APPROACHING SUSTAINABILITY
– An Engineer's Perspective

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ABSTRACT

In order to rationally develop an approach to the goal of sustainability, it is important to establish a scientific as well as a sociological context, *i.e.*, examine the factors (technical, economic, etc.) that determine the degree to which sustainability can be achieved in practice. For purposes of discussion, sustainability may be defined as providing the physical needs of human society with no depletion of natural resources nor adverse impact on the natural environment. Ideally, all the resources required can be obtained from "renewable" sources (*e.g.*, biomass) or from recycle or reuse of human wastes. Defined in this way, sustainability is a philosophical goal to be pursued, but one that can never be completely attained.

Engineers traditionally define an "optimum" solution to any problem, technical or otherwise, as one that requires compromises among various, sometimes opposing, constraints. Technical constraints may include the relative efficiency of recycling processes and the amount of energy that must be expended in the process. Economic constraints include the cost of resource recovery and the cost of labor. Sociological constraints include population growth as well as the "standard of living" demanded by society. Political (or legal) constraints include distribution and consumption of resources as well as the willingness to accept limits on population growth and standard of living increase.

Some of the above constraints can be quantified to some extent; most constraints, however, cannot. It is probably impossible to define a single optimum approach to sustainability because the compromises that must be made will vary from one nation to another. This paper will discuss some of the technological factors, including recycling efficiency and energy consumption, which must be considered in defining any approach.

INTRODUCTION

Sustainability has been defined (by AIChE) as providing all of the physical needs of society without decreasing the ability of future generations to do the same. Ideally, all of the physical needs of society can presumably be provided with no use of "nonrenewable" resources and no discharge of wastes into the "natural" environment. As a philosophy, this forms a context within which to judge the actions of individuals as well as societies and governments. There is a tacit assumption that use of renewable resources such as wind and water power for energy production and living plants (and animals) for food, clothing, shelter, tools, etc. is ethically acceptable and not subject to any technical, economic, or environmental restrictions.

As a "program" sustainability may be divided into two broad areas, energy production and materials production. Most of the current media attention is devoted to energy production. The primary goal is elimination of the use of fossil fuels. Curiously, one of the acceptable alternatives appears to be nuclear power, even though the "proven reserves" (expressed as years at current rate of use) of fissionable uranium may be lower than the reserves of fossil fuels. There is less attention devoted to materials production, primarily because few "renewable" alternatives currently exist to replace steel, copper, and other metals in most applications. Sustainability efforts in this area tend to emphasize resource recovery: decreasing consumption of "virgin" materials (mining of iron and other ores) and increasing recycle of waste materials. Ideally, zero mining of virgin ores would be required and one hundred percent recycle of all waste materials would be achieved. [Note that this would presumably eliminate the need for waste disposal.]

Unfortunately, ideal sustainability cannot be achieved. It is physically impossible to recycle one hundred percent of waste materials (and uneconomical to even approach one hundred percent for most wastes). In addition, as population increases or the standard of living of a given portion of the population increases, consumption of all types of materials must increase. Stated another way, achieving true sustainability requires that either the population or the standard of living (or both) must decrease.

ENGINEERING AS A PROFESSION

There are many definitions of engineering. An old copy of the *Oxford American Dictionary* on my bookshelf defines engineering as: "the application of scientific knowledge for the control and use of power, as in works of public utility such as the building of roads and bridges (civil engineering), machines (mechanical engineering), electrical apparatus (electrical engineering, etc." [As a chemical engineer by training, I feel somewhat left out !!] That definition is not very satisfying. I prefer the definition that engineering is simply "finding optimum solutions to technological problems." In other words, engineers are basically problem solvers, but solvers of problems which require a certain level of scientific knowledge to analyze and understand.

The key word in the above definition is "optimum". The response of a true engineer to almost any question is seldom "yes" or "no" but rather "it depends." The optimum solution to an engineering problem represents a compromise between competing "constraints." Historically the primary constraints have always been technological efficiency and cost. As efficiency increases, cost increases. The question becomes: "How much efficiency can be afforded?" [In a very real sense, the "standard of living” may be defined as the amount of “efficiency” an individual or a society is willing and able to purchase.] More recently, consideration of a third constraint, environmental impact, has become a requirement for most processes involved in materials or energy production. In some cases, it has become the most important requirement. More recently still, especially in the United States (which has become increasingly litigious), consideration of additional constraints, government regulations and public acceptance, have also become important. For example, a lawsuit by an individual was able to block construction of a hazardous waste incinerator in western Florida. The presiding judge required engineers to guarantee ZERO discharge of any pollutants. Since no reputable engineer would guarantee to achieve zero discharge, knowing it to be theoretically impossible, the project was cancelled.

