction
B. Public relations
C. Materials management
D. Pollution prevention
E. Product enhancement

13) Give at least two steps in ethanol production that presently depend on fossil fuels.

14) Showing a film on the pros and cons of waste management techniques is an example of enhancing the viewer’s:

A. Ethical Awareness
B. Ethical decision making
C. Ethical behavior
D. Ethical cost accounting

15) LCA consists of all of the following steps, except:

A. Defining the goal and scope
B. Conducting the epidemiological survey
C. Conducting the life cycle inventory (LCI)
D. Assessing the Life Cycle Impact Assessment
E. Interpreting the LCA.

Background Articles and Websites about Environmental and Social Issues in Engineering

- Teaching Ethics and Technology Studies to Engineering Students (North Carolina State University)
- Macroethics of Emerging Technologies (Vallero, July 11, 2007 at NCSU)
- Beyond Responsible Conduct of Research: Macroethics of Nanobiotechnolgogies (Vallero, April 11, 2007, Brooklyn)
- Hardin's "Tragedy of the Commons"
- The President's Green Chemistry Award
- The Physiome Project: The Macroethics of Engineering toward Health
- EPA's Green Engineering
- GSA's Green Engineering
- Guiding Principles of Sustainable Design (Park Service)

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