Life Cycle and the Approaches to Sustainability Research

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Abstract

The challenges of sustainability go beyond normal technological decisions. In fact, sustainability is so complex that a rationale approach is needed to identify subparts that can be more easily analyzed and potentially can clarify what alternatives are important for specific product issues. In this paper an approach toward simplification is described.

Within the broad area of sustainability, there will also be technical decisions since the industrial sectors are major contributors to sustainability. This industrial role derives from society's dependence on industry to meet major aspects of personal and societal needs. What we seek is not just the environmental and economic consequences, but also measures of technology benefits relate to the output of the industrial sectors. A review of some sustainability models will be given. In addition, the utilization of the intrinsic energy value of products through recycle/reuse will be examined in the context of global sustainability.

Introduction

There are several advanced environmental frameworks that have emerged to describe the next several decades of concepts and actions in the environmental field. These are

- Green engineering and chemistry
- Industrial ecology
- Sustainability

Advanced environmental frameworks represent the direction for the overall environmental improvement sought by manufacturers, governments, and stakeholders. Sustainability is one of these frameworks and appears to be the most widely adopted by corporations and policy makers. Since sustainability is largely undefined at the operational level, this provides the opportunity to tailor sustainability to the views of each organization. Thus we see a variety of definitions for sustainability and at the corporate level this includes decisions to assure the long term sustainability of the organization and their future markets. This leads to a very complex landscape of sustainability concepts, actions, policies, and underlying technologies.

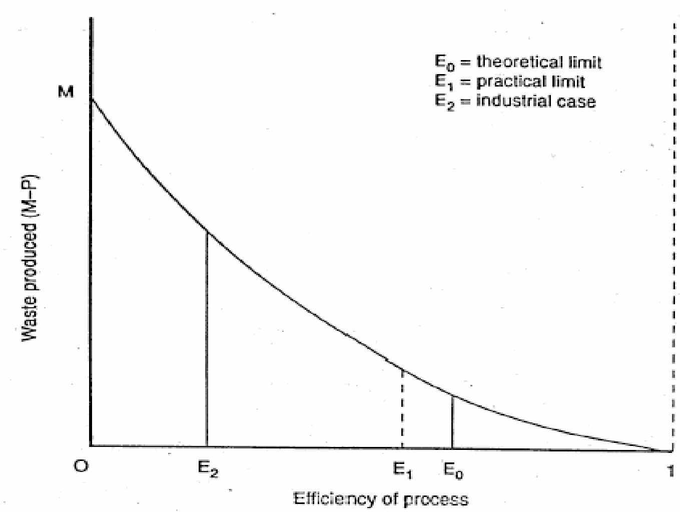
Research on sustainability is thus addressing complex issues. However research on any complex issue has certain similarities and must be approached by segmenting, understanding, and then reassembly to evaluate the system response or behavior.

Sustainability is a good example of such a complex issue. First, research must move from the qualitative, philosophical views to quantitative decision-making. Life cycle is a major tool in such quantification and analysis. A second requirement for research on complexity issues, such as sustainability, is the generation of system models to test hypotheses, to discover fundamentals, and to probe new areas of study. Several of the models that we have developed or use are described in the balance of this paper.

Sustainability Concepts and Research

A research model for the generation of chemical losses from manufacturing and energy use has been generated to aid research in sustainability and manufacturing sector environmental improvement (Jackson, et. al, 1993; Overcash, 2001; Overcash, 2003). This model incorporates the first and second laws of thermodynamics to reflect the conversions needed to transform natural resources into products or services. These products can be chemicals from molecular structure building (such as di-n-butyl phthalate acid ester) and durables or consumables in which macrostructure has been built (such as a camera or automobile bumper). The sustainability of these molecular or macro- structure transformations is related to both the inputs to manufacturing plants and to the chemical/material losses (input (M) minus product (P) outputs = losses).

Figure 1. Global manufacturing efficiency and environmental emissions



Theoretical and practical limits to conversion efficiency.

