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Environmental and Social Dimensions of Engineering Research

SUNY - University at Binghamton - Responsible Conduct of Research for Engineers

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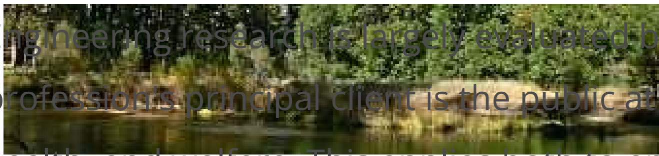
Introduction



Engineering research is largely evaluated based on its risks and reliability. The engineer profession's principal client is the public at large; holding paramount the public safety, health, and welfare. This applies both to engineering practice and research. Engineers may be asked if they have appropriately considered human and ecological impacts, not merely from the way they conduct research, but also in how that research is or will be applied. Furthermore, whereas all engineering research should be sustainable, emerging technologies present a particular challenge, owing to the numerous areas of uncertainty. Could the design lead to environmental risk and will this risk be distributed proportionately throughout society? In short, engineering ethics requires justice. It also requires a commitment to the future, including sustaining and improving environmental quality and ensuring public health and welfare.

Learning Objectives

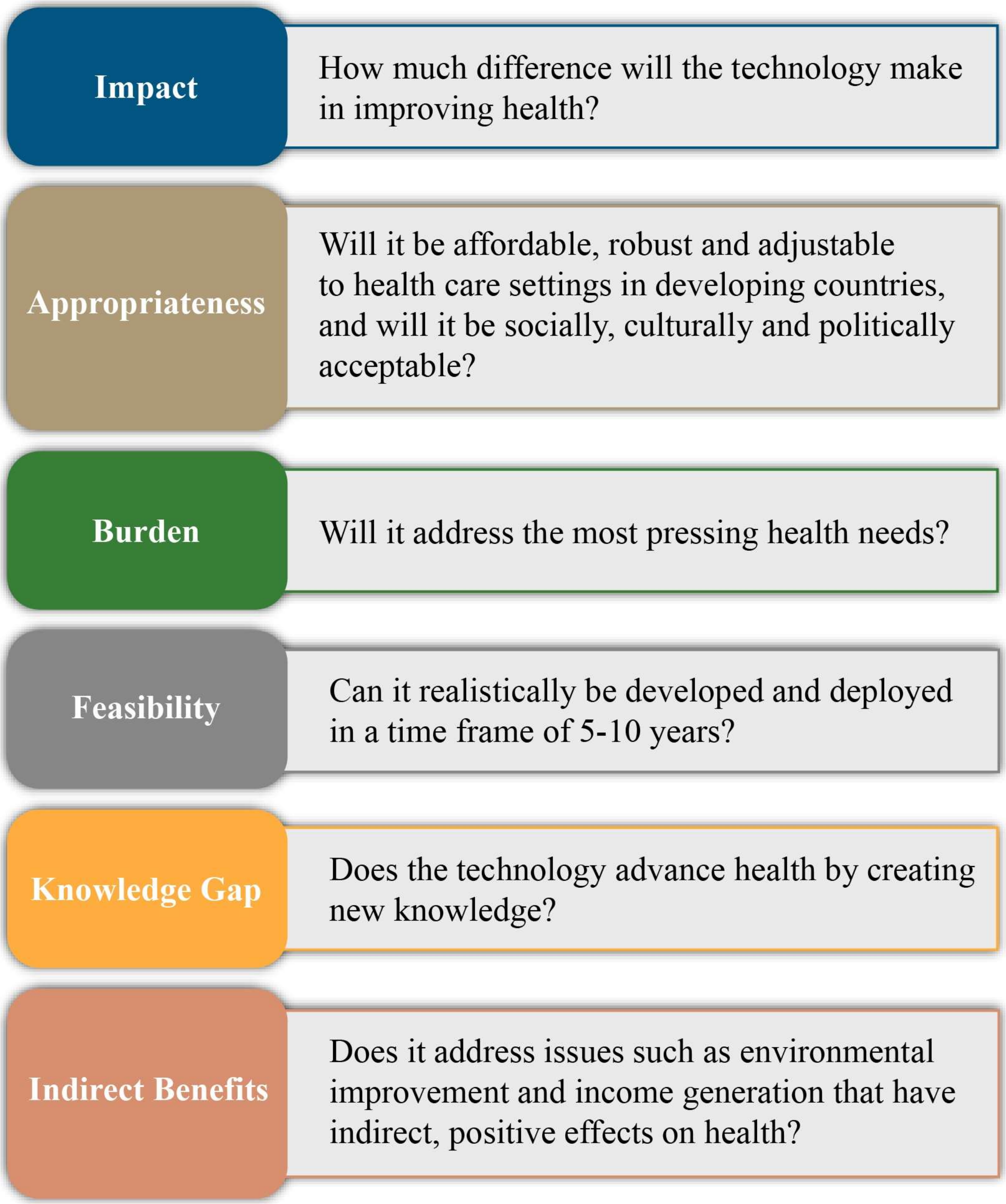
By the end of this module, you should be able to:

- Identify key ethical frameworks relating to ethics and the environment.
- Discuss risk and other related concepts.
- Describe the importance of sustainability.
- Describe the importance of green engineering.

