GRAND CHALLENGE 5:

Foster Informed Decisions and Actions

Addressing the world's largest environmental problems will require major shifts in our approaches and actions.[259] New strategies and technologies will only be effective in solving these grand challenges with widespread adoption, which may require regulatory changes at the governmental level and behavioral changes at the community and individual levels. For this to happen, decision makers in the public and private sectors and a significant portion of the general public must believe that the environmental problems are serious enough to warrant change—and that proposed solutions are worth adopting. In other words, addressing grand environmental challenges requires, in addition to effective solutions, a pervasive recognition that implementing those solutions is in our best interest.

Achieving this will require, first, engendering a civil society that is well informed about how the environment affects human well-being and prosperity. This is not about changing people's preferences or making the public "care" more about the environment. Rather, it is about equipping people with options that provide solutions and with information to make wise choices based on an understanding of the potential outcomes and costs associated with each course of action and the potential risks from inaction.

Second, it is important that experts and stakeholders act in partnership to identify problems and consider alternative solutions. There is sometimes a gap between what scientists and engineers believe will be useful for stakeholders and what the stakeholders themselves understand as useful.[260] It is possible to reduce this gap by taking a collaborative approach that engages both experts and stakeholders to define and prioritize problems, select alternatives to be considered, identify constraints and criteria for success, and consider issues of equity and distribution.

These first two elements—understanding and stakeholder engagement—create a foundation for identifying and implementing policy, management, and regulatory approaches to promote outcomes that are consistent with the collective priorities. Although the responsibility for engaging stakeholders and fostering full understanding of environmental choices does not lie entirely with environmental engineers, there is much that the engineering community can contribute.

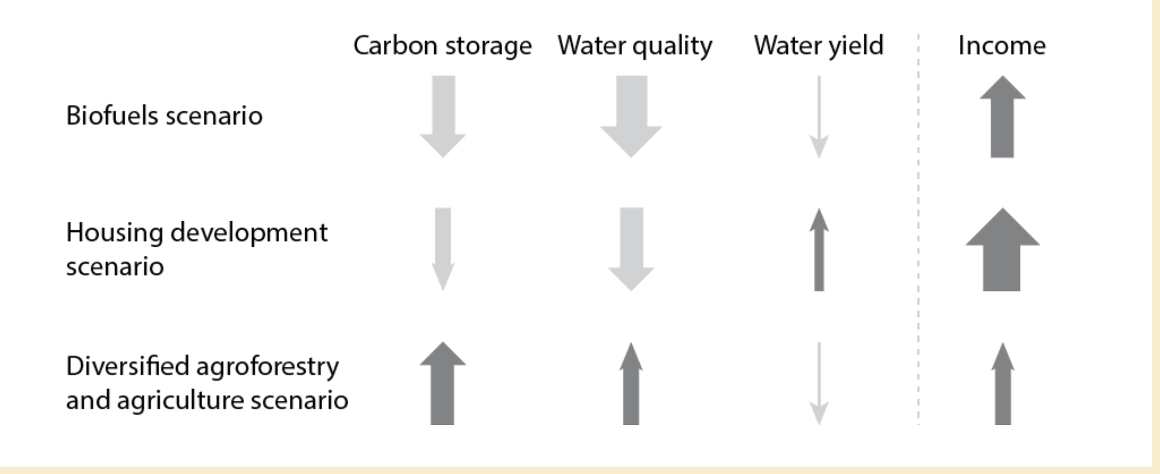
Understanding Linkages Between the Environment, Human Well-Being, and Prosperity

In the context of environmental challenges, understanding potential consequences involves making the connection between our actions (or inactions) and the impacts that these have on the environment and the well-being of different individuals or groups in society. The choices made by individuals or groups can have spillover impacts on the well-being of others. For example, consider a property developer in an urban area deciding on the design of a new building and surrounding landscape. Incorporating features such as green or reflective roofs, reflective pavements, and increased tree plantings can reduce a property's contribution to urban heat island effects, but doing so often comes at a cost to the developer.[261] Similarly, farmers deciding how much nitrogen fertilizer to apply will typically consider the benefit from improved yields and the cost of purchasing and applying the fertilizer. But applying nitrogen fertilizer has additional costs, such as when fertilizer leaches into surface water or groundwater, polluting a nearby town's water supply or downstream estuaries.[262] Some of the excess nitrogen will volatilize in the form of nitrous oxide, a powerful greenhouse gas, or to ammonia and nitrogen oxides, potentially contributing to regional air pollution.[263] The developers or farmers may be unaware of the impacts of their choices on the well-being of others. But even if they are aware, they typically have inadequate incentives to reduce environmental impacts because many of the consequences are borne by others (what economists refer to as "externalities").