The thermodynamic principles state that the transformations necessary to bring natural resources from the earth into the state of a product must utilize energy and must produce waste. If a summation of these wastes for all global manufacturing plants is made, as a function of process efficiency, then global manufacturing waste is represented in Figure 1. The thermodynamically impossible state of 100% efficiency would be zero waste or energy used. Inputs to manufacturing, but no product is a case in which waste = inputs

(M). The first law of thermodynamics establishes a lower than 100% efficiency (E_o) and hence a nonzero waste and energy. The second law of thermodynamics of entropy production for nonequilibrium processes, establishes and even lower efficiency (E_1) and hence more waste and energy, Figure 1. And of course we are somewhere along the overall efficiency curve as a reflection of overall industrial efficiency (E_2). Sustainability research must build on the phenomena in this Figure 1 to address questions such as

a) How can we define the thermodynamic limits shown in Figure 1
b) Can we modify these first law efficiency limits to include the manufacturing realities of the second life for products
c) In 2006, where are countries, regions, sectors, etc along Figure 1.

Answers to these and other sustainability questions depend on much larger life cycle inventory databases for analysis than currently exist.

For sustainability, there are several models for environment and resources, but few for social and economic impacts of sustainability. One early sustainability model was captured in the equation in Figure 2. Evaluation of each of these three factors as a function of time is given in Figure 2. The overall environmental impact is thus linked to three factors representing technology, quality of life, and social population. Given that

$$Pollution = \left(\frac{Pollution}{GDP}\right)\left(\frac{GDP}{Population}\right)(Population)$$

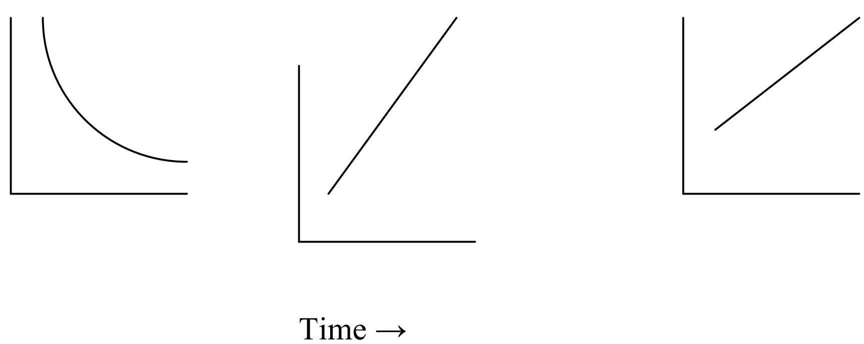


Figure 2. Global sustainability equation determining environmental impact

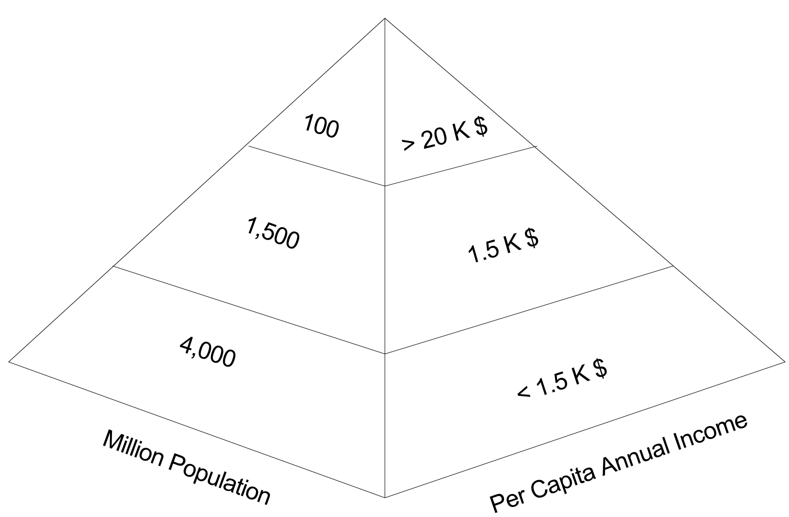
the use of energy and the inefficiencies of conversion processes to manufactured products or provided services (Figure 1), can rarely be driven to zero, then the aggregate global environmental impact will remain nonzero and growing unless there are changes in the quality of life or population factors.

One of the tenets of sustainability research is to analyze how products meet population needs on a country and a global basis. The consumption or use of products is dependent on basic human needs (Maslow, 1998; Max-Neef, M., 1992), but also the individual or family income available to purchase products. Hart (1997) captured the global distribution of income that then governs the utilization of products, Figure 3. In the context of Figure 2, a research model for the individual utilization of products addresses the second global factor (utilization of products per capita).