Advancing Knowledge vs. Utility

Engineering researchers are interested in advancing knowledge but with an eye toward practice. Engineering practice and research share a common feature; both call for balance. Society demands that the state-of-the-science be advanced as rapidly as possible and that there are no dangerous side effects. This calls for a multivariate approach, with tradeoffs among numerous options. One of the many strengths of the engineering practitioner and researcher is the ability to optimize among numerous variables for the best design outcomes. This approach can be used not only for technical decisions but also to ensure that these decisions are ethical.

The individual engineer must abide by the principles of practice and codes of ethics. For example, the professional engineer in the U.S. must adhere to the code of ethics of the National Society of Professional Engineers. Likewise, specific disciplines must adhere to their societies' codes, such as those of the American Society of Civil Engineers (ASCE 2006) and the American Society of Mechanical Engineers (ASME 2012). However, such codes are limited in at least two ways. First, they address general aspects of practice and, as such, do not speak directly to engineering research. Second, these codes are solely aimed at the individual engineer. Thus, larger issues like sustainability and emergent technologies are not wholly addressed by this "bottom up" approach. Emergent areas are associated with some degree of peril. A query of top scientists regarding biotechnologies needed to help developing countries indicates the range of concerns (see **Table 1**). The international experts were asked the following questions about the specific technologies (Darr et al. 2002):



Engineers as agents of technological progress are in a pivotal position. Societal challenges require that each engineer understand the implications and possible drawbacks of technological developments. Key among them will be biomedical and novel technical advances, including at smaller scales that approach the molecular level, such as nanotechnologies, because of their potential to impact human health and environmental quality For example, genetic manipulations can lead to so-called "gene flow," which means that genetically modified organisms (GMOs) may share their altered genetic information with native organisms, so that untargeted populations may irreversibly change. Thus, there is a possibility of completely displacing native species. This is an example of dramatic changes in outcome due to seemingly small changes in initial conditions.

Perspectives on Ethics

> "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] 1981)*

Engineers are comfortable with the dimensional analysis by which they can measure and describe physical, chemical, and biological attributes of what they design. But can ethics be "measured" in a similar way? Longstanding disagreements continue about which specific ethical tradition to embrace. However, there is widespread consensus that ethics is a rational and reflective process of deciding how humans ought to treat each other.

Indeed, engineering ethics is a combination of many different schools of thought. It is neither completely deontological (duty based) nor teleological (outcome based). It is a combination of these, based on reasoning. Engineers not only ask what is their duty and what is the desired outcome, but why is the project being undertaken in the first place and are there better and safer ways to accomplish this.

One Means of Describing an Ethical Situation Is By Its Reach in Space and Time

The engineering profession has a moral responsibility to ensure that designs and technologies are in society's best interest. In addition, the individual engineer has moral obligations to the public and to the client. The moral obligations of the profession as a whole are greater than the sum of the individual engineer's obligations. The profession certainly needs to ensure that each of its members adheres to a defined set of ethical expectations.

Political theorist Langdon Winner (1990) has succinctly characterized the moral imperative to which engineers should adhere by stating that:

> 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.

Kant's Categorical Imperative and Other Approaches to Ethics

One approach to ethics that may help to resolve professional challenges is offered by the philosopher Immanuel Kant ([1785] 1992). Kant's categorical imperative states that in order to determine whether something is ethical, one should consider what would happen if that act was universalized. In other words, could it become a law adopted by everyone? If the law upholds the ideal of showing respect for rational beings, the act is moral; if, on the other hand, it displays a lack of regard for humanity, the act is immoral. Kant embraced the categorical imperative as the theoretical underpinning for duty ethics.

The President of Agnes Scott College, Elizabeth Kiss, explains Kant's categorical imperative in contemporary terms and labels her version the "Six O'clock News" imperative. If you are pondering whether something is ethical or not, consider how your friends and family would feel if they heard about the decision on television news.

Another approach to ethics is offered by John Stuart Mill. His utilitarian axiom of "the greatest good for the greatest number" is moderated by his "harm principle". That is, even though an act can be good for the majority, it may still be unethical if it causes undue harm to individuals.