Identifying and quantifying the full set of consequences of human actions on the environment and human well-being are active areas of research involving environmental engineering, ecology and other natural sciences, ecological and environmental economics, and other social sciences. Uncovering the important impacts often involves active cogeneration of knowledge by stakeholders and experts, as discussed in more depth in the next section. Over the past two decades, ecologists working with many other disciplines have made substantial progress in describing the benefits that nature provides to people, known as ecosystem services.[264] Ecosystem services include:

BOX 5-1. KAMEHAMEHA SCHOOLS: ANALYZING ECOSYSTEM SERVICES AND ENGAGING STAKEHOLDERS TO IMPROVE LAND-USE DECISIONS

In Hawaii, the largest private landowner is the education trust Kamehameha Schools, which owns roughly 8 percent of the land in the state. In the early 2000s, Kamehameha Schools faced a decision about what to do with a large block of land on the north shore of Oahu. Kamehameha Schools, engaged the Natural Capital Project[266] to analyze the effects of alternative land-use plans on carbon sequestration, water quality, and economic returns (see figure below). These endpoints and alternative land-use plans were developed in consultation with Kamehameha Schools and the local community with goals of balancing economic, environmental, educational, cultural, and community returns. A diversified agriculture land use was ultimately selected as the plan that best met the overall goals, even though monetized income returns were the lowest for this scenario. Kamehameha Schools was awarded the American Planning Association's 2011 National Planning Excellence Award for Innovation in Sustaining Places.[267]



Projected changes in ecosystem services under three future land-use scenarios.

1. The provision of material goods (food, fiber, energy, and other materials);
2. Ecosystem functions that naturally regulate environmental conditions in ways that improve human living conditions, such as filtering pollutants from water or air, providing protection for coastal communities from storm surge, or reducing riverine flooding; and
3. Nonmaterial services related to psychological, spiritual, and cultural values.

Work on ecosystem services has highlighted many ways in which environmental protection or improvement can provide tangible benefits for human quality of life and prosperity (see Box 5-1). In addition, such work can highlight the risks posed by continued environmental degradation, including the potential for crossing thresholds with sudden catastrophic changes that may be difficult or impossible to reverse.[265] In the face of such risks, increasing system resilience is an important component of system design.

Another approach to quantifying the full set of environmental consequences is life-cycle assessment. This technique, commonly used by industrial ecologists and environmental engineers, aims to measure environmental impacts associated with producing and consuming specific products, from production of raw materials to the disposal of the product at the end of its useful life.[268] Life-cycle assessments

often measure impacts in physical units, such as materials and energy consumed or the amount of carbon dioxide emitted, and do not require assessment of impacts in monetary terms. This simplifies the analysis in some respects but can make it difficult to compare alternatives that have different types of environmental impacts. Other tools are also available to quantify the full environmental consequences of actions and to help engage stakeholders in this process (Box 5-2).

BOX 5-2. TOOLS TO CLARIFY SOCIAL, ENVIRONMENTAL, AND ECONOMIC DIMENSIONS OF CHOICES

A number of tools are used to help decision makers measure, monetize, or evaluate the potential impacts of a decision or action, including multiple social, environmental, and economic dimensions. Some tools help identify a full range of consequences of a given action. In addition to *life-cycle analyses, social impact assessments* identify possible social effects of an intervention or action.

Complex decisions often come down to weighing benefits against costs or risks and perhaps most importantly who pays the costs and who reaps the benefits (including intergenerational considerations). Tools to help clarify such decisions include *risk assessments* and *economic benefit-cost analyses*. *Chemical-alternatives assessment* evaluates hazards to human health and the environment of comparable chemicals (functionally) to choose the safest alternative. *Environmental-justice analysis* evaluates exposure and risk for minority populations and low-income populations to inform equitable decision making.

