

## Delayed Substitution

The American now uses 2,500 times as much energy as he did two centuries ago, which means that, in terms of the common energy source of antiquity, he has some 60 slaves at his disposal.

—R.J. Forbes

*The Conquest of Nature: Technology and Its Consequences*

Here's a little problem to think about. Consider a pond in which lily pads are growing. The area covered by the plant doubles each day. For many days, the coverage is rather insignificant, and, even on the 29th day of growth, the coverage reaches only half of the pond. How long will it take for the lily to cover the entire pond? The answer, of course, is one more day, a simple consequence of exponential growth.

Although we routinely deal with exponential growth in our work as control engineers, there is still something shocking about the suddenness with which saturation is reached. The large open surface area remaining after 29 days, which misleads us into complacency, is completely obliterated in only a single day.

This anecdote is something I remember vividly from the 1972 book



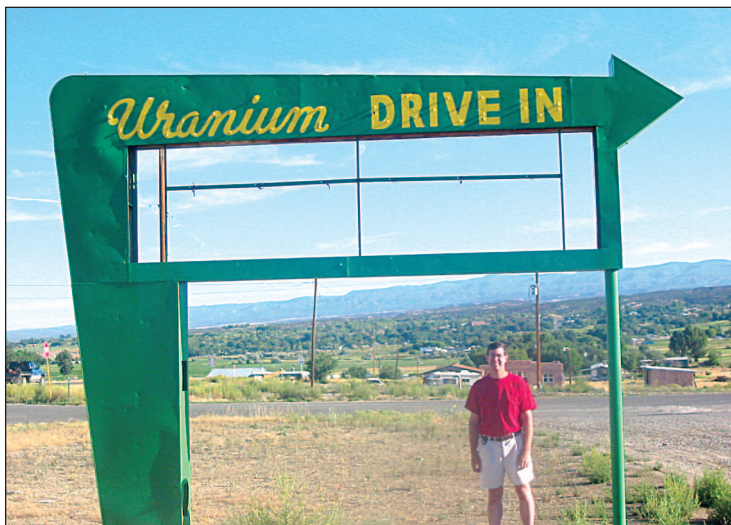
Editorial board meeting held during the 2005 American Control Conference in Portland, Oregon. From left to right are Carl Knospe, Jan Swevers, Takis Tsiotras, Hashem Ashrafiuon, Daniel Rivera, Pablo Iglesias, Zongli Lin, Dawn Tilbury, Sam Ge, and Kent Lundberg. Randy Beard and Tariq Samad also attended the meeting but were not present for the photo. Dennis Bernstein was the photographer.

*The Limits to Growth* by Meadows et al. A watershed in systems thinking, this book is a highly feedback-intensive study of the future of the global econ-

omy. The authors make various assumptions about the interactions among industry, population growth, natural resources, and many other quantities, and then, for various choices of parameter values, simulate the future. Much like the book *The Population Bomb* by Ehrlich, *Limits* provided a kind of warning alarm of the consequences of our accelerating use of natural resources.

An important issue discussed in *Limits* concerns the dynamics of the global enterprise when the limits to growth are reached—or even overshoot—as some believe has already occurred (see the book *Overshoot* by Catton). Much of economics is based on the substitution principle, that is, as

Dennis Bernstein, posing under a relic from the past in Nucla, Colorado, near Uravan, Colorado. “Uravan” is derived from uranium + vanadium, where these elements were extensively mined from 1936 to 1984.



JASON BERNSTEIN

one commodity becomes scarce and expensive, consumers switch to more plentiful and less expensive alternatives. The concern is whether the global economy will reach a sustainable equilibrium rather than experience disastrous collapse.

As a control engineer, I fully accept the idea that humans make rational decisions that reflect supply and demand, a natural consequence of negative feedback. As oil prices rise due to shortages or political instability, individuals, governments, and industry will switch to or invest in more energy-efficient technologies. Those who drive fuel-hungry vehicles will either drive less to cut fuel costs or spend more on fuel and less on other needs and luxuries. Because they're in business to make money, vehicle manufacturers will retool or go out of business, replaced by more nimble or far-sighted firms.