It is also important to recognize that all engineering decisions are constrained by ethical considerations as well. The first of the “Fundamental Canons” in the Code of Ethics of Engineers (published by the National Society of Professional Engineers) states that: “Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties.” This may be used to justify consideration of pollution control, but may also justify assigning pollution control a lower priority if the cost of pollution control limits the resources available for food, medicine, etc.

Environmental Engineering may be loosely defined as “that branch of engineering that deals with design and operation of facilities to protect human health from adverse effects of the environment and to protect the environment from adverse effects of human activities.” It may be somewhat unique among the engineering disciplines in that sociological and political considerations usually outweigh considerations of technological efficiency or cost. The public is willing to spend outrageous amounts of money in the name of environmental protection!!

Partly because “environmental engineering” is closely associated with publically owned facilities, another term has been coined for emphasis on protection of the environment regardless of engineering discipline. “Green engineering” goes beyond consideration of direct impact on the environment and includes a wide variety of indirect impacts, including resource and energy conservation. In building design, it may include use of recycled materials in construction, design of windows to minimize energy losses, or installation of photovoltaic panels. In product design, it considers the “life-cycle” of the product from use of environmentally benign materials of construction to ease of recycle or disposal. Again, minimization of environmental impact is assigned a higher priority than cost or technological efficiency. It is important to recognize, however, that there are practical limits to the application of such principles.

LIMITS ON SUSTAINABILITY

Allow me to divide limitations on sustainability into three categories: technological, environmental, and sociological. One of the primary goals of sustainability is reducing both consumption of nonrenewable resources and disposal of wastes by recycling as much as possible. It is important to recognize that recycling 100% of any waste stream is technologically impossible. Consider this “disposable” pen. [First, let me say that its design violates green engineering principles because its useful life is too short and recycling is too difficult.] Which parts of this pen could conceivably be directly reused? If the ink reservoir could be refilled and the pen point replaced or refurbished, the external case and cap could probably be polished or repainted. There is a limit, however, to how many times they could be (or would be) reused before being discarded. Once in the waste stream, can the paint or other finish be removed and reused? Assuming that were possible, could 100% of the paint be recovered? As in any separation process, increasing the separation efficiency requires use of larger and more complex process equipment. In addition to increasing the cost of separation, the amount of energy consumed also increases. Although a relatively high percentage of the paint might be recovered at relatively low values of cost and energy consumption, 100% recovery requires infinite cost and infinite energy consumption. Likewise, as the number of different components being separated increases, both the cost and energy consumption increase. Note that it is possible to design products to facilitate recycle. For example, this pen does not have to be painted at all; the coating does not facilitate its use (unless the color of the exterior matches the color of the ink inside). Designing most products to facilitate recycle, however, usually increases the cost of production (and / or decreases the convenience or ease of use of the product). From an engineering viewpoint, the optimum design depends upon how much emphasis is placed on one constraint (cost) over another (environmental benefit).

It may be argued that it is unnecessary to recycle components that are made from "renewable" materials. If the coating on the pen can be made from a biomass rather than from a petroleum source, it may be freely discarded (burned) because the carbon dioxide will be naturally recycled into new biomass. This argument, unfortunately, contains several fallacies. One is that the supply of biomass is not infinite. Another is that harvesting and converting biomass is likely to be more costly and energy intensive that use of current materials. A third is the possibility that biomass derived materials may not possess the properties needed (an automobile body could be made of wood, but it would probably not be as durable as one made from metal). In almost every case, existing products are made using materials and processes that minimize cost of production. If use of different materials or processes were less expensive, the market would immediately adopt them.

I think it is important to emphasize that reducing use of nonrenewable materials, whether by recycling or by replacement with renewable materials, must inevitably increase both the cost of consumer products and the energy consumed in the production process. Of course, there is a tremendous amount of interest in developing "renewable" energy sources as well. It must be recognized, however, that like renewable materials, the supply of renewable energy sources is not infinite. Use of those sources is also likely to be more costly, even considering the continuing increases in oil prices.

