like. He devotes a final important chapter to sustainability. In the face of pollution, global warming and population increase, how will it be possible to ensure an adequate supply of food, water and energy for all of Earth's people while maintaining respect for the well-being of other creatures? Loomis recommends a programme of voluntary population reduction, requiring both political leadership and a radical change of public opinion.

Loomis identifies the source of his title *Life As It Is* — his wife apparently — but not its significance. The idea that a realistic understanding of biology will usher in a paradise of ethical correctness is naive: the panoply of extra-scientific considerations that influence ethical decision-makings cannot be ignored or minimized. A weakness of Loomis's book is his comparative neglect of such considerations. But if his intention is less ambitious, namely that a realistic appreciation of biology ought to inform ethical decision-making, then that is incontrovertible. ■

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Engines of life

Energy in Nature and Society
by Vaclav Smil
MIT Press: 2008. 512 pp. $70, £45.95

Tim Lenton

The explosion of myriad life-forms throughout Earth's history has been fuelled by their ability to collect and process increasing amounts of energy. Thus organisms have become ever more complex, culminating in humans and our technology. In *Energy in Nature and Society*, Vaclav Smil describes in quantitative detail the evolutionary and technical innovations responsible, from photosynthesis and respiration to solar cells and steam turbines.

The first living things probably accessed chemical energy by breaking down large molecules into smaller ones. By 3.7 billion years ago, the first photosynthesizers evolved. These organisms could capture energy from sunlight and use it to split simple molecules and liberate electrons, which they used to make sugars from carbon dioxide. Their ingredients probably included electron donors — hydrogen (H_2, then H_2S) and later iron (Fe^{2+}) — that were in limited geological supply. This restricted global productivity to at most a tenth that of the modern marine biosphere.

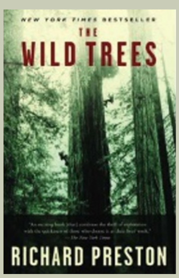
Next came the greatest energetic innovation in the history of the planet: oxygenic photosynthesis, the ability to capture enough energy from sunlight to split water, thus liberating oxygen gas. This evolved in cyanobacteria more than 2.7 billion years ago. Initially, oxygen production was confined to microbial mats and sunlit surface waters; 2.4 billion years ago it rose in the 'great oxidation' of the atmosphere.

When oxygen reacts with organic matter during aerobic respiration, an order of magnitude more energy is liberated than was available for earlier anaerobic respiratory pathways. Ultimately, this source of power allowed the evolution of larger and more mobile organisms, including humans.

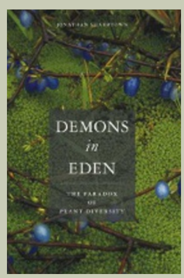
Smil is brief on the history of the biosphere. He gives a fascinating assessment of its present energetic state, quantifying global energy capture in photosynthesis and the uses that all organisms, including humans, put it to. Then he shifts the focus to human technological innovations that have progressively increased the capture and conversion of energy into forms that are useful to us. *Energy in Nature and Society* tells this story wonderfully, from hunter-gathering to traditional agriculture, the shift from human to animal power, the invention and refinement of water wheels and windmills, improvements in roads and ship design, and to charcoal production and its use in metallurgy. The fossil-fuel age takes off with exponential global increases in coal, then oil, then gas extraction and consumption.

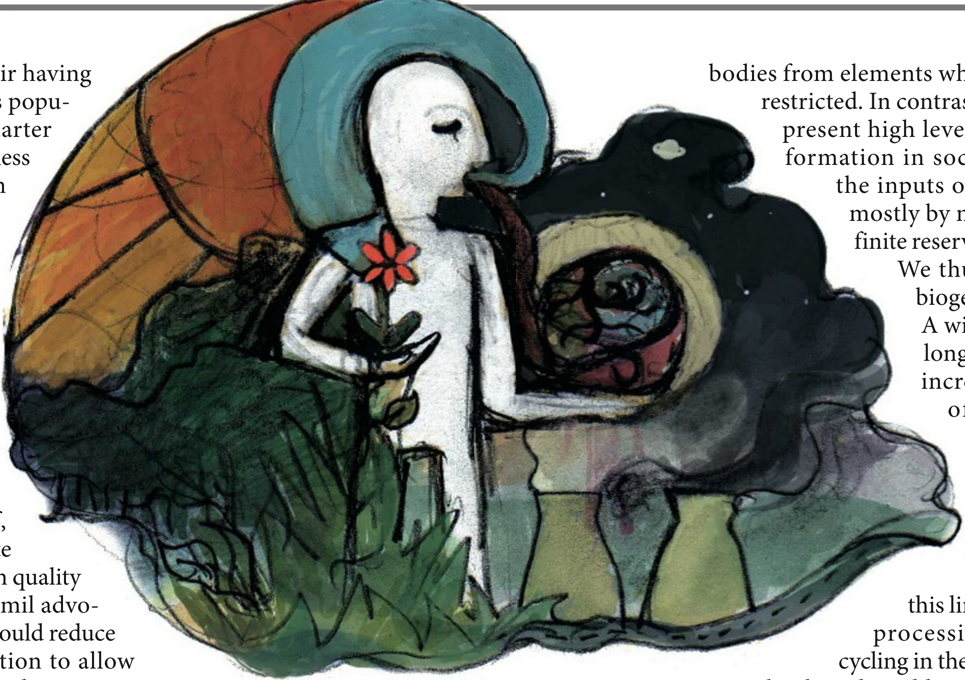
In a feat unprecedented for a single animal species, humanity's total energy use has now exceeded that of the entire ancient biosphere before oxygenic photosynthesis, reaching about a tenth of the energy processed by today's biosphere. Almost half of the world's total primary energy supply is consumed by the rich

The Wild Trees
by Richard Preston (Random House, $16)
A dramatization of the lives of Californian botanists, Richard Preston reveals the hidden world of the coastal redwood trees, the tallest organisms the planet has sustained. Science, adventure and a passion for trees are combined.



