

SUSTAINABLE DEVELOPMENT THROUGH THE PRINCIPLES OF GREEN ENGINEERING

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INTRODUCTION

Concerns regarding population growth, global warming, resource scarcity, globalization, and environmental degradation have led to an increasing awareness that current engineering design can be engaged more effectively to advance the goal of sustainability and that there will need to be a new design framework that consciously incorporates sustainability factors as performance criteria. Sustainability has been defined as “meeting the needs of the current generation without impacting the needs of future generations to meet their own needs” and is often interpreted as mutually advancing the goals of prosperity, environment, and society. The 12 Principles of Green Engineering (Anastas, 2003) are collectively a design protocol for engineers to utilize in moving towards sustainability.

The impact of population growth has long been understood as one of the grand challenges to mutually advancing these goals and creating a sustainable future. When the issue is examined more closely, the data demonstrate that the vast majority of population growth is occurring in the developing world while population is stagnant, and in some cases declining, in the industrialized world (Figure 1). This may suggest that within the complex equation of growing population including birth and mortality rates, socio-political pressures, access to health care and education, cultural norms, etc., there is an empirical correlation between the rate of population growth and level of economic development, often equated with quality of life.

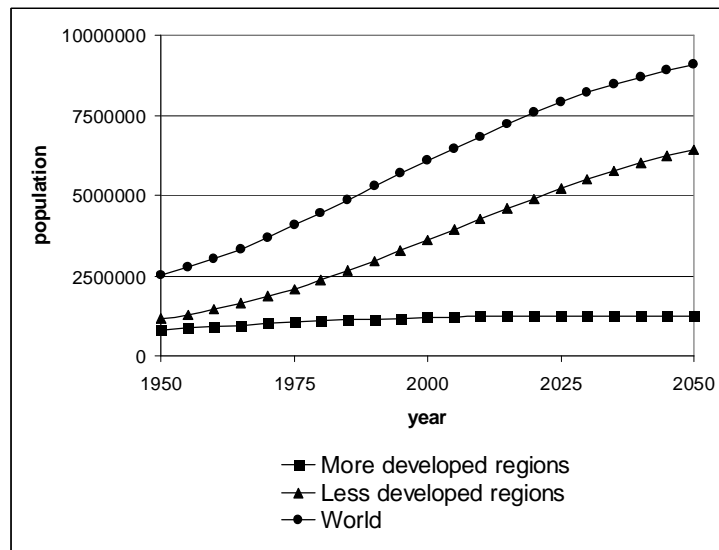


Figure 1: Projected population of the world, more developed regions and less developed regions where more developed regions comprises all regions of Europe plus Northern America, Australia/New Zealand and Japan and less developed regions comprises all regions of Africa, Asia (excluding Japan), Latin America and the Caribbean plus Melanesia, Micronesia and Polynesia (UNDESA, 2004).

This relationship suggests that one approach to be seriously considered in meeting the challenges of stabilizing population growth and advancing the goal of sustainability is through expanded economic development and improved quality of life. Historically, however, increases in development and quality of life have been inextricably linked with environmental degradation and resource depletion. There is a significant amount of evidence that suggests that conventionally an increasing human population has put an increasing strain on natural resources used for consumption and waste assimilation. While there is no single satisfactory index of the state of the environment, the relationship between population and environment can be analyzed in terms of resource depletion or dimensions of environmental quality such as land use, water quantity and quality, pollution generation particularly from increased energy demand, biodiversity,

and climate change. A brief review of each of these indicators supports the notion that, traditionally, population growth has had a detrimental impact on the environment.

Therefore, the question is how to bring about continued development and enhanced quality of life in both the developing and developed world without the historical environmental degradation and resource consumption. Green Engineering, along with Green Chemistry (Anastas, 1998), are engaged through science and technology on ensuring that quality of life, or state of economic development, is increasing through benign chemicals and materials and life cycle-based design as well as material and energy efficiency and effectiveness. This decouples the historical relationship of population growth and environmental degradation on the path towards an improved quality of life. The 12 Principles of Green Engineering (Anastas, 2003) (see Table 1) provide a framework for scientists and engineers to engage in when designing new materials, products, processes, and systems that are benign to human health and the environment.

THE 12 PRINCIPLES OF GREEN ENGINEERING

A design based on the 12 Principles moves beyond baseline engineering quality and safety specifications to consider sustainability factors and allow designers to consider them as fundamental factors at the earliest stages as they are designing a material, product, process, building or a system. These Principles were developed to engage in design architecture – whether it is the molecular architecture required to construct chemical compounds, product architecture to create an automobile, or urban architecture to build a city, the Principles are applicable, effective, and appropriate. If not, the value of these design principles diminishes as their usefulness becomes dependent on local

parameters and system conditions and they cannot effectively function as global design principles.

