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“Knowledge, Science, and Technology – or, Energy, Energy, and Energy”

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Abstract

Regarding the roles of my assigned topics of knowledge, science, and technology in the future of Planet Earth, I suggest that the three most critical challenges now facing civilization on Planet Earth are energy, energy, and energy:

- *Knowledgeable* understanding of past *energy*-driven changes that have literally created Earth and life on Earth
- *Scientific* recognition of the importance yet limitation of *energy* use in Earth’s biosphere and in our global society today
- *Technological* advancement needed to provide for our descendants’ future *energy* needs on and beyond Earth.

Energy ... its wise usage is ... likely to be the single greatest factor by which humankind can manage, indeed enhance, its future well-being.

Introduction

It is often said that a most effective way for people to better both their present condition as well as their future well-being is to acquire real estate – in which case, the marketing phrase often heard is “location, location, location.” Whether in downtown Manhattan, the Rocky Mountains, or the African bush, embracing a localized bit of our planet is a reasonably good way to improve the lives of individual humans. I regard nothing wrong with “buying a piece” of our planet – literally owning a part of the rock called Earth, however small, in that way perhaps feeling more responsible for our home in space.

Likewise, a most effective way to improve civilization’s condition and future on Earth is to acquire an understanding of the events that caused our emergence, maintain us now, and will likely enhance our future – a kind of intellectual real estate that might be summed up with a parallel, emphatic phrase: “energy, energy, energy.” Energy is not only the most common currency in all of natural science and the driving force for much of modern society; its wise usage is also likely to be the single greatest factor by which humankind can manage, indeed enhance, its future well-being.

Whether galaxies, stars, planets, or life forms, it is energy more than anything else that keeps open, non-equilibrium systems functioning ...

Role of Knowledge in Managing Earth’s Future

The scientific story that led from big bang to humankind is basically one of constant change, flowing energy, and rising complexity. Knowing how energy, in particular, helped create Earth in the past, as well as how it maintains all life on Earth presently, helps us understand energy’s vital role in our civilization’s future. To be sure, today’s civilization runs on energy for the simple reason that all ordered, complex systems need energy to survive and prosper. We are not *apart from* the biosphere; we are *a part of* the biosphere. UNESCO’s program MAB – Man and the

Biosphere – should be renamed "Men and Women in the Biosphere."

Whether galaxies, stars, planets, or life forms, it is energy more than anything else that keeps open, non-equilibrium systems functioning – to help them, at least locally and temporarily, to avoid a disordered state (of high entropy) demanded by the 2nd law of thermodynamics. Whether living or non-living, dynamical systems need flows of energy to endure. If stars do not convert gravitational matter into heat and light, they would collapse; if plants do not photosynthesize sunlight, they would shrivel and decay; if humans do not eat, we too would die. Likewise, society's fuel is energy: Resources come in and wastes go out; all the while civilization goes about its daily business.

Throughout the history of the Universe, as each type of ordered system became more complex, its normalized energy budget increased. Expressed as an energy rate density [Watts/kilogram], a clear ranking in energy usage is apparent among all known ordered structures that have experienced, in turn, physical, biological, and cultural evolution [Chaisson, 2001]:

- stars and planets have small energy rate densities (10^{-4} -10^{-2} W/kg)
- plants and animals have larger energy rate densities (0.1-10 W/kg)
- humans and societies have the largest known energy rate densities (~10^2 W/kg).

Of specific relevance to this meeting's topic of Earth's future is the rise of energy use within the relatively recent past among our hominid ancestors, continuing on to today's digital society and presumably into the future as well [Simmons, 1996; Christian, 2003]:

- hunter-gatherers of a few million years ago used ~1 W/kg (0.05 kW/person)
- agriculturists of several thousand years ago used ~10 W/kg (0.5 kW/person)
- industrialists of a couple of centuries ago used ~50 W/kg (2.5 kW/person)
- citizens of the world today, on average, now use ~50 W/kg (2.5 kW/person)
- residents of the affluent United States now use ~250 W/kg (12.5 kW/person).

Such energy *rate* values have clearly increased over the course of recorded and pre-recorded history. The cause of this recent rise is not population growth; these are per capita power densities caused by the cultural evolution and technological advancement of our civilization.

... energy needs to be at the center of policy decisions regarding future of Earth and life on Earth.

Implications of Advancing Science and Technology

Energy – especially the flow of it in and out of systems – is at the heart of Earth's biosphere, and within it our civilization. Here are some of the noble objectives that we all aspire to achieve in future years, all of them energy-intensive:

- clean environment
- drinkable water
- enough food
- better health
- eradication of poverty
- security of nations
- enhanced cyberspace

Each of these, to be sure, is a socio-political issue, but their solutions share the same common denominator: increased energy use. And because their solutions are indeed partly political, energy needs to be at the center of policy decisions regarding future of Earth and life on Earth.

