The Four Dimensional Product:

Integration Over Time is the Only Way to Understand Sustainability

William F. Banholzer and Mark E. Jones
The Dow Chemical Company

Sustainability is a question of time, integrating knowledge of production, use and end-of-life. Far too often, hype has surpassed reality, boundary conditions have been neglected and actions taken that don't truly lead to a sustainable future. Singular focus on attributes like renewable content or biodegradability gives the wrong answer. Quality engineering forms the foundation for any meaningful discussion of sustainability, providing insights into energy and material flows, energy return, and thermodynamic constraints. The chemical industry is increasing resource and energy efficiency through innovation in both products and processes. Our mastery of materials science enables unique energy producing and energy saving products, products that improve sustainability by being significantly better than the next best alternatives during use.

The words "sustainable" and "sustainability" a experiencing a rapid increase in use. Google ngrams allows the determination of usage of words or phrases in published books. At the current rate of increase, a simple fit to the ngrams data indicate that one of the two words will appear on ever book page at least once by 2026 and in every sentence by 2062. Further extrapolation indicates that by 2098 plus or minus about 15 years, the entirety of the English language will just be these words.[1] Words used with such frequency and experiencing such growth in usage seem ripe for misuse. Any discussion of sustainability must begin with a discussion of what it actually means.

Figure 1: The plastic cup is a frequently used metaphor for our disposable society. Which of these cups is most sustainable?

Figure 1 shows three cups, a conventional red plastic cup, a version of that same cup made from wood and one made from granite. The red plastic cup is a useful metaphor for sustainability. It attracts ire as the prototype disposable item, used once and tossed away. Asking an audience which is the most sustainable can provide a variety of responses. Some fixate on the renewable aspects of the wooden cup, recognizing that the plastic and the granite cups are made from finite geologic sources. Others focus on the potential for long life of the granite cup, recognizing that wooden cups have a limited lifetime and stone may well last forever. The answer is that you can't know by just looking. Sustainability is not an intrinsic property of a material. A discussion of sustainability demands that you know where raw materials are sourced, how they are processed, how they are turned into a product, how that product is used and what happens to the product at the end of life. This puts materials suppliers, like the chemical and polymers industry, at a disadvantage. There is no way to have an effective discussion about sustainability looking only at pellets or bulk shipments. Studies of sustainability require that you know about the product that is made and how it is used. It requires an integration over time.

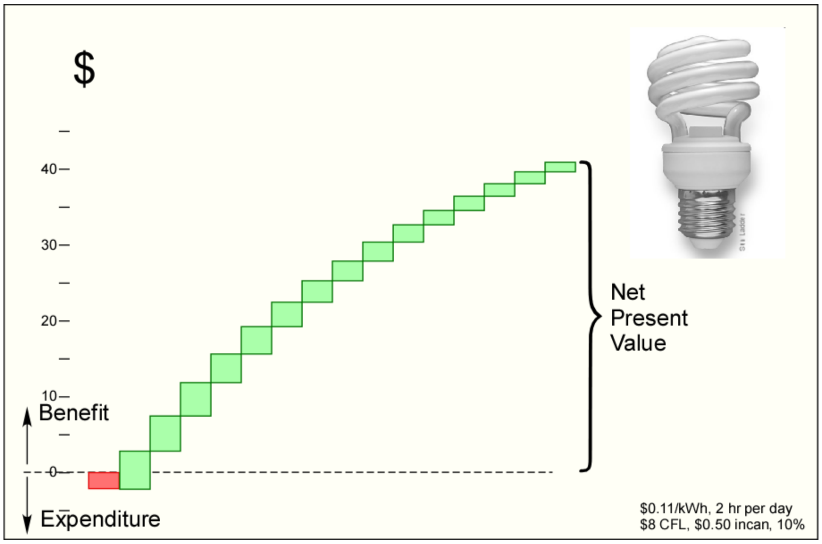

Figure 2: A net present value (NPV) calculation for the use of a compact fluorescent bulb instead of a conventional incandescent bulb. This analysis looks at the relative value over the lifetime of a CFL bulb. The red indicates the cost (negative value) as the difference in initial purchase price. The green is the savings in energy cost in use, discounted for future value.