ENVIRONMENTAL CONSTRAINTS

Reliance on renewable materials and energy will also have severe effects on the natural environment. If biomass-derived materials (including fuels) are to replace petroleum-derived materials, huge amounts of currently uncultivated land will have to be put into cultivation. Note that petroleum possesses a very high energy density, *i.e.*, energy content per unit mass, due in part to its relatively low oxidation state (oxygen content). Biomass possesses an intermediate level of oxygen content and a relatively low energy density. Thus more biomass is required to provide the same fuel value or material value as petroleum. The conversion efficiency from biomass to ethanol or other liquid fuel is low (less than 10%) as is the efficiency from solar energy to biomass (also less than 10%) and solar energy is relatively diffuse. Thus a large land area must be harvested to provide the fuel and material currently derived from petroleum. One crude estimate of the amount of land that must be planted in corn in order to produce enough ethanol to replace the petroleum derived vehicle fuel usage in Florida alone is a value equal to the entire land area of the state. [See Appendix A.] The current high priority given to preservation of natural ecosystems would have to be significantly decreased. Although the priority level may be lowered, it is unlikely to be abandoned entirely. The amount of waste generated in the processing of biomass will also represent a large environmental problem. It is unlikely that all of the fertilizer value of the waste can be recycled for use in growing new biomass, and thus the use of inorganic fertilizer is likely to increase rather than decrease. This does not even consider the loss of habitat and subsequent extinction of some species.

Other alternative energy sources, whether solar or wind power, will also require increased consumption of raw materials and increased production of waste (much of it “hazardous”). The amount of energy consumed in waste recovery and recycle will also dramatically increase resulting in even more environmental impact. There is also significant objection to construction of wind energy equipment solely on the basis of aesthetics !

SOCIOLOGICAL CONSTRAINTS

Unlike most engineering problems, solutions to environmental engineering problems are often based as much upon sociological or political considerations as upon technical, economic, or environmental considerations. As noted above, sustainability becomes much more difficult to achieve if population continues to increase. Currently, Europe is the only continental region with declining population (although petroleum consumption continues to increase, as shown in Appendix B). To date, however, China is the only nation in the world to attempt governmental control of population growth. The draconian measures employed (one child per couple) cannot be used (at least in the foreseeable future) in any democratic society. Without a stable population, however, all efforts to increase recycling, reduce use of virgin material resources, etc. can only slow, but not stop, depletion of natural resources and environmental degradation.

It is also important to recognize that the “standard of living” of any society may be measured (indirectly) in terms of material and energy consumption. The United States is a world leader in per capita consumption of natural resources and energy as well as in production and disposal of wastes from such consumption. In the short term, conservation measures and technological innovations (as well as cost of a product) can decrease per capita consumption without significant decrease in standard of living (*e.g.*, per capita consumption of fossil fuels in the US has been level or decreasing for the last 30 to 40 years, as shown in Appendix C) if the beginning levels of consumption are relatively high. Eventually, however, decreasing consumption of materials and energy must be reflected in a decreasing standard of living. It is difficult to imagine any society being willing to accept such a decrease. This is especially true of “developing” nations whose current standard of living is far below that of more developed nations. Note that China has already surpassed the United States in fossil fuel consumption, and India will surpass the United States within the next few years.

SUMMARY

Engineering decisions are based upon multiple constraints. "Optimum" solutions to engineering problems require definition of priorities with respect to those constraints. In "developing" societies, cost is usually assigned the highest priority. As societies develop, technical efficiency (defined as the amount of labor required) becomes a major priority. Only after achieving a relatively high level of development does environmental protection become a significant concern. To assign "sustainability" the highest priority may require a level of development that has yet to be achieved.

The question that must be answered, however, is not whether to assign the highest priority to sustainability, but rather how high a priority should be assigned. What compromises should be made among resource depletion, environmental degradation, cost, energy consumption, population growth, economic growth, etc. Who should make these decisions? Only one thing is certain. If population continues to increase and that population continues to demand an increase in standard of living, no amount of "green" engineering can achieve true "sustainability."

