

A PRIMER ON SUSTAINABLE TECHNOLOGY AND DEVELOPMENT

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A commitment to sustainable development requires us to reconcile our desire to improve the quality of our lives with the limitations imposed on us by our global ecological support systems. It requires us to shift our thinking to actions and events that take place over greater scales, impacting larger geographic regions, encompassing complex, interconnected socio-technical systems, and evolving over many human generations. Sustainable development requires innovative solutions for improving human welfare that stem from practices and technologies that work harmoniously with earth's systems and across diverse cultures.

Although there is no general agreement regarding the precise definition of sustainable development, most interpretations of

the term “sustainable” refer to the availability of natural resources and functioning of ecosystems over many generations. Sustainable economic development enhances human living standards while maintaining, or even improving, ecosystem functioning. Many people use the United Nation’s definition of sustainable development:

... Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs...

(Source: Report of the United Nations World Commission on Environment and Development, 1987.)

SOCIAL CONSIDERATIONS FOR SUSTAINABLE DEVELOPMENT

Sustainable development is fundamentally a social phenomenon. Every day we make decisions in our personal lives and at work—and on behalf of others as leaders of industry and governments—about the quality of our lives, the goods and services we need, and the technologies we desire to meet these needs. What we perceive as a “quality” lifestyle depends on our cultural and political values. Our decisions determine our own welfare and the welfare of others, how wealth is distributed among our fellow humans today (sometimes called

intra-generational equity) and among future generations (or, inter-generational equity).

A SUSTAINABLE SOCIETY MUST SEEM
DESIRABLE—TO ME

When we talk about promoting a more sustainable society, we imply something more than trying to “save the Earth.” Many environmental advocates focus on saving particular endangered species or critical ecosystems such as rain forests. They recognize the intrinsic and instrumental

values of such species and systems for mankind. As advocates for a more sustainable society, we build upon environmental values, but we place our emphasis on making the world a more desirable place in which humans may live, today and tomorrow. As such, our commitment to sustainability must address not only the concerns of Mother Nature, but also the realities of basic *human* nature.

At the most fundamental level, **people need to perceive that the quality of their lives in a more sustainable society will be at least as high as it is today.** This doesn't necessarily mean that quality of life is defined by quantity of material possessions or wealth. This conclusion about human motivation is borne of practical considerations. According to many social scientists, few rationally self-interested persons would voluntarily sacrifice their own standard of living without some compensating benefit. In our strategy to promote the creation of a more sustainable society we shouldn't discount the possibility of altruistic acts, but we must also address individual aspirations more broadly. When we ask people to adopt a more sustainable style of living, we should be prepared to meet their perceived needs so that they feel they will benefit from their commitment in some way. In many cases, technological ingenuity can provide more sustainable alternatives to meet these needs.

MEETING THE NEEDS OF THE PRESENT

Perhaps the most difficult challenge to creating a more sustainable society is the large difference in living standards between people living in developed versus the developing nations. An agenda that takes into account intra-generational equity presents two basic challenges: distributing resources so that the poorest people in the world may

survive, and accommodating the aspirations of all people in both developing and developed nations so that they may continue to thrive.

When people are concerned for their very survival, and lack basic human rights, it is difficult to engage them meaningfully in the global agenda for sustainable development. Of course, the definition of basic survival is culturally dependent. But in situations where fundamental biological survival is threatened, as it can be in the famine-struck regions of Africa or in our turbulent inner cities, the first step towards intra-generational equity is to improve living conditions. For most of us, the conditions which merely support basic, biological survival would not qualify as a high standard of living. As we move from surviving to thriving, the definition of a quality standard of living becomes more culturally entwined. **It has been estimated that if the current world population lived at the standards of the world's wealthiest nations, it would require three times the resources available on Earth.**

(Wackernagel and Rees, 1996) Clearly, we cannot afford to do this, but how do we proceed?

