Engineering & Science welcomes letters. Send correspondence to Douglas L. Smith, editor, *E&S* magazine, Caltech mail code 1-71, Pasadena, CA 91125, or email dsmith@caltech.edu. We reserve the right to edit any letters selected for publication for length, content, and clarity.

LETTERS

SUNLIGHT IN YOUR TANK

First a general comment: the Fall 2009 issue of *E&S* seems meatier than usual. Thank you.

While the science from Professor Sossina Haile's group is interesting, isn't the pursuit of chemical fuels from sunlight for use in internal combustion (or even gas-fired turbine) engines a bit of a futile exercise if the energy conversion in the engine is only 25%? 25% × 25% = 6% overall (sunlight to fuel × fuel to mechanical). Photovoltaic and electric motors seem to do better at 13% × 80% = 10% (sunlight to electrical × electrical to mechanical). Even if one adds storage, for example 70% for pumped hydroelectric, the final result is 7% versus 6%.

Vertically migrating zooplankton would seem to contribute to vertical transport of energy in at least two other ways—the current needed to maintain position in the water column if they are not neutrally buoyant, and the transfer of heat when they descend from warmer surface waters coupled with the "heat deficit" when they return to the surface after spending time at depth.

Phelps Freeborn [BS '65]

▪ ▪ ▪

In his letter to *E&S* in the Winter 2010 issue, Frank Weigert (PhD '68) comments on the brilliant research reported in the previous issue that gives some hope of finding a solution for CO_2 recycling.

He noted that the process requires high temperature from a solar power tower to strip the catalyst of its oxygen, then using the catalyst to strip oxygen out of a mixture of steam and CO_2 to produce mixture of H_2 and CO known as syngas.

The syngas can then be used as feed stock for a Fisher-Tropsch unit to produce usable fuels.

Weigert quite rightly makes the point that solar power towers and FT processes, as they're known today, are not cheap and cannot compete with oil and gas production.

He forgets that science and engineering never stands still, as proven all the time in *E&S* magazine.

I can't comment on the future cost of solar tower power, but I can on FT processes.

The Oxford Catalysts Group and its subsidiary, Velocys Inc., has invented a microchannel reactor and a hyperactive FT catalyst. The two of them together outperform the best in class fixed-bed reactor by a factor of 15.

This opens the possibility of economic applications of small-scale gas-to-liquid or waste-to-liquid. One demonstration unit is being installed in Güssing, Austria, to test a feedstock from a wood-chip gasifier, and in Brazil to test its potential to avoid gas flaring in offshore production.

In other words, science never stands still, and every avenue to stop or to recycle CO_2 should be investigated with an open mind.

Pierre Jungels [PhD '73]

THE ARROW OF TIME

Sean Carroll, in his interesting article, "The Arrow of Time," says that "effects always follow causes. It turns out that *all* (emphasis in the original) of these phenomena can be traced back to the second law [of thermodynamics]." I am a big fan of entropy—I've even written poems about it—however, there are examples of effects following causes that are unrelated to changes in entropy.

Consider the following closed system. One atom of carbon-13 is in its first excited state and stationary in the rest frame of the observer, and another atom of carbon-13 is in its ground state and moving with respect to the observer along a vector directly toward the first atom, and at a speed equal to the recoil speed that the first atom will have as it makes a radiative transition to the ground state. Assume further that the photon emitted by the first atom is directed at the second atom and is absorbed, putting the second atom in its first excited state.

Causality requires that the absorption of the photon occurs at a later time than the emission of the photon. This is certainly true in the observer's rest frame, and according to Einstein, it will be true in all frames. Please correct me if I'm wrong about that. The final state is not the same as the initial state, but it is essentially the same as a time-reversal of the initial state, so it will have the same entropy. I do not think that quantum mechanical uncertainties—line width of the ground and excited states, the fact that the atoms' positions and velocities have uncertainties, and that the photon energy is also somewhat uncertain, since it has a finite lifetime—will change the conclusion. (Again, please correct me if I'm wrong).

