looks at biology through the lens of computer science and electrical engineering. This is conceptually the deepest chapter but its brevity limits it to a few well-chosen examples. The technologies of any age have always provided metaphors for biology — from myths about our origin involving dust and clay to the industrial revolution's hydraulic and, later, electromagnetic imagery, from telegraphs to telephones and finally to computers. The book contains almost no explicit discussion of complexity, and this omission is particularly noticeable here. Much of computer science is about organizing complexity, from 'very large-scale integrated' circuit design to object-oriented programming and the layered protocols of the Internet.

The history of flight is again instructive. By the nineteenth century, engineers had realized that lift, drag and propulsion were the key fundamental mechanisms, and toy gliders became commonplace. Yet only with the Wright brothers' insight that active control was needed for steering and compensation for uncertainties did flying literally take off. By the 1940s, unpiloted aircraft had demonstrated fully automatic transatlantic flight and landing, and some engineers now argue that flight would generally be safer without pilots.

Similarly, the vast majority of computers now are 'embedded', with automated sensing, control and actuation, all entirely hidden during normal operation. Computer control systems such as these represent both the main use of computers and the main source of complexity in technological systems, but are barely mentioned either in this book or elsewhere. This is a pity, as they are the points of greatest contact between engineering and biology. Biologists would have benefited from a discussion of sensing and adaptation in computation and networking, such as Internet routing and congestion control, because sensing and adaptation are widespread in biology, for example in the immune system. Perhaps biologically inspired computing is not yet at a 'Wright brothers' stage, with many fundamental mechanisms just emerging, old superficial metaphors being set aside, and systems-level integrating concepts remaining murky. Hopefully, the Wright brothers of biologically inspired computing are among the many fascinating characters described by Forbes, and their subjects will take off as promised.

This book is easily accessible but is probably most suited to, and beneficial for, biologists, as a clearly written, non-technical primer describing activities on the other side of campus. Biologists will have to ignore some unfortunate simple errors (such as neurons called axons, AIDS as an autoimmune disease and vaccines made from weakened antigens) but can easily read around them. Nonetheless, this text helps to bridge a daunting technical language barrier and should facilitate further dialogue between biologists and computer scientists. ■

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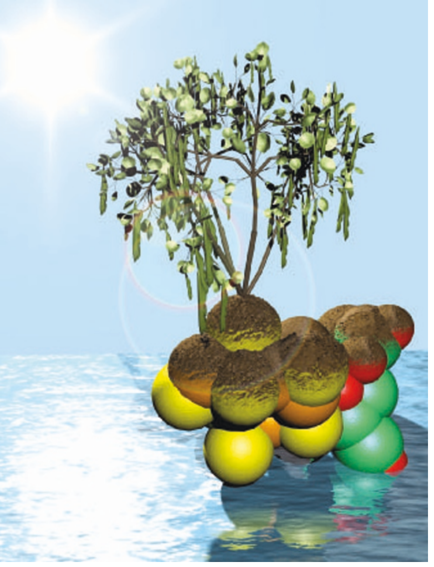

The roots of nitrogen fixation

The World's Greatest Fix: A History of Nitrogen in Agriculture
by G. J. Leigh
Oxford University Press: 2004. 254 pp. £20, $29.95

Vaclav Smil

The discovery by Fritz Haber of a method for fixing ammonia from its elements led to the development of the modern nitrogen-fertilizer industry. The growing applications of nitrogen compounds in agriculture have had enormous demographic, economic and environmental consequences. Most histories of nitrogen fixation focus on this part of the story, but in *The World's Greatest Fix*, G. J. Leigh provides a more evenly distributed account. Nearly two-thirds of Leigh's text is devoted to general considerations of nitrogen's chemistry and agronomy, and of technical developments before Haber's discovery.

The book begins with a brief introduction to nitrogen fixation and its importance for agriculture, before tracing the development of agronomic practices in pre-Colombian America (by the Aztecs and Mayas), dynastic China and the Roman Empire, with particular attention to classic agricultural accounts (and the value of manure) by Cato the Censor, Columella, Pliny the Elder and Varro. Next, the story advances to the modern era, focusing on English farming from Roman times to the beginning of scientific agriculture in the seventeenth century, before moving on to the trade in guano (bird droppings are a rich source of nitrogen) and Chilean nitrates (originally Bolivian and Peruvian) — England was the leading importer of these sources of nitrogen. Leigh then takes us into the laboratory, dealing with the alchemy of nitre and the early chemistry of nitrogen (from Paracelsus to Lavoisier and Chaptal), the birth of agricultural chemistry (thanks to Davy, von Liebig and Boussingault) and the discovery (by Hellriegel and Wilfarth) that microorganisms and some plants can fix their own nitrogen.

