Long-Term Global Heating From Energy Usage

Even if civilization on Earth stops polluting the biosphere with greenhouse gases, humanity could eventually be awash in too much heat, namely, the dissipated heat by-product generated by any nonrenewable energy source. Apart from the Sun’s natural aging—which causes a approximately 1% luminosity rise for each 100 years and thus almost 3°C between 1000 and 4000 years—a total energy budget of society on Earth will likely continue growing for three reasons. First, world population is projected to increase until at least the late 21st century, when it might level off at approximately 9 billion people [United Nations Department of Economic and Social Affairs, 2006]. Second, developing countries will mature economically, perhaps for the next several centuries, until equity is achieved within the world community of nations. And third, the per capita energy rate will probably continue rising for as long as the human species culturally evolves, including conditioning our living spaces, relocating cities, pushing up rising seas, and sequestering increased greenhouse gases—which implies that even if the first two reasons grow weak, the third will continue increasing society’s total energy budget, however slowly.

Heat By-Products

Current fears of energy shortfalls aside, in the long term our true energy predicament is that the unmitigating and increasing use of energy from any resource and by any technique eventually dissipates as heat at various temperatures. Heat is an unsalvageable by-product of the energy extracted from wood, coal, oil, gas, atoms, and any other nonrenewable source. The renewable sources, especially solar, already heat Earth naturally, but additional solar energy, if beamed to the surface, also would further heat up our planet.

Regardless of the kind of energy utilized, Earth is essentially a large collection of heat exchangers that we industrialize by our societal activities. We already experience it in the big cities, which are warmest due to their size, height, and nuclear reactors, which warm their adjacent waterways. A study of the town of Tokai, for example, found that city streets are about 2°C warmer when air conditioning units are not only suck hot air out of offices but also dissipate heat from the back of those inefficient machines [Okauchi et al., 2007]. Everyday appliances—including toaster, boilers, and lawn mowers—all generate heat while operating far from the theoretical efficiency limits. Electric production is currently around 37% efficient, automobile engines are roughly 25% efficient, and ordinary incandescent light bulbs are only around 5% efficient; the rest is immediately lost.

Even every Internet search creates heat at the Web server, and each click of the keyboard engenders heat in our laptops. Information data processing of mere bits and bytes causes a minimal rise in environmental temperature (owing to flip-flop logic gates) but much colder discussion of bits and information (individual’s attempt to gather, read, and analyze). The information has already been gathered and even further higher energy use, namely, be threatened by self-immolation. Such widespread inefficiencies would seem to present major opportunities for improved energy conversion and storage. But there are limits to advancement. No device will ever be perfectly efficient, given friction, wear, and corrosion that inevitably create losses. Conversion and storage devices that are 100% efficient are rare and ideal—and they violate the laws of real-world thermodynamics. Just like perpetual-motion machines, they cannot exist. To give but one example of less than ideal devices, today’s photovoltaics currently achieve 10%-20% efficiency, and when optimized they might soon reach 40%, yet the absolute theoretical (ideal) limit for any conceivable solar device is approximately 70%. Even with improved efficiencies, per capita and therefore societal demands for energy have continued to rise—and, in any case, all nonrenewable energy used must be eventually dissipated by our planet.

As we increasingly pollute the air with heat, adverse climate change could conceivably occur even in the absence of additional greenhouse gases. How much energy can all of our cultural devices—automobiles, stoves, factories, whatever—produce before Earth’s surface temperature increases enough to make our planet potentially hostilely uninhabitable?

Global Temperature

The equilibrium temperature T at Earth’s surface is reached when energy acquired on the dayside equals energy radiated away isotropically as a black body:

$$\frac{4}{3}kT^4 = \sigma \varepsilon r^4 T^4 + \sigma (\varepsilon^4 + 4\varepsilon^2)$$

where k is the solar constant at Earth (370 watts per square meter), r is the distance from the Sun (in astronomical units), A is Earth’s albedo (0.31), k is Earth’s radius, ε is the effective surface emissivity (0.61), and (ε^4 + 4ε^2) is Stefan’s constant. The result, including effects of natural greenhouse heating, is 288 Kelvin, or a globally averaged temperature for Earth’s surface of 15°C. This is the surface temperature value that has risen during the twentieth century by around 0.5°C [Intergovernmental Panel on Climate Change, 2007]. Albedo changes are now and will likely continue to be negligible globally.

Nature’s power budget on Earth is dominated by the Sun. Compared with our planet’s solar insolation of 120,000 terawatts (absorbed by the land, sea, air, and accounting for Earth’s albedo of 31%), our global civilization currently produces an imperceptible approximately18 terawatts, about two thirds of which is wasted. But with humanity’s power usage on the rise c-25% annually [International Energy Agency, 2004] as our species multiplies and becomes more complex, society’s energy demands by the close of the 21st century will likely exceed 100 terawatts—and much of that energy will heat our environment.