Not only must the final state occur at a later time than the initial state, there is the intermediate state—consisting of two atoms, both in the ground state, and a photon—which must occur after the initial state and before the final state, and which will have the same entropy.

Bill Tivol [BS '62]

▪ ▪ ▪

The article in the Winter 2010 issue of *E&S* entitled "The Arrow of Time" had some interesting information, but neglected to mention two very important applications of the second law of thermodynamics in understanding today's crisis in energy and mineral resources.

Any machine produces work (mechanical energy) by transferring heat (thermal energy) from a high-temperature reservoir, usually some sort of energy-consuming heat source, to a low-temperature reservoir, or heat sink; the second law of thermodynamics gives the maximum efficiency of this process as $(T_{hi} - T_{lo})/T_{hi}$, where T_{hi} is the temperature of the heat source and T_{lo} is the temperature of the heat sink. In order to achieve an efficiency of one (the holy grail of all perpetual motion machines), the engine would have to exhaust into a reservoir having a temperature of absolute zero.

Naive optimists viewing the ever-increasing cost of mineral resources, particularly fossil fuels, are fond of saying that "we can always find more by digging deeper." Unfortunately, the second law of thermodynamics tells us that our exploitation of the limited number of highly concentrated mineral resources has resulted in a vast increase in entropy as these resources are chemically transformed and/or spread around the world. This is a process that can't be reversed, just like Sean Carroll's arrow of time. It is obvious that the key to the survival of our civilization in the near term, i.e. the next several hundred years, is to switch to more renewable energy resources and to recycle precious materials such as gold. Digging deeper is not the answer; the high concentrations of minerals are limited to the earth's crust, which is less than 30 miles thick).

Of course, it is possible that our planet could cycle through another period of several hundred million years of high temperatures and enough carbon dioxide to produce a biomass large enough to lay down another rich layer of fossil fuels. Or the planet could undergo extreme volcanic activity to produce new mineral deposits by bringing precious elements to the surface in very localized magmatic intrusions. Sadly, this would take a very long time, during which the planet would not be very habitable for *homo sapiens*.

Peter Gottleib [BS '56]

▪ ▪ ▪

I just read "The Arrow of Time" in the latest *E&S*. It sounds like the author thinks that it is possible to know the exact state of the universe, but the Heisenberg uncertainty principle states that this is not possible. In addition, Conway and Kochen's free will theorem denies any possibility of "hidden variables"—assuming that humans have free will; this cannot be proven, but without it, all human endeavor is pointless. If there are indeed no hidden variables for predicting the outcomes of quantum measurements, then this is a much stronger argument than entropy for the arrow of time.

John Lindal
[BS '94, MS '95, PhD '01]

ANDREW LANGE REMEMBERED

I was saddened to hear of Professor Andrew Lange's passing recently. I was also disappointed to see that his obituary in the Winter 2010 *E&S* omitted his work with students of Caltech, and undergraduates in particular. More than 10 years on, I recall Lange's interest and involvement with the student body, through mentoring, student government and the House system. I'm sure that he would have wanted this mentioned, even in this tightly abbreviated listing of his contributions to the Caltech community. One online collection of folks remembering Lange through testimonials and photos can be found on Facebook; search for "Andrew Lange."

Kohl S. Gill [BS '98]

Professor Lange's obit, short by necessity, was adapted from the press release. A campus memorial service for him will be held on Friday, May 7. Look for complete coverage of it in the next issue of E&S. —ed.

ANNENBERG CENTER DEDICATED

I was pleased to read in the article about the dedication of the Annenberg Center that Caltech has a professor of computer science and applied mathematics.

In about 1976, I applied to study the application of then-nascent principles of computer science to the development of mathematical software. Professor Francis Buffington, who I had known as an undergraduate student lab technician in Engineering 91, had the duty to inform me that the computer science department (then called information science) thought my interests and qualifications fit well with the applied mathematics department, while the applied mathematics department thought I fit well with the computer science department.

Van Snyder, La Cresenta, CA