Some argue that what is needed now is technological innovation – startling changes like those that did better our lives during the past century, such as: antibiotics that perhaps made the biggest advance in human welfare; telecommunications that "shrank the world," from radio to the Internet; and air travel that made us genuine global inhabitants, eventually enabling us to view our world from space.

Yet, future technological innovation in the context of a globalized world will also require increasing amounts of energy. Energy is not only a big science concept, but it is also at the core of most technologies. And some technologies, and our seemingly incessant need to invent new technologies, worry me.

Until a couple of hundred years ago, technology was invention-based; talented and wealthy tinkerers used their intuition to invent, by trial and error, new gadgets that were then handed down to the next generation. With the flowering of the Industrial Revolution in the mid-19th century, technology became more science-driven; knowledge of the underlying science kindled inventions, which were then patented and sold to the next generation. Now, new technologies still stem from basic science, but those same technologies often act as tools to discover new science – and the result is a rapid acceleration in the pace of our technological society that engulfs us.

The pace of change today is almost frightening – and I say this as a scientist who uses much of the latest technology daily. Think back to when you began using email or surfing the World Wide Web. I recall first using email in 1990 at the Kennedy Space Center, when we were trying to get the Hubble telescope launched; and my first use of the Web was in the mid-1990s, when I was transforming my annual course at Harvard into a multi-media format. That's hardly more than a decade ago, yet now look around and note how much of our daily lives are absolutely orchestrated by the digital revolution. Technological change is indeed accelerating, and I'm worried that we are becoming overly dependent upon it.

Not all technological advancement is necessarily positive. This past winter, we had a great deal of snow in Boston and I noticed that everyone in my neighborhood was using an energy-powered snow blower to get rid of it – while I was using a shovel. I noticed much the same thing last fall when the leaves fell from the trees; I was the only one using a rake to rake those leaves, while everyone else was using powered leaf blowers. I live in Concord, Massachusetts, where Henry David Thoreau arguably founded the environmental movement in America, yet, sadly, my neighbors don't always act accordingly. They subscribe to environmental newsletters, abhor global warming, and act so well informed about the need for cleaner air, yet they routinely pollute the neighborhood with gases and noise. If this happens in an environmentally sensitive town, how can we hope to use technology intelligently elsewhere?

Recall the Maya, one of the most sophisticated civilizations that once peopled our planet. They had a sophisticated social state, naked-eye observatories to scan the sky, and calendars more advanced than the Spaniards who conquered them. But they hardly ever used the wheel or metal. While it is true that their children's toys had wheels, and their ornaments and trinkets were partly made of metal, they never scaled up the use of either to become useful in any utilitarian sense. Even their wonderful pottery used no potter's wheel; instead, the potter walked around the pot while creating it. Why could not the Maya realize that both the wheel and metal would have advanced their technologies (especially in hindsight knowing that the Spaniards used both in the form of rolling cannons)? Or were the Maya so wise that they knowingly rejected technology?

What constitutes too much future technology? Are we becoming increasingly vulnerable from an overdependence on technology?

What constitutes too much future technology? Are we becoming increasingly vulnerable from an overdependence on technology? Take but one example: active versus passive solar energy generation – a topic for which I am sometimes considered a heretic, for why would any astrophysicist question space-based solar power? The bottom line is that passive collection of solar energy with panels on Earth's surface, as opposed to solar energy actively captured in space and beamed to Earth, will enable the indefinite powering of civilization without additional heating of the biosphere.

This month, I authored the feature article in one of the American Geophysical Union's journals [Chaisson, 2008] – an article on "global waste heat" that derived from a study that I did last year for an earlier Foundation For the Future meeting in Seattle [Chaisson, 2007]. Basically, this peer-reviewed paper argues that, independent of any greenhouse gases, humanity's continued use of nonrenewable energy alone will eventually cause our biosphere to heat owing solely to the 2nd law of thermodynamics. Well within a thousand years, Earth will inevitably heat (by 3°C) unless:

- human population declines, which is unlikely
- per-capita energy use declines, which is even less likely
- passive solar energy powers our future civilization.

Three referees urged publication of my paper immediately, saying it was "correct," "important," and even "fascinating." But because the energy-induced heating will not likely occur for centuries, a fourth referee repeatedly tried to block publication of the paper, asserting that it was "irrelevant and distracting" to the greenhouse problem now confronting us. This last referee clearly had no interest in humankind's long-term sustainability, no inclination to see the expansive forest beyond the trees.

Space-based collection and beaming of solar power to Earth's surface is a vulnerable, centralized, and potentially dangerous energy system; by contrast, passive solar is resilient, decentralized, and arguably safer. Is space-based solar power the scaled-up analog of snow- or leaf-blowers? Could it be a startlingly new form of over-reliance on technology, a kind of technological overkill – some say, literally, given its many potentially unhealthy and environmental tradeoffs?