Demons in Eden: The Paradox of Plant Diversity
by Jonathan Silvertown (Univ. Chicago Press, $16)
How is plant biodiversity maintained and why is the world not overgrown by aggressive weeds? Jonathan Silvertown explores the dynamics of the plant world and suggests that "tasting the fruit of evolutionary knowledge may provide us with a ticket for readmission to the Garden of Eden", according to Peter Moore's review (*Nature* **438,** 27; 2005).





G8 nations, despite their having only 12% of the world's population. The poorest quarter of humanity consumes less than 3%. For them, even modest increases in per capita energy consumption significantly reduce infant mortality and increase life expectancy. Above about 60 gigajoules per capita (the amount used, for example, by citizens of the French city of Lyon in 1960) these benefits level off, indicating that profligate energy use bears little on quality of life. Consequently, Smil advocates that rich people should reduce their energy consumption to allow poorer people to increase theirs.

Today's high-technology societies mostly rely on fossil fuels. These concentrated reserves of stored ancient sunlight — the remnants of past organisms — are finite, and the products of their combustion have undesirable consequences, from respiratory problems to climate change. Smil argues that we should stop the seemingly endless growth of energy consumption while we switch to cleaner and more sustainable sources of power.

In the long term, Smil's solution is solar power, because the total supply of sunlight at Earth's surface exceeds current global fossil-fuel consumption by more than a thousand times. Until then, he supports a careful transition away from fossil fuels and points out that carbon capture and storage have limited capacity. He dismisses most renewable energy sources because their power densities are too low to supply the needs of the present global population, let alone future ones. This includes first-generation biofuels, where their poor energy returns could ultimately mean feeding cars in place of people. In *Energy in Nature and Society*, Smil contends that power from nuclear fission would become limited by uranium supply until a viable commercial fast-breeder reactor is available, and fusion power is too far from commercial deployment. All of which implies a difficult transition period involving substantial carbon dioxide emissions and climate change.

If we are to have a long and happy future on this planet, we need to follow life's example and find more efficient ways of extracting free energy from sunlight. But energy isn't everything. The successful major transitions between past biospheres also required increases in material recycling, because the organisms capturing energy built their bodies from elements whose supplies were restricted. In contrast, to maintain our present high level of energy transformation in society, we increase the inputs of many elements, mostly by mining them from finite reserves in Earth's crust. We thus perturb global biogeochemical cycles. A wiser strategy in the long term would be to increase the recycling of materials that accompany the capture and use of energy.

I would like to encourage Smil to strengthen this link between energy processing and material cycling in the next edition of his book, and to address whether the combination of solar power and recycling might allow energy transformation by humans and the biosphere to grow again. For now, the energy required to read this comprehensive and scholarly tome is extremely well spent. ■

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Biology from the bottom up

What Is Life? Investigating the Nature of Life in the Age of Synthetic Biology
by Ed Regis
Farrar, Straus & Giroux: 2008. 208 pp. $22

Steven Benner

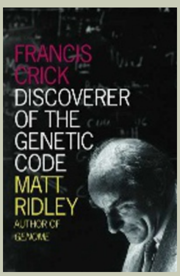
Book titles should display ambition, and Ed Regis' latest certainly does that. Implicit is progress between two areas of biology. *What Is Life?* recalls Erwin Schrödinger's famous book of the same name that encouraged many physicists to begin working in molecular biology in the 1940s; synthetic biology is the fast-moving area today.

The term synthetic biology was coined in 1974 by Waclaw Szybalski to describe the modification of organisms by adding and subtracting genes. In those days it was known as 'genetic engineering' or 'recombinant DNA technology'. By altering the genes, the organisms act in new ways.

At the time, Szybalski's synthetic biology prompted fear. The city of Cambridge, Massachusetts, banned genetic engineering entirely. A conference was convened in Asilomar, California, to decide how to manage the new ability to create artificial organisms.

Three decades of experience have shown the risks to be negligible but the rewards enormous. Today, the field of synthetic biology is expanding, spawning new university departments, such as the one that hosts Jay Kiesling's laboratory at the University of California at Berkeley in which bacteria are created to produce

Francis Crick: Discoverer of the Genetic Code
by Matt Ridley (Harper Perennial, £7.99)
The story of Francis Crick extends beyond the discovery of DNA. Matt Ridley's biography details how he came to study biology, sets in context his controversial ideas and gives a glimpse into the character of one of the most famous scientists of the twentieth century.



The Music of Life: Biology Beyond Genes
by Denis Noble (Oxford Univ. Press, £7.99)
Instead of taking a blinkered view based on genes and genomes, Denis Noble argues, we must realize that life is a process. To see its workings, we should look at interactions on every level — genes, cells, the body, systems and the environment.