ACKNOWLEDGEMENT

This paper was previously presented in August, 2008, at the Oxford University Roundtable.

APPENDIX A

Estimate of Land Area Required to Replace Fossil Fuels with Corn Ethanol

Energy Usage for Transportation in US = 25.82×10^{15} Btu / yr

Ethanol Equivalent = 3.29×10^{11} gal / yr

Land Area Required * = 1.3×10^{9} acres = 2.0×10^{6} sq.mi.

57% of total land area of the United States (including Alaska).

* Estimates of ethanol obtainable from corn range from 250 to 500 gal / acre. This calculation used the lower value, 250 gal / acre. Using the higher value would reduce the land needed to 26% of the total area of the US.

Assuming that energy usage for transportation is proportional to population, the values for Florida alone would be 1.5×10^{15} Btu / yr, 1.9×10^{10} gal / yr, and 116,000 sq.mi. respectively. This area is 199% of the land area of Florida.

It should be noted that: (1) transportation represents only 30% of the total fossil fuel consumption in the United States, but (2) other crops may yield more ethanol or other fuels per acre (especially if a cost-effective method of converting cellulosic materials to ethanol can be developed)
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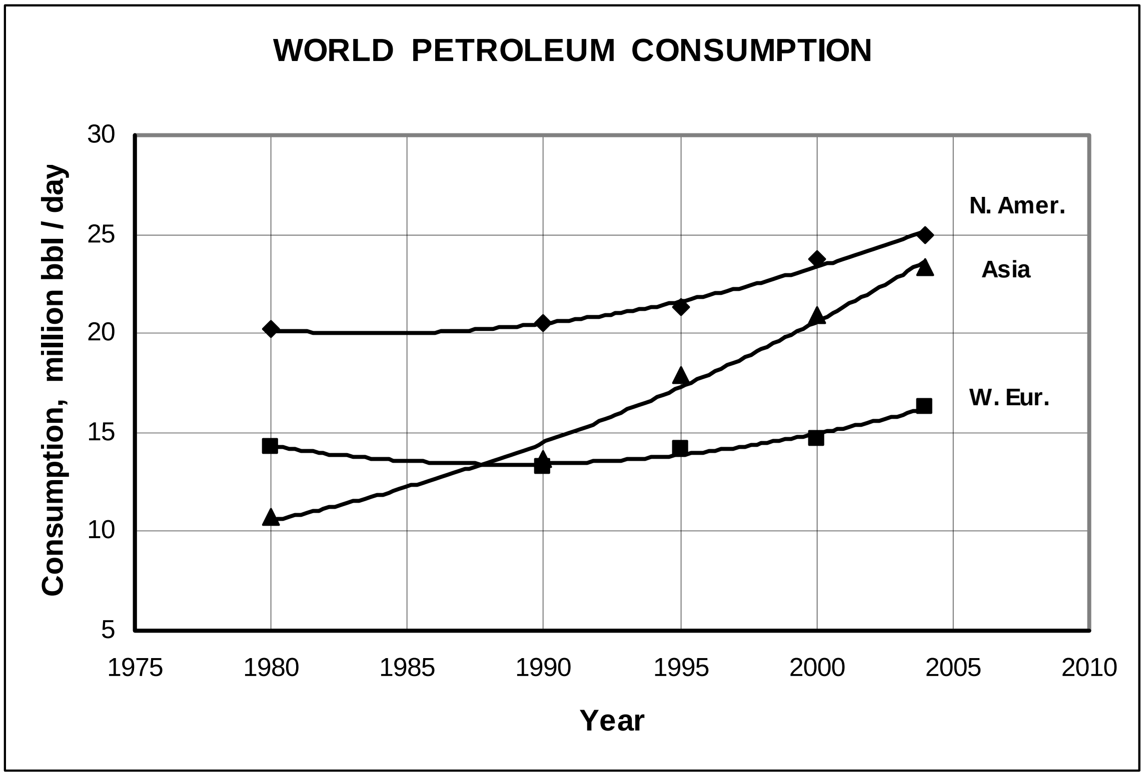
APPENDIX B

World Petroleum Consumption

(Source data: New York Times 2007 Almanac)



APPENDIX C

United States Total and Per-Capita Energy Consumption

(Source data: New York Times 2007 Almanac)