Table 1: The 12 Principles of Green Engineering (Anastas, 2003).

PRINCIPLE 1 - Designers need to strive to ensure that all material and energy inputs and outputs are as inherently non-hazardous as possible.

PRINCIPLE 2 - It is better to prevent waste than to treat or clean up waste after it is formed.

PRINCIPLE 3 - Separation and purification operations should be a component of the design framework.

PRINCIPLE 4 - System components should be designed to maximize mass, energy and temporal efficiency.

PRINCIPLE 5 - System components should be output pulled rather than input pushed through the use of energy and materials.

PRINCIPLE 6 - Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse or beneficial disposition.

PRINCIPLE 7 - Targeted durability, not immortality, should be a design goal.

PRINCIPLE 8 - Design for unnecessary capacity or capability should be considered a design flaw. This includes engineering "one size fits all" solutions.

PRINCIPLE 9 - Multi-component products should strive for material unification to promote disassembly and value retention. (minimize material diversity)

PRINCIPLE 10 - Design of processes and systems must include integration of interconnectivity with available energy and materials flows.

PRINCIPLE 11 - Performance metrics include designing for performance in commercial "after-life".

PRINCIPLE 12 - Design should be based on renewable and readily available inputs throughout the life cycle.

Two fundamental concepts that engineers should strive to integrate at every opportunity when designing within the Principles framework are life cycle considerations and the first principle of green engineering, inherency. The materials and energy that enter each life cycle stage of every product and process have their own life cycle. If a product is environmentally benign but is made using hazardous or nonrenewable substances, the impacts have simply been shifted to another part of the overall life cycle. Accordingly, designers should consider the entire life cycle, including those of the materials and energy inputs. This strategy complements the selection of inherently benign inputs that will reduce the environmental impact across life-cycle stages.

Making products, processes, and systems more environmentally benign generally follows one of the two basic approaches: changing the inherent nature of the system or changing the circumstances/conditions of the system. Although inherency may, for example, reduce the intrinsic toxicity of a chemical; a conditional change can include controlling the release of, and exposure to, a toxic chemical. Inherency is preferable for various reasons, most importantly to preclude “failure”. By relying on technological control of system conditions there is a potential for failure that can lead to a significant risk to human health and natural systems. However, with an inherently more benign design, regardless of changes in conditions or circumstances, the intrinsic nature of the system cannot fail. The Principles provide a structure to create and assess the elements of design relevant to maximizing sustainability.

The application of the Principles across scales and across disciplines has been documented with case studies from a variety of sectors (Zimmerman, 2003; Zimmerman 2005). While there are differences in terminology and jargon between molecular designs systems designers or designers in industrialized systems and those in developing communities, the fundamental approaches and guidelines in moving toward sustainability are common. By clearly illustrating how the framework of principles has worked in the past, these case studies can also provide a blueprint for how these guidelines can be applied in future designs for improving quality of life and ultimately advancing sustainability.

ADVANCING GLOBAL SUSTAINABILITY

Science and technology will play a fundamental and vital role in advancing global sustainability by engaging in next generation design of fundamental products, processes, and systems necessary for maintaining and enhancing quality of life while protecting the

planet. For global sustainability to be advanced the current operational model of unilateral knowledge transfer from the industrialized world to the developing world could be expanded to include knowledge exchange. The exchange would allow for learning about indigenous knowledge and traditional design, potentially simple and elegant, which has developed and adapted for local people and place. This would provide an opportunity to integrate the best and most appropriate knowledge, methodologies, techniques, and practices from both the developed and developing worlds in terms of designing for sustainability. The examples of innovations in science and technology from the developing world highlight alternative strategies to deliver services such as clean drinking water, medical treatment, energy and power production, material and product development, building technologies and techniques.

Developing nations typically have a long history of practical innovation and successful application of their indigenous knowledge systems to serve individuals and communities (Mihelcic, 2005). Innovations in science and technology in both the developed and developing world can provide fundamental shifts in the quantity and type of energy and materials utilized to improve quality of life and advance prosperity while protecting and restoring natural systems. The incorporation of the cutting edge thinking from a global perspective will create a robust and representative effort in achieving the common goal of sustainable development.

CONCLUSIONS

The achievements that have been obtained using green engineering principles are exceptional examples of design with a new sustainability perspective. If the challenges of sustainability are going to be addressed both within the currently industrialized nations

as well as those developing nations whose path to development will be most consequential for the environment and society, it will be essential that these new design imperatives be incorporated systematically in the next generation of products, processes, and systems. Within this context, the technological dialogue that takes place between the developed and developing world must be able to consider and utilize both a high level understanding of complex systems as well as an incorporation of simple elegance found in millennia of experience and tradition. The sources of technological inspiration will likely need to be broad and diverse if we are to design the products and systems of tomorrow to be sufficiently improved and more sustainable than those of today.

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