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The End of Science? **Hardly*!***

By Mary Essary; June 2007

In 1997, John Hogan, then a senior staff writer at *Scientific American*, published a book entitled *The End of Science*, in which he argued (between comments about clothing and other side issues) that all of the true breakthroughs are behind us; that in many fields, we have reached the limits where theory becomes philosophy; in others, we are simply filling in the details, working harder and harder to know more and more about less and less.

Now June of 2007, ten years later, I have just attended nine of the twelve middle- and high-school Massachusetts State Science and Technology Fairs: for the first time, there was a "Clean Energy" award which went to the best project related to any aspect of clean energy, sustainability, or understanding global climate. My role was to verify which projects were eligible. And somewhere along my journey through these student fairs, I began to realize just how wrong Mr. Hogan was.

We are confronted with the simultaneous problems of understanding the impact our past choices for energy are having on the earth and at the same time of supplying energy resources for our growing world economies. What I realized is that this challenge will make 21st century science a most exciting and almost brand-new world for these students.

First of all, there is the science itself. Why is it so difficult for us to understand global warming?

To one person looking at the sky, the atmosphere seems unlimited, but we already know that it is not – we have sent rockets outside to the moon and beyond. We already know (since the 1700s) that burning things requires oxygen and produces something else. We may not know why CO2 traps heat, which is to say, that it absorbs longer wavelength light, but we have been told it enough times, and seen our children do enough greenhouse soda-bottle experiments to believe that it's true. (By the way, it's because carbon dioxide has three parts (atoms), with a carbon "holding hands" (via sharing of electrons) with an oxygen atom on each side; these electron "arms" can absorb lower grade energy to move (vibrate) — to flap their oxygens around the middle C. An oxygen (O_2) or nitrogen (N_2) molecule only has two parts — it is a "rod" that can only roll around or stretch and bend).

So why do so many of us have difficulty believing that all this burning of fossil fuels — essentially putting back in a few hundred years the carbon dioxide that photosynthesis spent a few hundred million years taking OUT of the atmosphere, creating the planet that we know and love — why do we have so much difficulty believing that it could be causing a problem??

I believe that the problem is the way we have been taught science — which is to say, in isolation. The need to evaluate climate change is instead forcing us to deal with the world as it is, in a way that we never had to before. It must be seen as a dynamic system, open with regard to energy flows (from the Sun) but closed from a materials standpoint. Inside this system are feedback loops with varying time constants, non-linear terms, all interacting with each other, producing the patterns within patterns that we call weather and climate.

We can no longer get away with the simpler tricks we played in the past. When we look at one piece of a system by itself, or cross out higher order terms, or keep our calculations down to three significant figures (or four or a hundred), we think that we have approximately the correct answer to three (or four or a hundred) significant figures. Now we are realizing that we might not get "approximately" the right answer, but a misleading — sometimes very misleading — answer; with small errors snow-balling into big differences. We cannot assume homogeneity in the system or simplify it in order to manage the calculations ("take a perfectly round chicken", the old physics joke goes); we have to deal with the loops and flows through the system; we cannot assign "constants" to interaction rates — the rate itself may be a function of other variables, of gradients, of context, of pre-existing conditions and saturation levels.

We have to understand in the most fundamental way, that stable is not static; that in fact stable is most likely dynamic; like a gyroscope — or even a bicycle. That introducing a rapid change in one variable in such a system can change everything, on time-scales that we can only get closer and closer to estimating. We cannot predict, we can only simulate; and as we discover new complexities, make new simulations that lead us to more refined (and more alarming) results.

And, most importantly, we have to realize, that *not* understanding the nature of dynamic systems is exactly what makes it so hard for us to appreciate the seriousness of the situation that we are in.

At the other end of the "spectrum", when you see these student projects, you realize that clean or sustainable energy is not just about new, more complicated science, or new, expensive, break-through technologies; it is also about old-fashioned curiosity and creativity. It is ushering in a new Age of Invention — a time for looking at what we have always done and asking why? Of taking what we already know, and asking what happens if we put the pieces together differently? Or think of things in a different way.

At these fairs, I saw genuine inventors, in their teens and pre-teens: A freshman from western MA, determined to find a substitute for the coal his father uses in his blacksmith's forge, and ending up with metallurgical-grade charcoal from sumac, a tree that grows so fast it is almost a weed . . .A team of two sophomores from Lexington wondering if the left-over energy from pumping a spinning wheel couldn't be used to run a lamp, and finding a way to do just that. . .Two seventh graders from different regions, both worried about clean water, and both building extremely simple, but working solar stills.

A team of two eighth-grade students from Amherst investigating the effect of temperature on microbial fuel cells. . . A seventh-grader wanting to see how much electricity an old-fashioned mill stream could generate, and building a working model from a spool, using plastic spoons as paddles.

And these students are not afraid of nonlinearities: a seventh-grader from Taunton wanted to know why "goop" (a non-Newtonian fluid) behaves the way it does; a middle-school team tested a more sophisticated version known as D30, which is generally soft and amorphous but crystallizes into a hard substance on impact; a student from Needham asked if the rate at which ice melts changes as it melts.

It was astonishing to see how much these students know that we don't; how able they are to look at things in new ways; how much they can understand with their still-open minds.

Often people say that we will find the answer in tomorrow's technology. What I learned from these young people is that there is no one answer: there are a thousand answers — and many of them are staring us in the face. More fascinating, these are mostly low-tech solutions; they are infrastructure-less, as Dean Kamen describes it, "on point" solutions that are as useful in a remote village in Bolivia as they might be in the sophisticated United States.

Congratulations to all of you, and thank you so much for what you taught me over the past three months.

My only hope is that these students manage to maintain this curiosity and concern for finding a better way. And that what they know filters out to the rest of us.

Mary Essary is Executive Director of The Foresight Project, and program director for IMAGINING TOMORROW: ALTERNATE ENERGY FUTURES. More information about the Massachusetts Clean Energy Award winners and their projects is available at www.ma.cleantechawards.org. .

