Feature Article

THREE LAWS WE MUST LIVE BY

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Most readers of this journal will have been exposed to at least some of the ideas regarding Thermodynamics in the course of their education or career. I can remember that as an undergraduate student 50 years ago I wrestled with the concepts of, and equations relating to, Enthalpy, Entropy, Free Energy, etc. Although I passed the courses with reasonable grades, I was, at the same time, completely incapable of grasping a genuine understanding of the subject! Later, having had a number of years working as a Chemical Engineer in industry, and as a graduate student in Physical Chemistry, I began to try to teach Thermodynamics to undergraduates in Science and Engineering. Near the end of that first year of teaching, I had begun to understand the topic myself, but could only hope that then, and in the future years, I could bring some degree of understanding to my students as well.

If you type "Thermodynamics" into Google today, the first of the 5.5 million results is a Wikipedia definition:

> "The starting point for most thermodynamic considerations are the laws of thermodynamics, which postulate that energy can be exchanged between physical systems as heat or work. They also postulate the existence of a quantity named entropy, which can be defined for any system...
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> With these tools, thermodynamics describes how systems respond to changes in their surroundings."

Today all the thinking people of the world, whether scientists or not, are (or ought to be) wrestling with the problematic concepts of Global Climate Change and its implications for our societies and economies. It is obvious that this problem involves energy in all its forms. Many of the first, tentative steps on the part of various governments are aimed at reducing the man-made cause of this upset in the balance of our climate, namely greenhouse gases (GHG), by introducing various economic incentives such as cap-and-trade systems or outright taxation of processes or operations that lead to production of such gases. In some countries, subsidies are being offered to encourage "green" products (such as hybrid cars) or energy conversion to electricity by wind, tidal or solar power. Outright sequestration or carbon dioxide is being touted as a cure all for being able to continue using the enormous reserves of coal in the ground.

I think it is very important to bring foremost into discussions of these problems, and proposed solutions of them, the most fundamental factors that govern our societies with respect to their interaction with Energy, namely the Three Laws of Thermodynamics, and so it is the purpose of this short article to point out how these Laws can be invoked to simplify some of the very complex

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routes our societies must take to coping with the problems associated with GHG.

The Three Laws of Thermodynamics are not really like the laws created by various societies through their governments - such laws have to be enforced by human means. The Thermodynamic Laws enforce themselves in that are expressions of the behaviours of energy that have been observed, They have been properly called "postulates of impotence" because they express the empirical fact that they have never been observed to be disobeyed for closed systems - they describe things we cannot do. For example the First Law means that you can never get more work out of a system than the energy you put into it; the Second Law says that systems behaving spontaneously always decrease the amount of order (Entropy) they contain, which has the implication that you will always get less work out of any real system than the energy you put in, thus rendering perpetual motion machines impossible; the Third Law says that you cannot reach the absolute zero of the temperature scale. Facetiously, the Three Laws are sometimes expressed as:

1. You can't win.
2. You can't even break even.
3. It isn't even worth trying.

Unlike man-made laws, there is nothing we can do to change these Three Laws of Thermodynamics, so we simply have to learn how to live with them, as they will dominate any solutions we come up with to ameliorate Global Climate Change.

The phrase "closed systems" in the previous paragraph is most important, and can be defined as any collection of physical entities where neither energy nor mass enters or leaves the system. This is an important limitation on the First Law, and it is equally important to recognize that the Earth's eco-sphere is also a closed system, with the notable exception of the Sun's energy. Indeed, it is the energy of the Sun which ultimately is what we are using when we burn fossil fuels or yesterday's freshly cut wood. It is also the energy of the Sun that we use when we build a hybrid auto, pour a concrete foundation, run a computer, pump water with a windmill, or cook a meal on a gas stove.

Therefore, except for the Sun's energy, our available energy is limited to what we already have in Earth's eco-system. This leaves only a few options for generating energy (such as nuclear fission or tidal power) which are not dependent on the Sun. Recognition of such a simple fact is important: in our attempts to limit the production of greenhouses gases generated by burning fossil fuels and other materials. We will have to look for large increases in the use of systems that capture energy from solar cells and wind turbines. But this in term raises the problem that sun-driven system will only work about half the time or less, and therefore must be supplemented by other means of energy production or storage. In fact, every method of energy production seems to come with some characteristics that somebody objects to: CO_2 from burning coal, oil, gas or any other fuel, radioactive waste from nuclear generation, noise and environmental disruption from wind turbines, high costs (energetic as well as monetary) from solar cells, etc. So any decision for a new energy producing facility will require compromises with respect to the choices available. This is, along with the fear of economic costs, the major factor restraining many countries from attacking the problems posed by burning fossil fuels.

