PERGAMON

International Journal of Hydrogen Energy 25 (2000) 603–604

International Journal of HYDROGEN ENERGY

Afternoon on a hillside

In which, reminded that hydroelectric stations don't consume water, we realize Earth doesn't consume energy. So we embark on a quest for what Earth does consume — and for its significance.

Late summer afternoon. I'm sitting on a nurse-log in an old-growth forest. The log lies across a granite outcrop that lifts it above the surrounding trees allowing me to see down into the valley. Relaxing, gazing, mindlessly breaking off pieces of bark, I watch a river course through the valley on its way to the Pacific. The river widens as it flows into a lake created by a dam. Below the dam, the water runs through the machinery of a hydroelectric generating station and then out into the lower valley, whence it travels around a bend, vanishing behind hills, seeking the ocean. Electricity lines march away from the generating station toward distant towns and farms, delivering power to lightbulbs, laptops, and milking machines.

It's an afternoon for reflection. The hydroelectric station *extracts* from water flowing through its machinery. But it does not consume water. Easy enough to understand. When upstream of the dam, the water had more gravitational potential energy than it had when leaving the station's tailrace. The turbines extracted most of this energy difference, scraped it out from the water passing through their innards, sent it away as electricity.

I smile at something fundamental. The hydroelectric station *does not consume water*. Rather, it *extracts energy* from the water that flows through its machinery.

To the east the moon, a few days before being full, floats above the mountains, ephemeral against a dimming sky. From the reality of my nurse-log the sight carries me into fantasy. I am lying back comfortably, weightless, in a space capsule drifting somewhere between Earth and its moon, gazing back at our planet. Through the viewing port I watch sunlight stream towards Earth. It is carrying inbound energy at the rate of some 180,000 terawatt (TW)[1] — of which about 58,000 TW is immediately reflected, bounced away to the depths of space. The remaining inbound energy, roughly 122,000 TW, is absorbed within the Earth's material.

After entering the Earth's material this 122,000 TW courses its way through the intricacies of Earth's machinery, where it powers things like tomatoes growing, oceans circulating, termites wiggling. As it moves through Earth's machinery, the energy often changes form, from electromagnetic to kinetic, to potential, to chemical, and back and forth again — an energy chameleon. Yet the stunning thing is that in spite of this twisting, transforming route through the Earth's bits and pieces, the energy always ends at the same place and in much the same form as it came, because ultimately, *all* this energy is exported to the universe as infrared radiation. So the 122,000 TW that the sun continuously delivers to Earth is matched by an equivalent 122,000 TW that Earth continuously sends back to the universe. Earth has an import–export trade balance in energy.

It may seem eerie that the rate of energy entering and leaving Earth is the same. But it is. Must be, or Earth

[1] The prefix, tera-, means 10^{12}. So a terawatt is 10^{12} W, the energy needed to feed 10,000,000,000 (ten trillion) hundred-watt lightbulbs. If you like to dream about being rich, you can use the prefix tera- to assure you dream large. Dream of having terabucks — or terayen, teramarks, or terapesos — in your bank account. Using this rather uncommon terminology, as we begin the 21st century, the world's gross economic product is about 40 terabucks — which is about 40 trillion US$. For whatever its significance — I believe its not much — this means that, today, our planet receives about 6 kW of sunlight for every US$ of GWP that civilization produces.

PII: S0360-3199(99)00091-9

would heat up if more energy came in than went out, or cool down if more went out than came in.[2] Its a bit like double-entry bookkeeping when, after incomes and expenditures are summed, the bottom line is zero.

Struck by the parallels between water flowing through the generating station and energy flowing through Earth, I recognize something else that is fundamental: Earth *does not consume energy*. Rather, it *extracts something-of-value* from the energy that flows through its machinery.

In the next few articles we embark on an odyssey to find that something-of-value. We must find what it *is*, how we get it, why we need it, how we distribute and use it. To engineers that something-of-value goes by many names like "structure", "information" or "negentropy" and perhaps best of all, "exergy". None of these can be understood without the concept of "entropy". Expect adventures along the way — like thinking about the laws of classical physics, what it means to be an engineer, and why we really mean exergy when we speak of energy. And like any odyssey worth its salt, parts of the journey will not be easy. Because acquiring a good feel for entropy and its siblings is not easy — and, for me, not easy to make easy.

Still, if you want to think more about what people *really* buy when they buy energy services — because they do not buy energy nor do they consume it — come along with me for the next few articles. The ideas we uncover can be useful for strengthening business planning or national policy — and they are certainly useful for industrial-process optimization. Astonishingly, these *same* ideas tell us something profound about what it means to be alive, hint at why we might like music, or food exquisitely set out on a dinner plate, or (as an engineer, dare I suggest) how we might distinguish good art from nonsense.

Indeed, our afternoon on a hillside can bring a wagonload of fodder for dreamers.

This is the tenth in a series of articles by

David Sanborn Scott
Institute for Integrated Energy Systems,
University of Victoria,
Victoria, BC, Canada, V8W 2Y2
E-mail address: dsscott@iesvic.uvic.ca

[2] Some people might ask, "What about energy contributed from geothermal or tidal sources or other things?" It turns out that all non-solar-sourced energy flows are trivial compared to solar-sourced flows. Much the largest of these non-solar sources is geothermal, and the magnitude of geothermal sourced energy flow is about two ten-thousandths the magnitude of solar-sourced energy flow. Tidal energy is trivial even compared to geothermal. Still, it you want to be precise, to account for geothermal and tidal contributions, the energy *leaving* Earth as infrared radiation must be a teensy bit larger than the energy *entering* Earth as sunlight — *and* starlight if you're picky about the "little bits". (After all that, you might ask: OK, but why is he saying "solar-sourced", rather than simply "solar"? Answer: Because there are all kinds of energy flows like wind or biomass — and, indeed, coal — that *are* solar-sourced but which we would not describe as solar.)