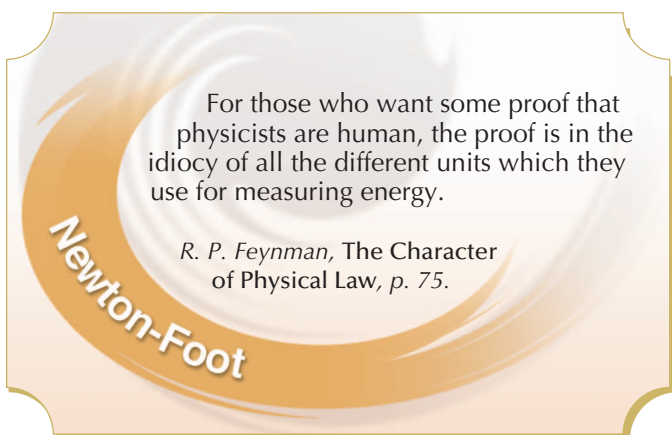
The principle of substitution works when alternatives exist or can be developed quickly but fails when alternatives do not exist. To facilitate smooth substitution, governments use funds from today's economy (taxes) or borrowed against future revenues (deficits) to develop energy sources for the future. Ongoing government-funded research (however limited) on wind, solar, and fusion power are examples of such investments. However, governments also delay substitution and suppress alternative technologies by subsidizing existing technologies in hidden forms such as nuclear waste disposal and, as many people believe, military ventures to ensure access to oil supplies.

The recent increase in the price of oil may be a blessing in disguise. By forcing energy consumers to seek alternative technologies, higher

prices provide an opportunity for innovators to develop alternative technologies while there is still time—and financial resources—to do so. To the extent that energy production and energy conservation depend on control engineering, we can all expect to be progressively busier as the global economy transitions along the substitution curve. But opportunities for technological innovation are not a sure thing. If our economy hits a brick wall, there won't be much funding for the needed development. By then it will be too late.



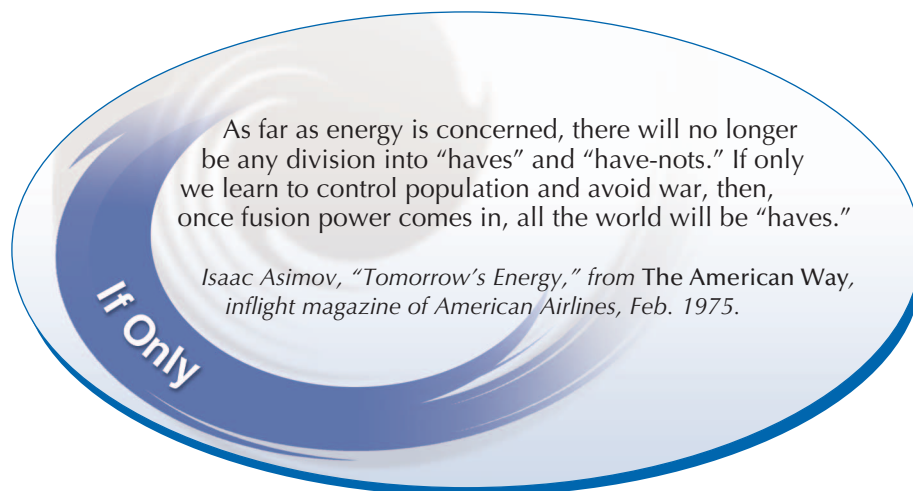
**Dennis S. Bernstein**  
*Editor-in-Chief*  
*IEEE Control Systems Magazine*



For those who want some proof that physicists are human, the proof is in the idiocy of all the different units which they use for measuring energy.

*R. P. Feynman, The Character of Physical Law, p. 75.*

**Newton-Foot**



As far as energy is concerned, there will no longer be any division into "haves" and "have-nots." If only we learn to control population and avoid war, then, once fusion power comes in, all the world will be "haves."

*Isaac Asimov, "Tomorrow's Energy," from The American Way, inflight magazine of American Airlines, Feb. 1975.*

**If Only**