Sustainable research is thus needed to address how to meet the needs in Figure 3, especially for all income categories. We know there is a specific environmental impact (energy use and chemical/material loss) for manufacturing of each product appearing in the global needs of our societies. Life cycle apportions that environmental impact across the categories of the life cycle calculated for a product. However, life cycle inventory research on the end-of-life segment of an overall life cycle has shown that reuse or remanufacturing/reuse provide substantial improvements in sustainability.

Thus our life cycle research program at NCSU began to examine how to quantify the sustainability benefit of multiple product cycles (instead of landfill or fuel value combustion) that might involve multiple layers of the global income pyramid. That is, if we engineer product life to exceed the initial use (already true for a large number of products because of fashion or technology changes) what are some of the environmental benefits to the transfer of products to multiple successive users. Specifically, if products could be transported globally for reuse at much lower prices, would the global environment be improved? Using the lci database (Overcash 1998-2006), we determined how much of the energy input during manufacturing a product (and thus still largely contained in the durable product after the first user) would be expended in the physical transportation of a product to some other country or location. The weight of each product and the transportation mix using emissions from trucks, rail, and ocean ships (approximately 15%, 40%, and 60%, respectively), were combined to quantify the lci of the transportation.

Figure 3 Global population and income distribution (Hart, 1997)



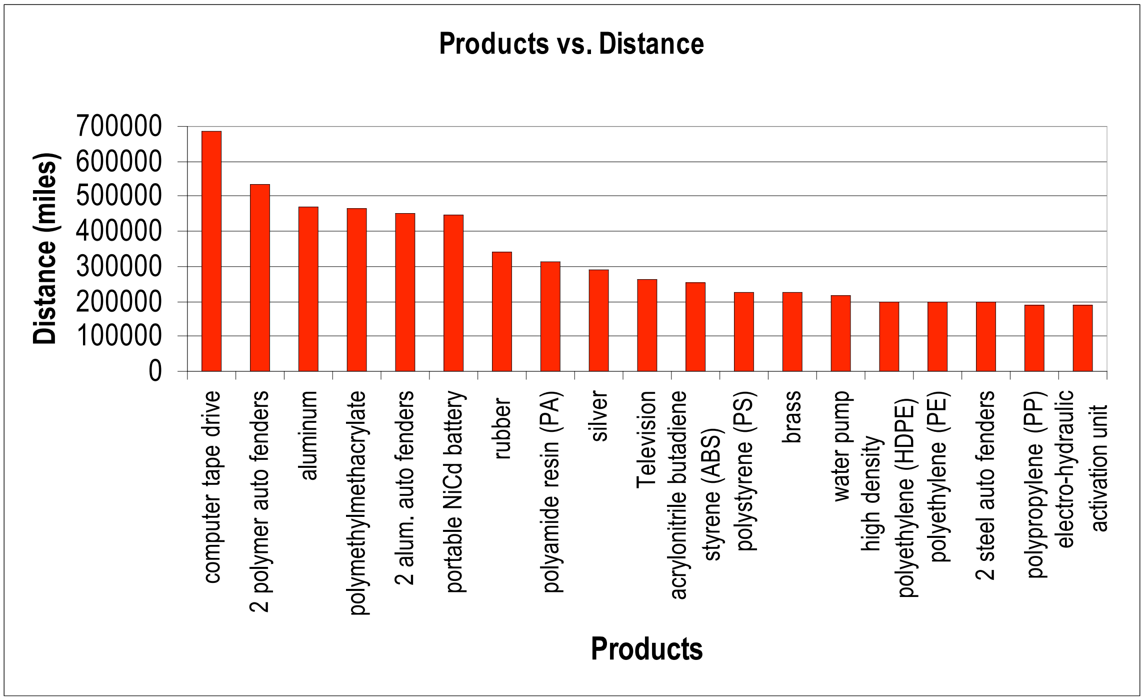


Figure 4 Potential reuse distances of products investigated (Mott, 2003)

Transport distances were expressed as increments of movement around the globe (one trip around the globe is ~25,000 miles), Figure 4. Of the 76 products for which an lci result for energy of manufacturing was found, 80% could be moved around the globe one or more times and still not exceed the embedded manufacturing energy. The largest distance was a computer tape drive which could be moved 30 times around the globe. This indirect study in sustainability research leads to further questions (such as which products cannot be transported without exceeding the product energy value) for which lci results are critical.

Conclusions

The complexity posed by sustainability of our manufacturing and product systems is an exciting area of research. Models of sustainability systems have been developed and now we are beginning to explore the models to answer questions in technology, economic systems, and social factors.

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