The global community engaged in promoting sustainable development is not a unified social or political movement. Advocates for sustainability encourage individuals and organizations, whatever their ideology or culture, to take into account a wider range of factors—including the physical limitations of earth's support systems—that will help them achieve their goals and, at the same time, move towards ecological and social sustainability. Nonetheless, numerous social and political movements exist. Some promote development of more democratic processes and the protection of human rights. Others

focus on redefining our notions of progress and prosperity (voluntary simplicity), or restructuring commerce and the global economy. **At the Georgia Institute of Technology and other engineering institutions around the world, our movement focuses on rethinking the design, development, and use of technologies.**

ALLOWING FUTURE GENERATIONS TO MEET THEIR NEEDS

We refer to the financial and technological resources we use to achieve a desired economic outcome as “capital.” There are other uses of this term relevant to a discussion of sustainable development. Natural capital is the stock of natural resources and the productive capacity of ecosystems. Social capital is the intellectual, political, spiritual and other societal resources that support the functioning of our communities. Our bequest to future generations, or our strategy to promote inter-generational sustainability, must **provide capital resources—economic, natural and social—so that future generations can determine the best course of action to meet their needs.**

This doesn't necessarily mean that we freeze our assets so that we can provide an

identical set of capital resources for future generations. The assets we leave in our portfolio simply must constitute a comparable set of capital resources. But for some resources, there are no substitutes. We will be challenged to make difficult decisions about the use of non-renewable resources, or the use of any resources in ways that effect irreversible changes in society.

Progress toward a sustainable society will require great scientific and engineering ingenuity. It will also depend on a more complete understanding of the social systems that decide which technologies to develop and how they will be used. A commitment to pursue sustainable technology and development offers enormous opportunities to advance our knowledge, to create new markets, and to improve the decision making process of individuals and institutions with regards to science, technology and development.

In the past century, we have witnessed the tremendous capacity we have for adaptation and innovation. While future generations will benefit from the intellectual capital accrued throughout history, **technological ingenuity alone cannot be relied upon to replace all resources.**

TECHNICAL CONSIDERATIONS FOR SUSTAINABLE TECHNOLOGIES

When presented with the term “sustainable technology,” many engineers wonder how such technologies differ from technologies they have developed in the past. In most cases, the fundamental scientific and engineering concepts and principles are the same. More sustainable technologies differ from conventional technologies (for lack of a better word) in the relative importance one places on the larger societal and ecological

context when defining the technology's characteristics and associated problems that will be addressed during technical design.

A more sustainable design incorporates material and energy considerations that extend beyond the immediate technological system to a larger system in which its effects in society and the ecosphere may be felt. The system boundaries will vary, but in

general, designers of technologies interested in creating a more sustainable society need to consider the following factors when creating and implementing a design:

1. the *quantity* of material and energy resources available
2. the *balance* in the rate at which resources are used and regenerated
3. the *quality* of those resources
4. the *best way* in which those resources may be productively used.

QUANTITY OF MATERIAL AND ENERGY RESOURCES

The quantity of matter that we have on Earth is finite. Matter cannot be created nor can it be destroyed—unless one considers nuclear technology for waste management, which is not only impractical but also politically unviable. When we throw away our trash, or burn it, the materials are merely transformed into compost, incinerator ash or gases. In simple terms, in a finite system, the more material we discard, the less we have of readily available, high quality material to use in the future. And more, since there really is no "away" in which to throw waste, these waste materials may eventually disrupt or endanger ecological system functioning.

Just as the amount of available matter on Earth is finite, the amount of energy available is also limited. Currently, most of our energy is derived from the sun. This energy is converted to chemical energy by photosynthesis or is trapped in the atmosphere as heat. Fossil fuels are actually reservoirs of the sun's energy trapped in plant and animal life eons ago and transformed into hydrocarbons in a complex process which would be difficult and costly to reproduce today. Thus, the fossil fuels are essentially non-renewable resources.

Some people believe that a truly sustainable society would live within the "solar budget," using only the current influx of solar energy to sustain human activity. In the U.S., the current antipathy towards building and operating nuclear power plants leaves only renewable energy technologies, such as photovoltaics, as potential sources of energy. However, the performance and affordability of renewable energy sources must improve dramatically for large numbers of people to live on a solar budget. During this transition, we must try to **use non-renewable resources at rates that accommodate the development and deployment of renewable substitutes.**

Whether renewable or non-renewable, most resources we use to meet our functional needs are valuable. As we said earlier, if all the people on Earth wanted to live like us in the U.S., we would need three times the Earth's available resources. It makes sense, then, that the first consideration in designing a more sustainable technology is to **satisfy functional (including aesthetic) needs by using as few material and energy resources as possible.** Such efficiency, sometimes called "eco-efficiency," not only makes sense in design, manufacture and commerce, but also in the way we choose to live our own lives. Once we've developed a lean design for a technology (in terms of the materials and energy needed to produce and use it), we must consider how to recover and reuse its material content and "embodied" energy when its useful life is over. Embodied energy is the energy required to harvest, refine, and process the materials used to make the technology.