Note that utilizing solar energy that naturally affects Earth (including solar-driven tides, wind, and waves), without generating any further energy via nonrenewable supplies, would not cause additional heat. But if we do generate heat from other, nonrenewable energy sources, in addition to the Sun’s rays arriving daily—or if we use space-based arrays to redirect additional sunlight to Earth that would normally bypass our planet—then the surface temperature will rise. That is, even if we embrace coal and sequester its carbon emissions, or use nuclear methods (either fission or fusion) that emit no greenhouse gases, these energy sources would still swap additional heat above what the Sun’s rays create naturally at Earth’s surface.

Heating Scenarios

Estimates of how much heat and how quickly that heat will rise rely, once again, on thermodynamics. Because flux scales as T^4, Earth’s surface temperature will rise about 3°C (an IPCC “sipping point”) when (283K) a 21°C is surpassed, namely, about 4% more than the current (25°C) daily average (289°C) is additionally produced on Earth or delivered to Earth. Such estimates of energy usage sufficient to cause temperature increases are likely upper limits, and hence the times needed to achieve them are also upper limits, given natural greenhouse trapping and cloud feedbacks of the added heat. How fast in the future, if ever, such heating might occur depends on assumptions [Chaison, 2007].

If a global nonrenewable energy use con tinues increasing at its current rate of about 2% annually and if all greenhouse gases are sequestered, then a 3°C rise will still occur in roughly 8 doubling times, or about 280 years (or ~350 years for a 10°C rise).
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More realistically, if world population continues to grow without abatement by 2050, developed (Organisation for Economic Cooperation and Development, or OECD) countries increase more than twice the total amount of energy used at 1% annually, and developing (non-OECD) countries do so at roughly 5% annually until east-west energy equity is achieved in the mid-21st century after, which they too will continue generating more energy at 1% annually, then a 3°C rise will occur in about 320 years for 1°C in ~50 years, even if carbon dioxide emissions end.

If around 4% additional solar energy is beamed to Earth, the surface temperature would quickly rise 3°C (or ~10°C for an additional 14% solar energy beamed to Earth). Even ascending that the above assumptions can only be approximate, the heating consequences of energy use by any means seem unavoidable within the next millennium—a period not overly long and within a timeframe of real relevance to humankind.

More than any other single quantity, energy has fostered the changes that brought forth life, intelligence, and civilization. Energy also now sustains society and drives our economy, indeed our species until health, wealth, and security. Yet the very same energy processes that have enhanced growth also limit future growth, thereby constraining solutions to global warming. Lesser use, sometime in the relatively near future, seems vital for our continued well-being, test Earth simply overall.

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Riverine Flow and Lake Level Variability in Southern South America
Considerable attention was directed during the 1930s to the remote connection that appeared to exist between the Southern Oscillation (SO) and anomalous rainfall over southern Brazil, Paraguay, and northern Argentina [Mannson, 1924]. It was Gilbert Thomas Walker’s group, then in India seeking the prediction of monsoon dynamics, that made the observation—seen with skepticism—that high volumes of flow along the Paraná River, as measured at the downstream Rosario (Paraná) gauging station, tended to occur during the negative phase of the SO, when surface level pressure (SLP) was anomalously high around Australia [Röss, 1928]. Such high surface level pressures, when associated with unusual low pressure along South America’s coast, tended to cause drying in regions bordering the equatorial Pacific Ocean and heavy rainfall in other parts of the Americas and the world.

The idea of such a large-scale link in weather patterns subsided somewhat during the following decades until Røeders [1966] and others established the now widely known link between the SO and El Niño events (ENSO). Man has expanded our knowledge on such processes, particularly since the early 1980s, when one of the strongest ENSO events ever occurred in the equatorial Pacific Ocean region.

In this brief report we review the present hydrological knowledge over South America in view of the current understanding of climate change. In particular, what are the hydrological trends and discernible connections with the El Niño/Southern Oscillation (ENSO) relationships in the most recent events, like ENSO, over southern South America?

Riverine Flow and Lake Level

Climate Features Over Southern South America
A monsoon-like system affects the atmospheric circulation over the Rio de la Plata drainage basin (see figure 1, region A), whose major feature is the South Atlantic Convergence Zone (SACZ) [Carvalho et al., 2004], which normally runs along the basin’s northeastern boundary (between about 20°S and 25°S). Also important in the regional climatic pattern is the southeasterly low-level jet that transports moisture along the corridor between the Andes and the Brazilian plateau. This corridor’s southeastern border is the transitional “and diagonal” (dashed line in figure 2, south of which westerlies control the atmospheric circulation.

The main result of the transition is that an austral summertime rainfall regime prevails northeast of the diagonal. However, in the area of the

Riverine Flow

Riverine Flow (continued on next page)