As professionals, engineers strive for excellence. This is articulated in codes of ethics, which over time has grown beyond merely a mandate to avoid actions that are clearly wrong, to a vision of engineering accomplishments that advance human endeavors. Part of the formula for ethical behavior is to know who is directly and indirectly affected by actions, which the aforementioned ethical perspectives may help bring into focus. Engineers should not simply solve immediate problems for a specific client. Rather, they should consider the larger public and future generations.

Engineering ethics can be viewed from the day-to-day perspective of the practicing engineer or individual researcher. This is known as **microethics**. While the codes of ethics stress this category of ethics, engineers also have responsibilities to society, often referred to as **macroethics**. Notable among macroethical responsibilities is the engineering profession's obligation to protect the environment.

Perspectives on Non-human Species and the Environment

Environmental ethics pertains to those actions held to be right and wrong about how people interact with the environment. Several major ethical viewpoints dominate the environmental literature: anthropocentrism; biocentrism; sentientism; and ecocentrism (see **Figure 1**).

Anthropocentrism

Biocentrism

Sentient-centered Ethics

Ecocentrism

Anthropocentrism

The philosophy or decision framework entailing that all and only humans are entitled to moral regard. Nonhuman species and ecological resources have value only in respect to their usefulness to human beings (known as instrumental value).

Biocentrism

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 moral value. Within this framework, respect for nature is the ultimate moral attitude. It is encapsulated by Albert Schweitzer's "reverence for life" ([1933] 1990).

Sentient-centered Ethics

Falls between anthropocentrism and biocentrism. This approach suggests that all creatures with a nervous system are entitled to moral regard. That said, this view would cause us to do what we can to prevent or at least reduce suffering in these other species. Biologists typically suggest that the difference between humans and animals is a continuum, as indicated by the development of the nervous system and other physiological metrics.

Ecocentrism

Based on the notion that the whole ecosystem, rather than just single species, has moral value. In his seminal work, A Sand County Almanac ([1949] 1987), Aldo Leopold grew to appreciate 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 (1949) 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."

Application of the Frameworks

Applying a single ethical framework in every circumstance can be problematic. Conversely, extreme biocentrism could halt useful advances in genetic engineering (for example, genetically modified organisms to treat hazardous wastes). Yet the awareness of these ethical frameworks can help to inform decision-making.

Risk, Reliability and Ethics

All design decisions can lead to unanticipated consequences. Some argue that there is a need to proceed carefully by following a precautionary principle.

Precautionary Principle

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 to avoid the action.

However, the precautionary approach must also be balanced against the potential for new advances. In other words, by being cautious are opportunities missed that would better serve the public and future generations? The key to balancing these connections can be a complete and accurate characterization of risks and benefits. Unfortunately, design decisions are often not fully understood until after the fact (and viewed through the prism of lawsuits and media coverage). Hazardous waste sites were the major impetus behind risk-based regulations. For example, Love Canal, Times Beach, and the Valley of the Drums in Kentucky are major cases that led to regulatory changes. Managing risks to human and ecosystem health is one of the principal engineering mandates.

Risk

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 cause damage, injuries, and even death. The hazardous waste cases emphasize the need to somehow quantify and manage risks.

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

Risk and Benefit

Engineers and others must consider the interrelationships among factors that put people at risk. Designs must be based on the sound application of the physical and social sciences. Engineers are held responsible for designing safe products and processes, and they are held accountable for the public's "health, safety and welfare." Engineers design systems to reduce risk and look for ways to enhance the reliability of these systems.

Both risk and reliability are expressed as probabilities. As such, the minimum likelihood is zero and the maximum likelihood is 100% (in other words, probability can be any value between zero and one). Individuals living near industries and waste sites, at least intuitively, compare the risks of living there to other factors such as affordability and proximity to work. For good reason, they want to be assured that they will 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, at least to some extent, in quantitative terms. Factors of safety are a part of every design.

This raises a key problem for engineers; how can the potential risks, benefits, and reliability of their designs be properly communicated to non-engineers? Just because the client or the general public is silent about a proposal does not necessarily mean they agree. Indeed, they are often in no position to agree or disagree since the project is quite technical in nature. Hence, expressions of risk and reliability require trust, akin to the trust that a medical doctor must gain from a patient about to undergo surgery that can only fully be understood in highly technical, medical terms.