A number of stakeholder engagement tools are being used to facilitate collaboration and to ensure that multiple viewpoints are considered. *Collaborative problem solving* brings together stakeholders to work on a particular concern that has been identified. *Design charrettes* help stakeholders develop a mutually agreed-on vision of future development, usually regarding land-use planning decisions.

More than one tool can be applied simultaneously. The U.S. Environmental Protection Agency's Design for the Environment program[272] uses a variety of tools as it screens new chemicals, including collaborative problem solving with manufacturers and chemical alternatives assessments. The use of collaborative problem solving in conjunction with environmental-justice analysis helped officials in northeast Ohio make decisions on the best infrastructure options to help meet stormwater discharge limits and to provide additional environmental and recreational benefits using green infrastructure, particularly in low-income communities.[273]

The field of environmental economics has devoted decades of research to assessing the benefits of environmental improvement.[269] To make it easier to compare alternatives, economists typically try to measure all benefits and associated costs of environmental improvement in monetary terms, using market and nonmarket valuation techniques. For example, even though there is no market price for clean air, economists infer the value of clean air to homeowners by observing how home values vary with air quality while controlling for other characteristics of houses that influence value, such as the lot size and number of bedrooms. However, some environmental impacts are difficult to measure in monetary terms, such as a community's sense of place or the value of the existence of other species. In addition, this approach can require a great deal of time and resources, and improved methods are needed to appropriately apply estimates developed in one area to other related areas.[270]

Because of the difficulty of quantifying all benefits in monetary terms, some business and environmental groups have pushed for a "triple bottom line" approach that captures environmental impacts, social responsibility, and financial returns without forcing all aspects to be evaluated in monetary terms.[271] Ideally, these assessments include metrics that reflect various values that are easily understood by stakeholders, such as measures of health impacts, water and air quality, biodiversity, and resilience. Using the triple bottom line approach to choose among alternative management or policy options would typically require a decision maker to weigh the relative importance of the three bottom lines.

Despite substantial progress toward understanding and quantifying the various impacts of our actions on the environment, important questions remain. For example:

- How do changes in policy and technology shape behavior in ways that affect the environment?
- How can knowledge from natural sciences, social sciences, and engineering disciplines be better integrated to understand how environmental change affects human well-being and prosperity?
- How can well-being and prosperity be measured in a rigorous and consistent manner and reported in a way that is readily understood by decision makers and stakeholders?

In addition, there is a great need to improve data collection to support robust ecosystem service analyses, life-cycle assessments, and other environmental analyses. This work should include consideration of the differential impacts on vulnerable communities and geographies due to physical, social, and economic factors. A significant part of this challenge is learning how to communicate clearly with decision makers and the broader community about the findings of environmental assessments and how various stakeholders value different benefits and costs.

Engaging With Stakeholders to Create Solutions

If progress is to be made toward the grand challenges, society must develop the right solutions for the right problems. The grand challenges identified in this report will manifest differently in different communities, and many efforts to address these challenges will play out on a local scale. Different communities have different values and priorities, and these should inform how problems are identified and addressed. In addition, the solutions that work in one community may not work in another. For successful adoption, it is crucial that innovations and approaches be acceptable and usable by the communities for which they are intended.

This cannot be achieved by scientists and engineers working in a vacuum. When considering specific strategies, multidisciplinary teams need to determine the circumstances under which they are most likely to be implemented, both in the near future and under a variety of future scenarios. What are the barriers to adoption and the potential for misuse? What are the economic, environmental, and social impacts of implementing these new strategies, including possible unintended consequences? How will the benefits and costs be distributed among different groups?