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I shall say this, for sure: Any intelligent civilization on any planet in the Universe will eventually have to adopt its own parent star as its principal source of energy. Why not stop raping our planet of its natural resources and move straightaway toward advancing technology smartly – by adopting passive solar energy as the next big technological challenge for the world as a whole, indeed one that will enable people of all countries to wean ourselves from all nonrenewable energies in the coming decades? Passive solar energy may be the single most important action that civilization can now undertake to leave our children a better planet. If we don't, the plants, which mastered the use of passive solar energy a long time in the past, will likely inherit the Earth for a long time in the future.

Reluctance to teach science well, or much at all, is at the heart of the issue we face going forward.

Educational Systems to Ensure Earth's Sustainability

The central issue for civilization on Earth today is sustainable development – not merely into the next generation or two, but in keeping with the millennial outlook of the Foundation For the Future: "The Foundation has chosen the thousand-year horizon because ... now more than ever humans must stretch their thinking to consider the long-term ramifications of the human impact on the livability of Earth," according to Deputy Director Sesh Velamoor.

All countries, individually and collectively, must learn to continue raising the quality of life without wrecking the planet. But how to do that? We can blame the politicians, the media, and maybe the economists, claiming that they don't understand today's technological society. But they are easy targets and only part of the problem. Another part of the problem is ourselves: the scientists, the technologists, the sci/tech policymakers. We are, at least as much as any other segment of society, to blame for the poor technical literacy that is essential to sustain the world today.

Reluctance by colleagues to work in interdisciplinary ways – in integrated research groups while considering large domains of space and long durations of time – is likely to be a concern for the Foundation as a foundation for the future. Although *interdisciplinarity* has become a buzz word in academic circles, most colleagues, indeed most co-workers in science, technology, and education, are unable or unwilling to embrace big thinking – problem solving outside the intellectual comfort zone of their specialized disciplines or beyond the temporal perspective of their own generation and perhaps that of their children.

Reluctance by colleagues especially to embrace long-term views – the big picture – is another problem affecting the Foundation's stated goals and objectives. Hundreds of years into the future, let alone the thousand years stipulated in the Foundation's mission statement, do not come naturally or easily or willingly to most people. Nor do commercial or academic or many other professions value or promote it. As E.O. Wilson once exclaimed with increasing fervor while walking through Harvard Square, " … we need to do more than *tolerate* big thinking; we need to embrace it, to honor it!"

Reluctance to teach science well, or much at all, is at the heart of the issue we face going forward. The culture of science is poorly welcoming toward disseminating, sharing, and communicating – at least regarding nonscientists. I once gave a talk before the National Academy of Sciences in Washington, where I argued that, unless we better science literacy from grade school to grad school, the public funding for science might end – if only because the public no longer understands or cares what we do. And the result might be something resembling a scienceless society, wherein knowledge for the sake of knowledge, science for the sake of science, beauty for the sake of beauty would enter eclipse, perhaps a bit like the Middle Ages when learning was largely devalued.

The mission of the Foundation For the Future includes the phrase, "diffusion of knowledge concerning the future of humanity," and the "E" in UNESCO stands for education. One of the most important contributions these two organizations can make to future generations is to recognize that children are synonymous with the future. Whenever and wherever, children not only represent the next generation but also symbolize generations to come. Yet it is impossible to teach during students' formal school years all the science we want them to know and all the science they need to know. Instead, a more urgent issue in education is to set students on paths toward lifelong learning. Societal-based, lifelong education is central to knowing how we, as indeed men and women in the biosphere, can sustain our planet for all humankind.

> ***… my personal mantra: Change is constant, time is irreversible, energy is ubiquitous, adaptation is essential.***

Summary

The future of Earth? As an astrophysicist, I can guarantee that future prospects for our planet, as a geological rock, are very good. Habitable Earth will continue orbiting the Sun for a good long time to come – our planet will not naturally heat to hellish temperatures for at least a billion years, or a million times longer than the Foundation's mandate of a thousand years. Humankind's ability to develop, sustain, and prosper in the meantime will likely depend largely on our efficient, effective, and ethical use of the same kind of energy that was most responsible for the emergence of both our planet and its life-forms billions of years ago – solar energy.

In sum, regarding my assigned topics of knowledge, science, and technology:

- Energy – specifically, the flow of energy per unit mass – is the single most unifying process that gave rise to increasing complexity over billions of years, thus helping to produce galaxies, stars, planets, and life.
- Energy – especially the rate of energy density usage, or per capita power consumption – is what maintains, indeed drives, our civilization today more than any other dynamic factor.
- Energy – again, the use of it per unit time and per unit mass – is a key technological and sociological issue around which to plan a better Earth for future generations, not merely within the next hundred years but also within the next thousand years.

Time is our companion, and change is our story. Or, as in my personal mantra: *Change is constant, time is irreversible, energy is ubiquitous, adaptation is essential.*

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