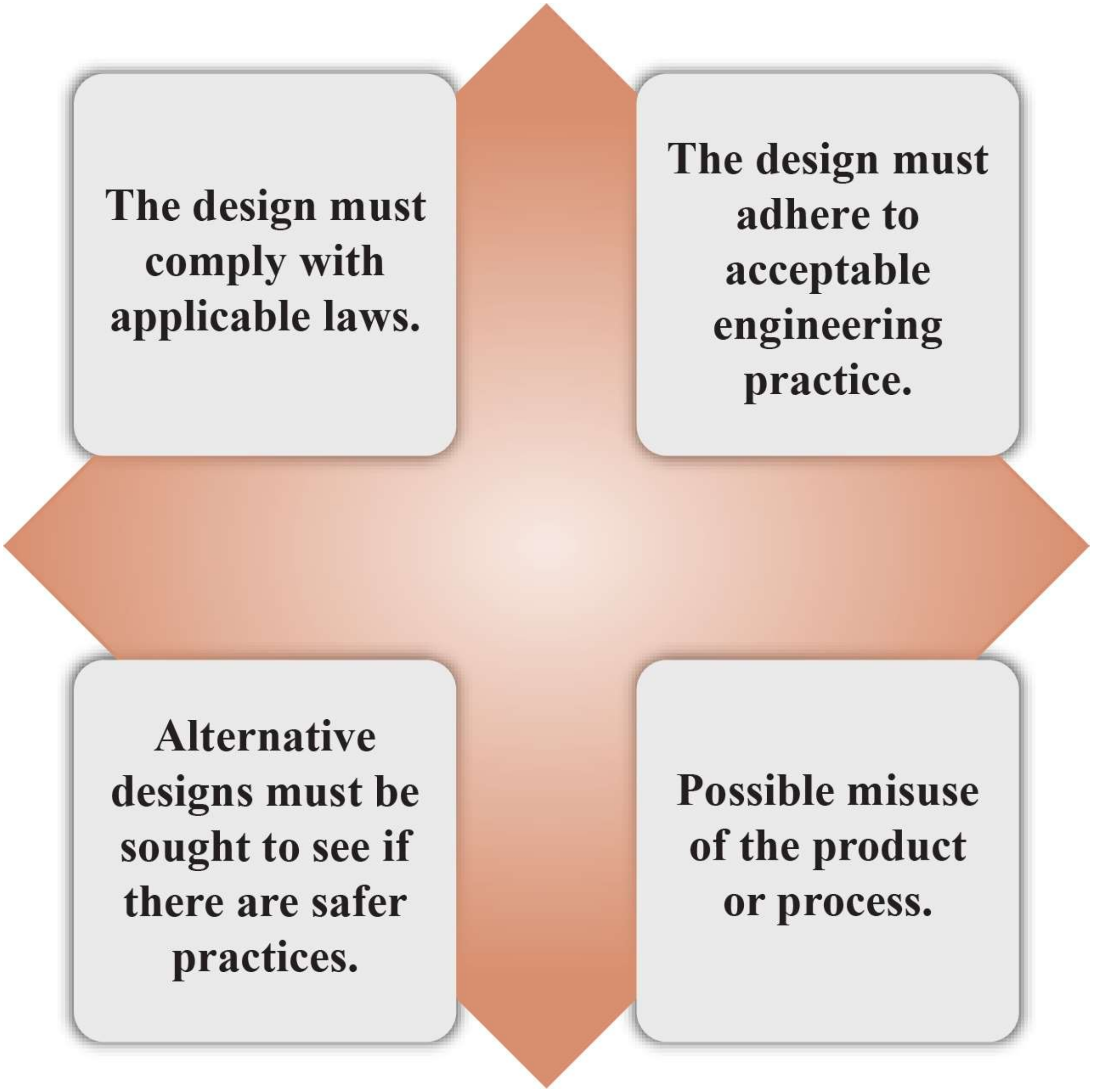
All design decisions are made under risk and uncertainty (that is why factors of safety are necessary). The risk management process is informed by the quantitative results of the risk assessment process. Managing risks also must consider other quantitative information, such as economic costs and benefits, as well as qualitative information, such as opinions shared by neighbors or community leaders. Thus, in addition ensuring that a project is the right project for the problem at hand and the project is executed in a sound manner, the engineer must also be mindful of the culture and social context of the project.

Engineering as Applied Social Science

Thinking of engineering as applied social science redefines engineering from a profession that builds things to one that helps people. By extension, educators must be vigilant about what and how engineering is taught. So, how do engineers fail to help people?

Engineering success or failure is in large measure determined by comparing expectations against what has actually occurred. Safety is always a fundamental facet of our professional duties. Thus, we need a set of criteria that tells us when designs and projects are sufficiently safe.

Four main safety criteria should be applied to test engineering safety (Fleddermann 1999):



Failure

The first two criteria are easier to follow than the third and fourth. The well-trained designer can look up the physical, chemical, and biological factors to calculate tolerances and factors of safety for specific designs. Laws have authorized the thousands of pages of regulations and guidance that indicate when acceptable risk and safety thresholds are crossed, meaning that the design has failed to provide adequate protection. In general, only other engineers with specific expertise can judge whether the ample margin of safety as dictated by sound engineering principles and practice has been provided in the design. Identifying alternatives and predicting misuse requires creativity and imagination.