Research has shown that solutions are more likely to be successfully developed and adopted when interested stakeholders are engaged in a genuine dialogue with scientists and engineers that allows for iteration and exchange between the producers and users of research and technology (Figure 5-1). Such a process helps to better define the problem to be addressed, improves the likelihood that the priorities of various stakeholder groups are understood, and ensures that a broad range of alternatives are considered. Engaging with stakeholders can often reveal social or institutional factors that may affect the long-term success or failure of a new technology or strategy. It also reduces misunderstanding, increases perceived credibility, and generates trust.[274]

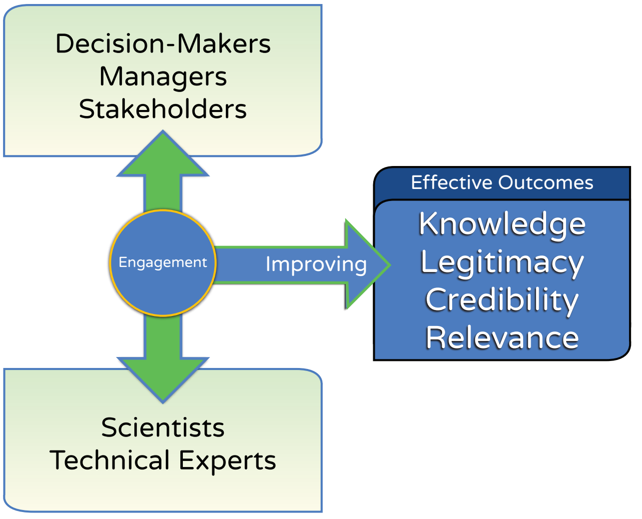


Figure 5-1. Effective public engagement on complex environmental challenges requires technical experts to learn from stakeholders and decision makers through a genuine two-way dialogue.

Distrust of science and technology are deeply held in many communities due to complex social, economic, and political forces, and this can present major barriers to the development of sustainable solutions. Like other members of the scientific community, engineers should work to understand the historical and political contexts behind these perspectives and identify opportunities for establishing new partnerships between engineers and stakeholders. Many well-intentioned scientists and engineers have focused their efforts on improving scientific understanding with the expectation that this will overcome skepticism. Yet, decades of social science research suggest that scientific literacy and technical knowledge have relatively minor impacts on the public's trust in science.[275] Rather than a lack of knowledge, skepticism more often stems from doubts regarding the honesty and integrity of outside experts and the institutions that they represent or concerns over the implications of proposed actions to their economic interests.

To overcome these tensions, engineers, scientists, and other experts should collaborate to forge relationships within skeptical communities, especially with trusted community leaders, to identify acceptable pathways forward. Transparency and inclusiveness should be prioritized in all aspects of the process, from data collection to decision making, by creating genuine opportunities for public participation, especially within communities that are seemingly disinterested, disadvantaged, or marginalized.[276]

Engineers should also strive to improve gender, racial, and ethnic diversity within the engineering community. Currently, African Americans, Hispanic Americans, and Native Americans are underrepresented in environmental engineering, and no gains have been made in increasing the percentage of undergraduate or graduate degrees awarded to underrepresented minorities in environmental engineering since 2008.[277] A community of engineers that represents and reflects the heterogeneous cultural and demographic backgrounds of society at large is necessary to understand the perspectives and interests of a diverse public. These varying life experiences will lead to the development of innovative strategies and technologies that may not necessarily come from a homogeneous group with similar world views.[278] In addition, improving professional opportunities for those from underrepresented backgrounds will bring in new talent and perspectives from wider segments of the population, generate healthy competition, and foster creativity.

Adopting Policy Solutions

The development of policy, both public and private, can encourage society to act with a full understanding of environmental impacts and long-term community priorities. Without policy interventions that help align private incentives to match societal objectives, the decisions and behaviors of individuals and businesses often do not account for externalities that are imposed on others. Most policy, management, and regulatory approaches relevant to addressing environmental challenges involve one or more of four basic elements: providing information, changing the decision context, creating incentives, and setting rules and regulations. Often a mix of these approaches is optimal.[279] In all four areas, research from the social and behavioral sciences combined with environmental engineering and science can help craft policies that are grounded in evidence and most likely to change behavior. Determining the best policy solutions to complex challenges, such as adapting to climate change, also often requires decision making under uncertainty, as discussed in Challenge 2.