The concept of integrating over time is well understood in business. Figure 2 shows the way an MBA would look at a sustainability choice we've all faced, and one to be face again as LED bulbs become more prevalent. It is a classic case of spending more to save over the long term. Plotted is the cost and benefit of replacing a 60 W incandescent bulb with a 14 W compact fluorescent. An $8 cost for the CFL and only 50 cents for the conventional bulb are assumed. In the case of cash flows, the cash flow is discounted to reflect the risk relative to a certain investment at a bank. To spend more today, you want to be certain that your return will be above a no risk option. In this analysis, a hole is dug, the future cash flows fill in that hole and then continue to pay dividends. Operated for 2 hours a day over the expected life of the CFL bulb, or 16 years, the $8 investment will deliver $40 of value over its lifetime. This is the net present value, or NPV, of the CFL investment.

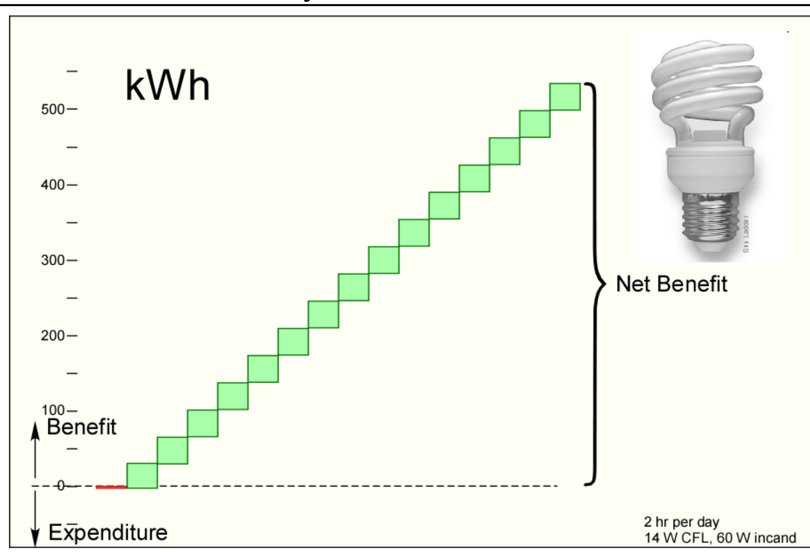

Figure 3: A look at the energy savings over the life of a CFL bulb relative to a conventional incandescent.

NPV analysis is very useful in business since it allows for the easy comparison of options. Two different

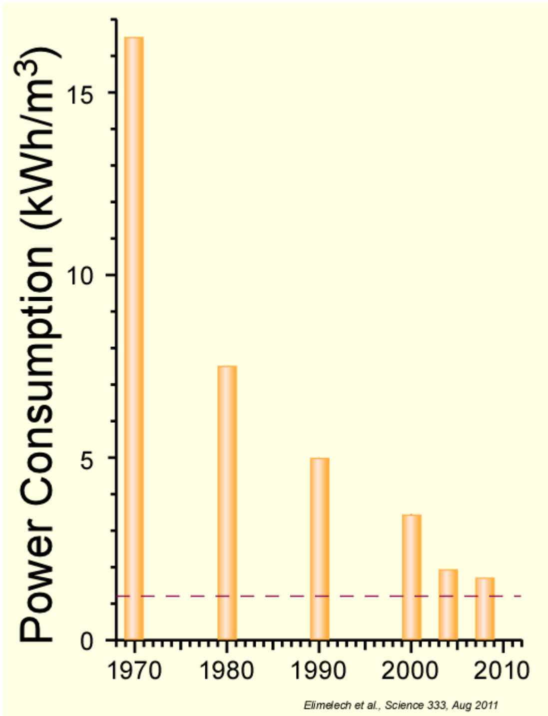

Figure 4: Improvement in reverse osmosis technology over time. Dotted line shows theoretical minimum energy required for desalination.

technologies can easily be compared, as with the comparison of a CFL and an incandescent. The option of doing nothing can be compared with the option of doing something. It is a comparison of options over time and is exactly the type of analysis that is required when determining the more sustainable option between two technologies.

To illustrate, Figure 3 shows a comparison of CFL bulbs with incandescent based on energy only. Like the NPV analysis, this is a look at benefit over time, substituting the energy benefit for the pure financial benefit. Energy is not the full story, but frequently dominates comparisons of sustainability. In this case, you dig a hole in consuming energy to make the bulb. That is reported to be less than 2 kWh versus a couple of hundred watt-hours for a conventional bulb. Each year of operation saves about 30 kWh. Over the life of the bulb, over 500 kilowatt-hours is saved. This is the energy benefit of that is provided by the CFL over the conventional technology.

Looking only at the bulb, the conclusion would be it requires more energy to make, using more resources and is, therefore, the incorrect decision.. It requires a lot more energy to make a CFL. Since emissions are highly correlated with energy use, the environmental footprint would be worse for the CFL is we only look at the production.