The Consequences of Failure

Failure in design can go beyond the textbook cases and those shared by mentors and passed on from one's predecessors. Two cases that go beyond the classical types involved Minoru Yamasaki: the Pruitt-Igoe housing development and the World Trade Center towers. By most accounts, Yamasaki was a highly successful designer. Tragically and ironically, Yamasaki may be best remembered for two of his projects that failed. The Pruitt-Igoe public housing development in St. Louis, Missouri was supposed to be emblematic of advances in fair housing and progress in the war on poverty (Birmingham 1998). Regrettably, the development became an icon of failure of imagination. Going forward, designers could probably benefit from the insights of Aldo Leopold and his contemporaries.

Yamasaki and Antonio Brittiochi designed the World Trade Center towers. Yamasaki strived to present an aesthetically pleasing structure. According to this criterion, he succeeded where many architects fail; aesthetic or operational (for example, ugly or an inefficient flow of people) are more often the cause of architectural failures than structural problems. Yet the towers failed when they collapsed (though the designers should not be blamed for this).

Most post-collapse assessments have agreed that the structural integrity of the twin towers was sufficient based on what was known at the time of design. However, future engineers must learn the lessons from this tragedy and adjust their designs accordingly.

The primary lesson is that engineering is an integrative enterprise. Design depends not only applied natural sciences but on the social sciences. Ethics, in particular, is crucial to an engineer's success. We should not miss opportunities to relate engineering and social science lessons from even the most life and society changing events (Bailey 1965; Vallero 2002).

Sustainability

One of the principles of green engineering is the recognition of the importance of **sustainability**. The recognition of impending global environmental disasters 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 as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission 1987).

The World Summit on Sustainable Development (WSSD 2002) identified five major areas that are considered key for moving sustainable development plans forward:

1	Consumption and production
2	Energy
3	Rural poverty and food security
4	Health and the environment
5	Fresh water

Sustainable design is analogous to the psychological concept of individual needs. Maslow was among the first to articulate a similar notion within a hierarchy of two classes of needs: basic and growth (see Figure 2). This can be adapted from an individual's personal development to larger population and ecosystem scales (Maslow 1970).

Basic Needs Applied to Larger Scales

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 (Maslow 1970).

Developing economies often cannot adequately provide food, clean water, and other basic needs for large segments of their populations. Ironically, the quest to meet these basic needs can be accompanied by environmental damage, if not carried out in a sustainable way. Industrial and economic development is currently occurring in many nations at substantial costs to environmental quality. For example, air, water, and soil pollution is increasing rapidly in China, India, and other nations with growing economies (analogous to the economic and environmental tradeoffs in the Western hemisphere following World War II).

Another aspect of sustainability is that development must be considered in a systematic way. What may be acceptable at one scale may be unacceptable at another. For example, providing the basic needs for one nation may adversely affect the region or the entire planet, such as the potential for the release of greenhouse gases that may alter climate at the global scale.

Growth Needs within the Province of Environmental Protection

The most basic of needs must first be satisfied before striving for more advanced needs. 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

Sustainability is a systematic phenomenon. 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. Thus, the chaotic nature of possible impacts must be considered by the engineer to ensure that solving one problem does not create a new one. This is known considering "downstream impacts" in the life cycle.

Implementing Sustainable Designs (Green Engineering)