Providing Information

Educating the public can be an effective strategy to drive widespread action or attitude change.[280] Successful public information campaigns, such as those launched to raise awareness of the problems associated with smoking or forest fires, clearly state the problem and provide simple actions that can be taken to address the problem ("only you can prevent forest fires"). Information can also be used to create social pressures that encourage change. For example, electricity bills that present a household's energy consumption relative to their neighbors have successfully reduced energy demand in many communities.[281]

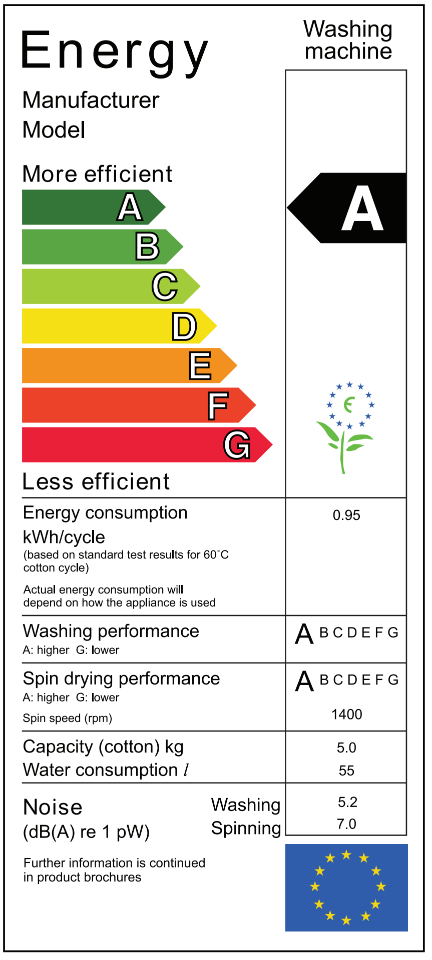


Figure 5-2. Manufacturer labeling is one strategy used to increase public awareness of environmental impacts and inform consumer choices.

In the context of complex environmental problems, information-based policies can take many forms including mandating disclosure, identifying chemicals of concern,

and advocating for transparency throughout the supply chain. For example, the "Ecolabel" program, developed in the European Union, identifies products that meet established environmental criteria considering a product's full life cycle. Governments, manufacturers, and retailers can make the environmental impacts of various products more transparent by supporting labels and collecting, curating, and sharing data (Figure 5-2). Environmental awareness could be further increased through calculation and expanded disclosure of carbon, water, and chemical footprints, supported by consensus-based standards and third-party audits. These efforts can in turn encourage innovation throughout the supply chain.

Subtle changes to the way information is presented can also have profound impacts by reducing known biases in decision making. For example, consumers systematically misunderstand fuel efficiency information when it is shown in miles per gallon. When the same information is depicted in gallons per mile, consumers make better financial and environmental choices.[282]

Changing the Decision Context

Policies that focus on changing behavior by modifying the decision context have gained much attention in recent years.[283] Such strategies are often designed to make a desired behavior easier or more probable by removing barriers to behavioral change. For example, reducing the paperwork and hassle required for a homeowner to participate in an energy efficiency rebate program can dramatically increase participation.[284] The percentage of people who have agreed to donate their organs is more than 95 percent higher in Belgium than in neighboring Netherlands, largely because citizens of Belgium are asked to sign a form to *opt out* of donating an organ, whereas citizens of the Netherlands must sign a form to *opt-in*.[285] Even though most citizens in both countries support organ donation, the hassle of opting in or opting out of a program can result in dramatic societal-level impacts on health and well-being. Careful consideration of default settings has resulted in improved environmental, health, and financial outcomes.[286]

Reducing barriers to behavior change is often less expensive and more politically feasible than other alternatives.[287] A challenge in implementing this approach, however, is for policy makers, social scientists, and engineers to collaboratively identify where such opportunities lie.

Creating Incentives

Policies can also be used to provide incentives for environmental solutions with broad societal benefits or disincentives for activities that contribute to environmental problems (see sidebar). Economic incentives are particularly valuable if technologies that provide broad ecosystem services come at a higher cost than similar technologies that do not. For example, tax credits have been provided to consumers to incentivize the purchase of electric cars and solar panels and to companies investing in renewable energy sources. Further, the government can take steps to reduce policy and financial risks for environmentally beneficial projects, such as by issuing partial loan guarantees and streamlining the permitting process, to make them more competitive with conventional projects among private investors.[288] Establishing disincentives for actions that are harmful to the environment is also an important policy mechanism. For example, if wetland impacts cannot be avoided as part of a permitted construction project, the Clean Water Act requires that other wetland areas be established or restored as compensation. Levees on carbon emissions could be established to discourage carbon emissions and stabilize the changing climate, while also funding permanent carbon sequestration efforts.