By virtue of the fact that you are reading this article, I can safely assume two things about you: you are a citizen of your country and you are a knowledgeable scientist or engineer, or at least technically astute. As a citizen, you have an obligation to pay attention to what your governments are doing; as a scientist you have an obligation to bring your unique knowledge to bear on what your government is doing. Let me give some examples.

1. You can't win :

The Kyoto Protocol was formulated 12 years ago and was ratified by many countries, including mine (Canada). Since then our greenhouse gas emissions have continued going up and Canada's government has delayed implementing any real measure of control. Most recently, it has promoted a scheme where the "intensity" of industrial greenhouse gas emissions would be reduced. That is the amount of CO2 per unit of production would be lowered. It does not take much mathematical sophistication to realize that if production continually increases, the absolute amount of GHG must ultimately increase. In a real sense, our political leaders seek to revoke the First Law. Not only are they unable (in the fullest sense of the word) to do that, but they are also playing games with the general public's inability to recognize the simple fallacy behind the use of "intensity" of greenhouse gas production as a cure-all for the problem. As scientists who understand this, it is our obligation to speak up against this crime of trying to disobey the First Law.

Another instance of this just came to me in the morning newspaper, where a distinguished professor of aerospace studies attempted to refute a major conclusion in George Monbiot's recent book, entitled **Heat : How to Stop the Planet from Burning.** Monbiot had calculated that airplane travel could not be reconciled with elimination growth of GHG by any means other than reducing plane travel immensely. The professor of aeronautics, although pointing out that travel increases ca. 5% per year, argues that "technical solutions" exist for the future that have the potential to reduce GHG production by as much as 50%. Simple arithmetic suggests that an annual increase of 5% in plane travel would eat up a 50% improvement in technology in only 9 years.

Besides misleading uses of intensity arguments, the First Law is often violated, intentionally or not, by advocates of supposed solutions for GHG problems by not doing full energy balances when considering the systems involved. Some years ago, a colleague of mine did a proper energy balance and demonstrated that plastic milk containers, much-derided by environmentalists for the "obvious waste" they represented, were actually more energy conserving than the alternative glass milk bottles because a full energy balance had to take into account both the extremely high energy required to make the glass bottles and the large amount of energy to wash and sterilize them properly before re-use.

Another good example of the need for full energy balances is the North American rush to embrace the use of ethanol as a substitute for petroleum in auto engines. Not only is the ethanol only very slightly better for the environment than the gasoline it replaces, but it also requires a very large amount of energy to produce it - so much that in the particular case of ethanol derived from corn, it may, in some cases, require more energy than the ethanol produces in the auto! The fact that there was a great deal of money to be made by farmers and/or large agribusiness developing ethanol plants has led governments to support this farce, rather than looking for better plant sources than corn from which to make ethanol.

2. You can't even break even

It is a bit difficult to fit the Second Law into a discussion of Global Climate Change, but it is perhaps best regarded as causing us to always have to make compromises with potential solutions to the problems we are facing. These compromises will often be of an economic nature. It is true that many attempts to reduce energy expenditures in various manufacturing processes have led to economic savings as well. That is wonderful when it happens, but it does so mostly because energy has been so inexpensive that there was little motivation to save it in the first place. Some process designs were therefore far more inefficient than they could have been — in a word, bad design was not punished! However, when we look at problems that involve recycling, either as a way to save on raw materials or energy, we begin to encounter the true meaning of Entropy: it is a measure of disorder.

Manufactured products of all kinds, whether an ocean-going freighter or a television set, or a tube of toothpaste, represent a high degree of order. Until recently, little thought was given to the design of such items such that the materials from which they are made could be re-used. In the case of the freighter, the energy content of its hull is enormous, and it is foolish to not consider re-using that material. Isn't it equally foolish, then, to design such a freighter without regard for its ultimate recycling? To an extent, that statement could be made for almost all manufactured products, but this is an idea which is a long way from general acceptance. One need only look at the ridiculous use of packaging for all sorts of trivial items to see the truth in this. The economics at the point of distribution and sales have dictated the use of such packaging; the energetic economics of the consequences of that packaging to the society where it is disposed have received almost no consideration except in the few places where it has been legislated. The Second Law tells us that we will always have need for such legislation.

3. It isn't even worth trying

If the Earth were a closed system, the Third Law and its application to our Global Climate Change would necessarily drive us to despair. Luckily, we can recognize that the open character of our system saves us from despair. We do have the sun and its infinite (for all practical purposes) input of energy to our planet. Much of that energy is available for utilization in the form of tidal power, solar heating and electric generation and wind power. We are only beginning to tap such sources in a meaningful way that can, ultimately resolve the crisis we otherwise would have to face.

It is worth trying, and we must do so.