Natural systems, or ecosystems, provide excellent examples on recycling and reuse of matter and energy. An ecosystem is a web of interlocking systems that enable waste to become the feedstock for a new generation

of plants and animals. In the biosphere, carbon, oxygen and other atoms that form the basic building blocks of life, are cyclically transformed, consumed, decomposed and restructured by a variety of natural processes. Our existence depends on the ability of these natural systems to perform their recycling functions so that finite material resources are made available for use again and again. Healthy ecosystems are essential to generate and regenerate the basic foundations of life, and to produce the goods and services that enhance the quality of our lives. Ecosystems produce goods (seafood, timber, fuels, raw materials for pharmaceuticals and other industrial products), purify air and water, maintain biodiversity, partially stabilize the climate, and provide beauty.

We humans, and our technological systems, are part of the larger ecosystem in which we live. We draw our materials and energy from the biosphere, and discharge our wastes into the air, our waterways, and on the land. If we want to design more sustainable technologies, we must think of ourselves and our technologies as functioning within the larger biosphere. Wherever possible, **we must avoid disrupting or impairing ecological functioning** when we select materials and energy sources, and reduce any impacts associated with processing, manufacturing, and ultimate use of the goods produced.

Nature's processes cannot break down and reuse all substances. Persistent and bioaccumulative substances move through the food web and result in unanticipated, and potentially harmful, exposures. Many of these substances are agricultural or industrial chemicals, while others are unintentional waste products and contaminants. Bioaccumulative substances, such as PCBs and chlordane, can cause cancer,

damage the central nervous system, impair the immune system, cause reproductive disorders and interfere with normal fetal and child development.

There are numerous international programs that focus on eliminating persistent and bioaccumulative substances from products and processes currently in use. In some cases, developing countries may benefit from the short-term social impacts gained by continued use of some pesticides. In these instances, a phase-out period may be established while viable alternatives are developed. Over the long haul, however, products and processes should be designed that **do not generate, or unintentionally create unwanted, persistent and bio-accumulative substances.**

IT'S A MATTER OF BALANCE

Because Earth's systems are so complex, we simplify the complexity by thinking of them in terms of the atmosphere, the hydrosphere, and the biosphere (or, the physical climate we associate as Earth). Matter and energy move between these "spheres" in cycles. The movement and transformation of matter and energy between the atmosphere, the oceans and the land-mass form the "hydro-logic" cycle, and the interactions between the biosphere, atmosphere and hydrosphere form various "biogeochemical" cycles. The "balance" in these systems refers to the rates at which compounds (such as carbon dioxide) and energy (heat, for example) are emitted, assimilated and regenerated by Earth's systems.

The carbon cycle provides an excellent example to explore the importance of "balance" further. Carbon, in the form of carbon dioxide in the atmosphere, is taken up by plants and converted to new plant structure (growth) through photosynthesis.

In turn, carbon dioxide is generated and released to the atmosphere by human, animal and plant respiration, and the burning of plants, trees and fossil fuels. Scientists, government officials, and industry leaders are concerned that carbon dioxide generated by our use of fossil fuels may exceed the capacity of forests and other natural systems to assimilate it. Furthermore, the demand for land by a growing population for settlements and agriculture may hasten the demise of vital forest ecosystems. The result is a net increase in carbon dioxide in the atmosphere.

The build-up of carbon dioxide in the atmosphere is one of the factors that may cause global climate change. Potential changes in the Earth's climate strike directly at the quality of all life including human life. Among other things, changes in climate patterns can impact food production in agricultural areas, threaten coastal settlements with rising sea levels, and wreak havoc with power generation capacity and demand in established communities. Such changes on a global scale may be irreversible in our lifetime. While sustainable technologies should be designed to **work in harmony with the natural limits of the assimilative and regenerative capacity of earth's systems**, we will be challenged by identifying the appropriate balance in such systems. In the absence of scientific evidence, the decisions must be precautionary and, inevitably, political in nature.

Just as the destruction of forests contributes to imbalance in the carbon cycle, harvesting other natural resources can create more immediate and observable forms of imbalance. When fishermen catch fish at faster rates than they can reproduce, they not only threaten the survival of the particular species of fish, but also their own livelihood.