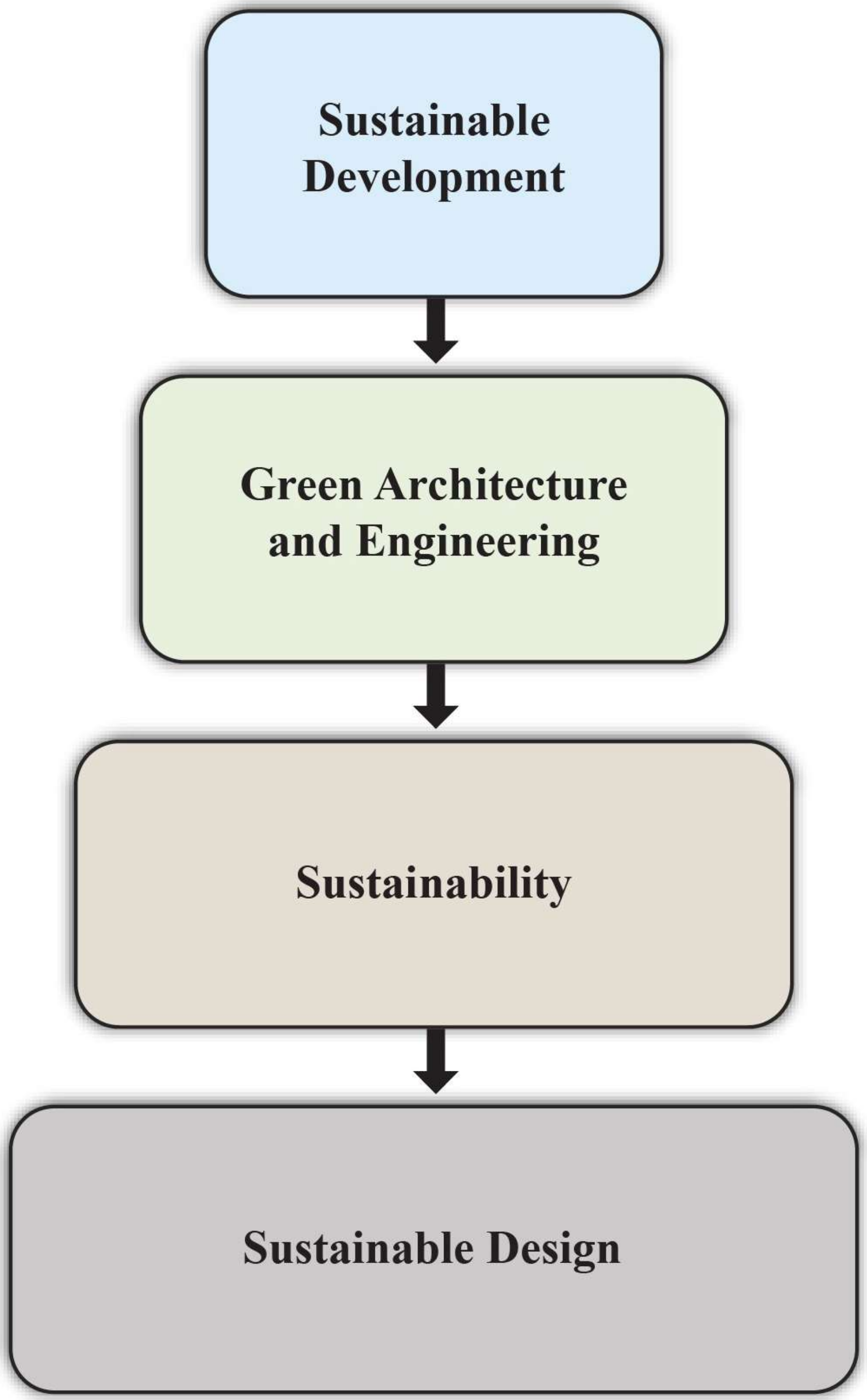
A common decision tool for engineers is the benefit-to-cost ratio (BCR). The choice of a pollution control option may appear to be a simple matter of benefits vs. costs. The engineer may want to know the cheapest way to achieve a specified level of environmental quality. For example, which pollution control technology is best at 99% removal of a pollutant from the waste stream? The answer to this question is clearly supported by the BCR. Thus, utility is a measure of success of any successful engineering enterprise. After all, engineers are expected to provide reasonable and useful results. As such, the BCR is a useful metric due to its simplicity and seeming transparency. To determine whether a project is worthwhile the benefits are summed in the numerator and the costs in the denominator. If the ratio is greater than one, the option's benefits exceed its costs (Vallero 2014).

A problem is that some costs and benefits are much easier to quantify than others. For example, those associated with quality of life are not conducive to quantification. Furthermore, the comparison of action vs. no-action alternatives is difficult or impossible within a BCR. Opportunity costs and risks can be missed, such as not applying a new technology that would be more effective. Comparing the status quo to costs and risks associated with a new technology and/or greener approaches may be biased toward no action by relying exclusively on proven technologies.

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. According to the National Academy of Engineering (NAE 2004):

> 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.

Sustainability requires adopting new and better means of using materials and energy. Operationalizing 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 is an ideal that can lead to sustainability, which can be accomplished through green engineering.

Green architecture and engineering treat environmental quality as an end in itself (Billatos and Basaly 1997). The U.S. Environmental Protection Agency (EPA 2017) discusses the importance of the interrelationships of feasibility, environmental quality, public health, and welfare by stating that "green engineering is the design, commercialization, and use of processes and products that minimize pollution, promote sustainability, and protect human health without sacrificing economic viability and efficiency."