Social science research is needed to better understand how people respond to incentives. For example, are social incentives more or less effective than financial incentives for particular objectives? How can incentives or disincentives be implemented effectively and efficiently, considering their monitoring and enforcement costs? Environmental engineering research can inform policy makers about the systemwide benefits and costs of various policy alternatives.

INCENTIVIZING WATER CONSERVATION WITH SMART SOLAR PUMPS

Growth in the use of solar-powered pumps has reduced the energy costs of pumping water to irrigate crops while reducing carbon emissions. However, heavily subsidized solar panels and free solar power led to another problem: excessive irrigation of crops and overuse of limited groundwater supplies. Faced with this problem, researchers from the International Water Management Institute developed a solution that is partly technological and partly based on policy and management. Their "smart solar pump" initiative, piloted in Gujarat, India, incentivizes farmers to sell excess solar power back to the grid. Through guaranteed solar buy-back, farmers supplement their income, the country expands its energy reserves while making strides toward its renewable energy goals, and groundwater resources are conserved.[289]

Solar pump in Jagadhri, India.

Setting Rules and Regulations

Local, state, national, or international rules and regulations represent another tool to discourage environmental impacts and encourage improvements. For example, the Montreal Protocol in 1987 led to an international ban on the use of chlorofluorocarbons, which had damaged Earth's protective stratospheric ozone layer, and the result is that the ozone hole is now healing. Several countries have implemented bans on phosphate in detergents to address phosphorus pollution in surface waters. In the United States, after more than half of the states adopted phosphate detergent bans, the industry voluntarily removed phosphate from laundry detergents.[290] Another policy approach is to set environmental performance standards for government or corporate contracting and purchasing decisions, which would provide incentives for alternative technology choices and further technology development. Environmental rules and regulations are built upon substantial scientific and engineering research, and these efforts benefit from clear communication of policy-relevant scientific findings.

What Environmental Engineers Can Do

To foster informed decisions and actions, environmental engineers should work in collaboration with decision makers, stakeholders, and other experts to increase the public's understanding of the consequences of their choices, identify problems, create solutions, and support efforts to develop effective policies. Environmental engineers have the skills to assess the broad risks and benefits of alternative approaches to address the grand challenges and to work across disciplines as integrators of information. To develop approaches that are effective and acceptable—and therefore likely to succeed—it is vital to partner with

communities (particularly traditionally marginalized communities), businesses, and governments and work in collaboration with experts in social and behavioral sciences, communications, environmental and ecological economics, computer science, policy and management, and other disciplines. Given the complexity of the challenges to be addressed, it is to be expected that continuous iteration will be needed to refine collaborative approaches and develop feasible, acceptable, and impactful solutions.

To meet this challenge and create solutions that meet the needs of all, environmental engineers will need to build new skills and proactively diversify the field, as discussed in more detail in the next chapter. Examples of specific opportunities for environmental engineers to help address this challenge are highlighted in Box 5-3.

BOX 5-3. EXAMPLE AREAS FOR ENVIRONMENTAL ENGINEERS TO HELP FOSTER INFORMED DECISIONS AND ACTIONS

Some of the many ways environmental engineers can partner with other experts and stakeholders to help foster informed decisions and actions include:

- Work with communities and other disciplinary experts, including ecologists, economists, sociobehavioral scientists, and communication experts, to analyze and clearly communicate the potential consequences of alternative choices associated with the environmental grand challenges. Analyses should include impacts and benefits to individuals and various groups in society so that stakeholders and decision makers can better understand the impacts of their choices.
- Proactively diversify the field by recruiting members of underrepresented groups to become experts in the environmental engineering field and partner disciplines.
- Develop new approaches and technologies to collect environmental data needed to support ecosystem services and life-cycle analyses.
- Partner with communities and citizens to collect and assess environmental and socioeconomic data, understand the connections between trends and individual, corporate, and governmental behavior, and communicate the implications of this information. Environmental engineers can also develop enhanced participatory science approaches and technology-enabled platforms. Particular attention should be given to communities that have traditionally been underserved and marginalized.
- Develop transparent, user-friendly decision tools that can assist decision making by synthesizing information on financial, social, and environmental risks, costs, and benefits.