In the chemical industry, we focus intensely on the production and making it energy efficient. What we don't focus on enough is what happens in use. It is only in use that the sustainability benefits of our products become evident. Just as in the case of the CFL, a sole focus on the expenditure of resources while ignoring the long term benefit gets you to the wrong answer.

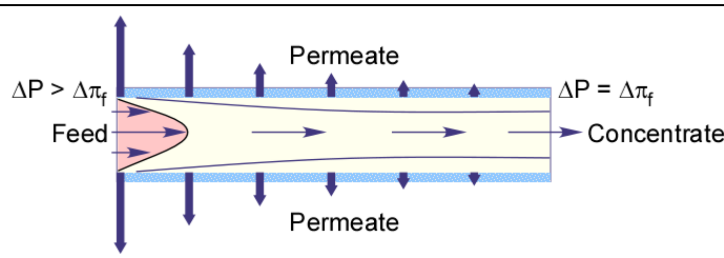

Figure 5: A reverse osmosis membrane in operation. Permeate flow drops along the module length.

There are many examples where products produced by the industry provide a lasting benefit. Reverse osmosis (RO) membranes are one that is a triumph of material science that creates a big advantage when compared with other options for water purification. Power consumption in reverse osmosis has been reduced dramatically since the commercial

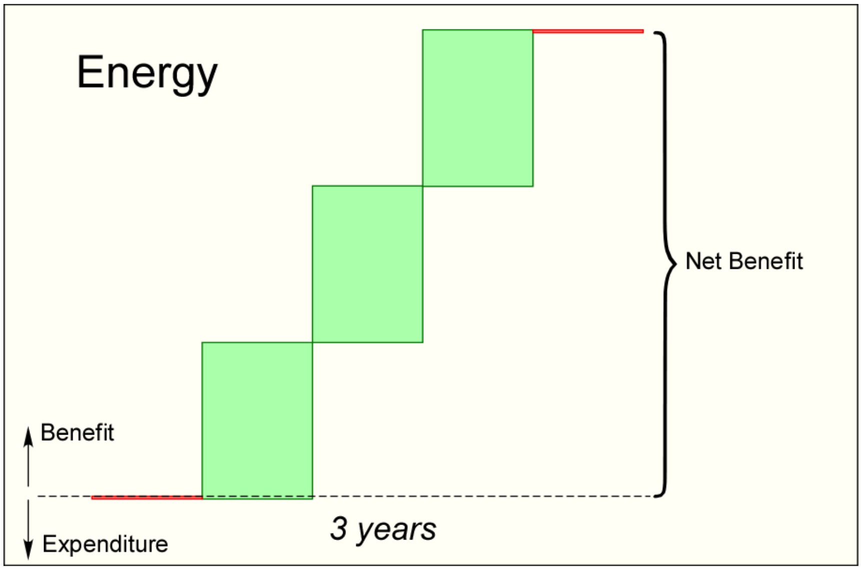

Figure 6: Energy savings over the life of a reverse osmosis membrane relative to best thermal technology. The energy use in making the membrane and decommissioning it are exceeded by the energy savings in use.

introduction[2], as shown in Figure 4. The most common configuration of RO membranes in commercial use is shown in Figure 5. Impure water flows in a central channel and pure water is forced through the membrane, overcoming osmotic pressure. The flow through the membrane drops as ionic strength increases in the concentrate. The increase in localized osmotic pressure is a thermodynamic effect, not a kinetic one. There is a minimum second law energy requirement that sets a minimum value, shown as the dotted line on Figure 4.

Reverse osmosis has been studied in terms of life-cycle energy use[3]. An approximate plot of this energy use is shown for a three year membrane module life in Figure 6. This plot shows only the energy savings relative to multi-effect distillation, a thermally-driven purification technology.

Energy savings enabled by RO is an example of how products enabled by the chemical industry enhance sustainability. It is only through taking a look over time that we can correctly assess the benefit or detriment of our products. Our industry's mastery of materials science enables unique energy producing and energy saving products, products that improve sustainability by being significantly better than the next best alternatives during use.

---

1 the idea for this analysis originated with http://imgs.xkcd.com/comics/sustainable.png

2 Elimelech, Menachem, Phillip, William A.; "The Future of Seawater Desalination: Energy, Technology, and the Environment", Science 5 August 2011: 333(6043), pp. 712-717

3 Raluy, Gemma, Luis Serra, and Javier Uche. "Life cycle assessment of MSF, MED and RO desalination technologies." Energy 31, no. 13 (2006): 2361-2372.