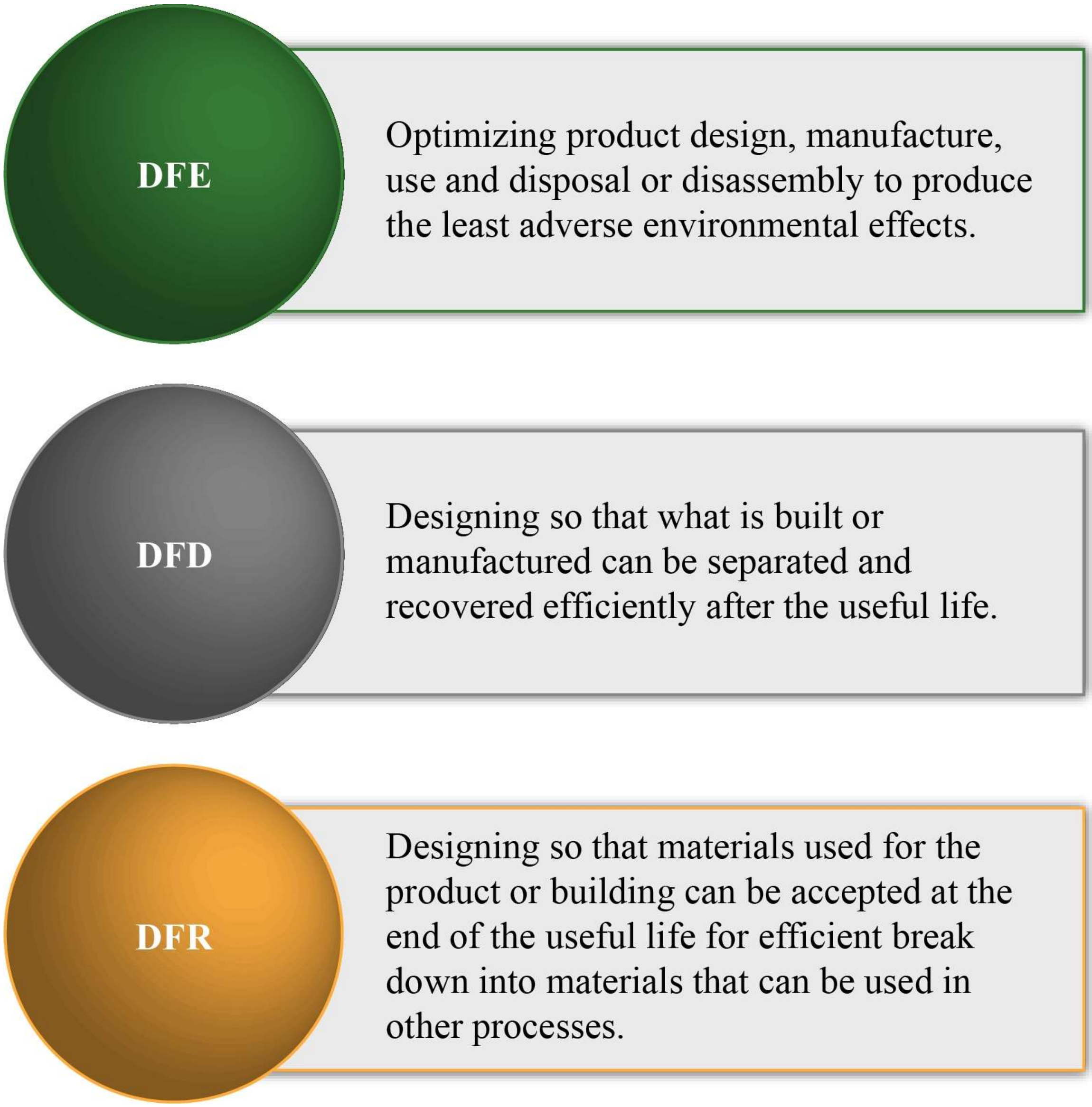
Decisions to protect human health and the environment can have the greatest impact and cost effectiveness when applied early to the design and development phase of a process or product.

Green engineering approaches used to be either absent or retrofitted into designs. In recent years, however, they have become more fully integrated into engineering guidelines. The principles underlying green engineering, along with engineering tools, can help the engineer meet green design objectives. Green approaches are actually examples of systems engineering, in other words, rather than focusing on a specific engineering discipline (for example, civil, mechanical, chemical, or biomedical), the design is considered from an interdisciplinary perspective for its entire life cycle.

To learn more about the principles of green programs, refer to **Table 2**.

Implementing Green Design

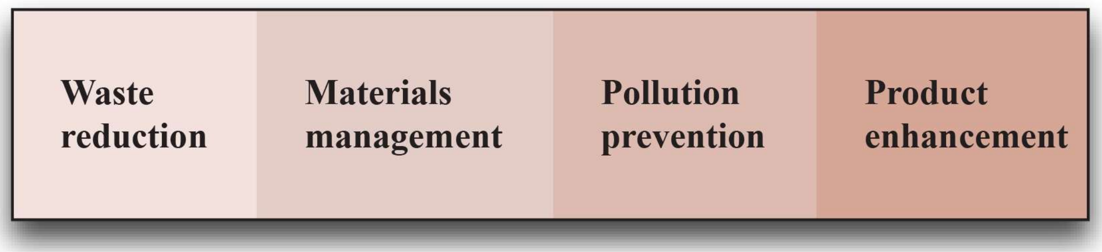
Considering a design's entire life cycle can make use of numerous industrial, commercial, and governmental green initiatives, including Design for the Environment (DFE), Design for Disassembly (DFD), and Design for Recycling (DFR) (Allada 2000; Vallero and Brasier 2008a):



These are replacing or at least changing pollution control paradigms. Policy and regulatory innovations call for improved technology based approaches as well as better quality-based approaches. This is a foundation for most sustainable design approaches, in other words, conducting a life-cycle analysis, prioritizing the most important problems, and matching the technologies and operations to address them.