In the case of forest resources, we may experience the consequences of overharvesting less directly. On a global scale, old-growth forests and the monoculture forests that replace them participate in the carbon cycle. On a regional scale, however, an old-growth forest provides a much greater level of vital ecosystem services than a monoculture forest, including the long-term protection of tree species from disease and pests. Thus, the design of more sustainable technologies must consider the rate at which renewable resources are harvested and regenerated, and **use renewable resources that are harvested at rates no greater than their sustainable regeneration rates.**

THE QUALITY OF MATERIAL AND ENERGY RESOURCES

Quality matters. We can define the "quality" of matter and energy in terms of the degree to which they meet our needs. When green plants grow through photosynthesis, the sun's energy is converted into plant structure that is made available to us as food. We can think of the "utility" of material and energy as the degree to which resources are structured or ordered, or that the stored energy they contain is available for our use. For example, the structured chemical energy embedded in an unlit match usually has greater potential utility than the dissipated energy radiating as heat from a recently lit and extinguished match. The energy from a lit match cannot be recovered and used again.

A fundamental challenge to maintaining the quality of our resources is the natural tendency of these resources to become less structured. Such tendencies can be observed every day: the cup of steaming hot coffee that gives up its heat to the surrounding area and becomes cold; the refrigerants that leak

from our cars' air conditioning systems; or an orderly office which rapidly becomes cluttered. The degree of disorder in a system is usually inversely related to its potential utility. Every time we use the energy embodied in fossil fuels to produce goods, we effectively increase the amount of disorder in the global system by releasing that energy in the form of heat and gaseous emissions. The goods we make may embody some of that energy, but over time, the material and energy content of these products will be dissipated and possibly irretrievably lost—unless they are designed for recycle and reuse.

The concept of recycling is not new, but we have only recently begun to explicitly design technologies for recyclability. We recycle aluminum cans into more cans, but plastic bottles are turned into parking lot bumpers. When we made those plastic bottles, we spent energy and resources creating the plastic laminates and forming them into bottle shapes. While recycling them into bumpers (maintaining some of the embodied energy) is better than incinerating them, it would be even better if the plastic in the bottles could be maintained and recycled for use in plastic bottles again—without further reprocessing. The key is not only to recycle the materials, but also design products so that they **preserve the quality of their constituent materials over their useful lifetimes and are more amenable to recycling**. More sustainable technologies should also be designed so that they **require**

as little energy as possible for recovery, recycling and reuse of their constituent resources.

USING RESOURCES WISELY

We began our discussion of sustainable technology and development with an overview of the ethical imperative to use our limited resources to “meet the needs of the present generation without compromising the ability of future generations to meet their needs.” We then focused on the scientific underpinnings of the design guidelines for more sustainable technologies. Before we summarize our technical discussion, **we need to remind ourselves that the challenges to creating a more sustainable society go far beyond designing better technologies.**

There's an old saying that a good engineer will design a bridge, but a great engineer will ask whether the bridge needs to be built in the first place. This is an important message for the designers of more sustainable technologies. Sustainable technologies are not independent of their ecological and societal context. Their design will reflect individual values and choices made within the larger context of corporate and national strategies to compete for and develop scarce resources. We need to make sure that we always ask whether the products and systems we create are **worth the expenditure of our limited time and resources.**

IN SUMMARY: DESIGN CONSIDERATIONS FOR SUSTAINABLE TECHNOLOGIES

What are the design considerations for technologies that support a more sustainable society? In order to assure that the material and energy resources we have on earth are available for generations to come, we need to design products and processes that . . .

- ✓ use nonrenewable resources at rates that accommodate the development and deployment of renewable substitutes
- ✓ satisfy our functional needs using as few material and energy resources as possible,
- ✓ minimally disrupt or impair ecological functioning,
- ✓ do not incorporate, or unintentionally create unwanted, persistent and bioaccumulative substances
- ✓ work in harmony with the assimilative and regenerative capacity of earth's systems,
- ✓ use renewable resources which are harvested at rates no greater than their sustainable regeneration rates,
- ✓ preserve the quality of constituent resources over their useful lifetimes,
- ✓ use as little energy as possible for recovery, recycling and reuse, and
- ✓ are worth the expenditure of our limited time and resources.

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FOR MORE INFORMATION

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