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 needed to be contained and treated. The hazardous waste production had to be constrained by selecting certain types of manufacturing, 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 to achieve four goals:



Systems engineering extends an engineer's responsibilities well beyond the construction, operation, and maintenance stages. An integrated matrix can be a visual representation of DFE by highlighting the technical and other factors associated with each component of the design, as well as the relationships among these components. These can include potential health risks, social expectations and environmental impacts, and other societal risks and benefits associated with a device, structure, product, or activity during the manufacturing, marketing, and application phases; yielding two-dimensional matrices (see **Figure 3**).

Each matrix cell indicates both the importance of a particular factor or component, along with the confidence (scientific certainty) regarding the underlying information used to assess the importance. The matrix approach is qualitative or at best semiquantitative, but provides a benchmark for comparing alternatives that would otherwise be incomparable. For some designs, it may be possible to assign numerical values to each cell to compare them quantitatively if the factors can be weighted. The matrix approach can also focus a specific measure, such as energy efficiency or product safety (Vallero 2014).

Optimizing for Sustainable Design

Green engineering encompasses numerous ways to improve processes and products to make them more efficient from an environmental standpoint. The designer must consider short and long-term impacts. Sometimes the most profound impacts will be on generations beyond the current one.

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 human exposure to molds and radon. It is easy in retrospect to criticize these decisions, but many were made for noble reasons, such as fire prevention and durability of materials.

Sustainable design requires a complete assessment of a design in place and time. The effects of a technology can be decades or even centuries away. For example, the radioactive wastes generated by nuclear power plants may have half-lives of hundreds of thousands of years.

Sustainable design can be demonstrated using the concept of "carrying capacity" in Hardin's "Tragedy of the Commons" (1968) wherein he imagines an English village with a common area where every villager can allow a cow to graze. At first, the common readily sustains the livestock. However, this begins to change after one of the villagers decides to graze two cows instead of one. The cost of the extra cow is shared by everyone, but the profit will be his alone. Others note his success and correspondingly each also graze two cows. Their logic is extended so that if two are better than one, then three must certainly be better than two. At some point, however, the village common is no longer able to support the large number of cows, the system crashes and everyone suffers. This concept can be extended to the using unsustainable practices for short-term gains, for example, overuse of non-renewable resources and fuels, and focus on initial costs without adequate attention to operation and maintenance demands.

Revisiting the Harm Principle: Managing Risks

Mill's harm principle suggests that even when an action can have benefits, there is a moral obligation to avoid such action if it causes undue harm. This is a difficult concept for those who operate in the quantitative domain, as most engineers do. The harm principle becomes even more complicated when not taking an action can lead to negative consequences.

Green and biomedical engineering can both require tradeoffs in addressing different hazards. For example, the choice of using a toxic substance is complex (see **Figure 4**). Critical paths and flow charts are commonly used in design and engineering, especially computing and circuit design (Vallero and Brasier 2008a; Vallero and Brasier 2008b).

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 (Fleddermann 2004). Other charts need to be developed for safety training, the need for fail-safe measures, and proper operation and maintenance. A "master flow chart" can be developed to track all of the decisions and subsequent consequences that ultimately led to the disaster.

Design for the environment (DFE) can be very challenging in the realm of biomedical engineering. For example, an asthma medication that is delivered to the lungs using a greenhouse gas (GHG) propellant. At first glance, 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 might be considered insignificant. When it comes to public health tradeoffs, the significance is often determined by medical efficaciousness. 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. A design decision can be visualized 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 5**).

The initial conditions will be driven toward influences. The stronger the influence of a factor (for example, medical efficacy), the greater the decision will be drawn to that perspective. If the factors are evenly distributed and weighted, the following diagram might appear (see **Figure 6**).

But, as the differential in magnetic force increases, that factor will progressively drive the decision. So, in the greenhouse gas propellant example, the medical efficacy drives the decision. The stronger the magnet the more likely that the decision made will be pulled in that direction (see **Figures 7A & 7B**).

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 "shaped" in a manner unique for that decision and that must be considered by the designer.

Summary

Engineers have a number of tools that can enable them to create socially and environmentally acceptable designs, including life cycle assessment and design for recycling. These tools can help to ensure that the engineering profession continues to grow in its call to protect the public and the environment.

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