Leigh then describes the evolution of the first commercial methods invented to fix nitrogen. The Norwegian arc process, which combines N_2 and O_2 in an electric arc furnace and uses the resulting nitric oxide to produce HNO_3, was made possible by inexpensive hydroelectricity. The synthesis of cyanamide, by reacting CaC_2 with N_2, also fixed nitrogen but was energy-intensive. Next come Haber's experiments, beginning in 1903, and the quest, led by Carl Bosch, to commercialize them, beginning at the BASF plant in Ludwigshafen, Germany, in 1909. Here I found the only factual errors worth noting: the German chemist who formulated the effective catalysts needed to run the ammonia synthesis was Alwin (not Alois) Mittasch. This work also led to the synthesis of methyl alcohol and the hydrogenation of coal. And Mittasch did not collaborate with Haber in 1903 (at the time he was Ostwald's assistant in Leipzig); he joined BASF in 1904, working under Bosch.

The penultimate chapter explores the continuing mystery of biological fixation, the author's main area of research interest — he spent most of his professional life at the Unit of Nitrogen Fixation, which was set up in the mid-1960s at the University of Sussex. He describes the discovery of nitrogenases — the enzymes that fix nitrogen in both free-living and symbiotic bacteria — and their modes of action; he discusses the structures made up of iron, molybdenum and sulphur that are at the heart of these remarkable molecules; and he reviews the unsolved puzzles regarding their active sites.

In closing, Leigh reviews the scale and effects of nitrogen-fertilizer use, focusing on aquatic eutrophication — in which excessive nitrogen promotes algal growth and the subsequent depletion of oxygen — and nitrates and human health. The health effects of nitrates are frequently exaggerated, but eutrophication, which Leigh treats rather lightly, still does not get enough attention, given its severity and increasing occurrence. There is also now considerable eutrophication of terrestrial ecosystems.

I always like unusual tit-bits, asides and images, and Leigh's book has its share of them. Among my favourites is a reference to Humphrey Davy's discussion of various fertilizers, including pilchards in Cornwall. There is also a photograph of Tyntesfield, an impressive Victorian Gothic Revival mansion built near Bristol between 1863 and 1866, financed largely with money from the guano trade. And there is a description of a frustrated British inspection of the world's first ammonia plant in Oppau, Germany, in 1919 with the intention of reverse-engineering it in Britain. Leigh conveys a great deal of information in 220 pages of text, and does so in an easy-to-read, clear and accurate style. This is altogether a fine book.

Those who would like to know more about the key protagonist of the nitrogen story, yet are unable to read German, can finally get an (abridged) English translation of Dietrich Stoltzenberg's massive 1994 biography *Fritz Haber: Chemist, Nobel Laureate, German, Jew* (Chemical Heritage Foundation, 2004). ■

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Freedom from smallpox?

The Life and Death of Smallpox
by Ian Glynn & Jenifer Glynn
Profile Books (UK)/Cambridge University Press (US): 2004. 288pp. £17.99/$25

Hugh Pennington

"The world and all its people" have "won freedom from smallpox", declared resolution WHA 33.3, signed on 8 May 1980 at the eighth plenary meeting of the 33rd World Health Assembly. The assembly was right to congratulate itself on the success of a campaign by its parent body, the World Health Organization, to eradicate smallpox as a "natural" disease.

There had been many difficulties. Money was often short. There were sceptical experts whose influence had to be countered. In the final stages of the programme, the virus went to ground in Somalia and Afghanistan, not the easiest places to hunt it down. In many ways, the virology was the easiest part — despite its reputation, smallpox couldn't spread as quickly as other viruses, such as measles, so it could be stopped in its tracks by isolating victims and using vaccination to create cordons sanitaires. It was also easy to track because of its highly visible and distinctive rash. Ali Maow Maalin, a hospital cook in Marka, Somalia, was the last person to receive a natural case of smallpox, developing his rash on 17 October 1977. The campaign had finally been successful.

But the people of the world have not "won freedom from smallpox". Unlike the dodo and the dinosaur, it is not extinct: it survives in frozen form in laboratories at Atlanta, Georgia, and Koltsovo in the Novosibirsk region of Russia. And it also survives as a threat in the minds of bioterrorism experts and the politicians they advise, as there is a worry, unproved, that Koltsovo might have been leaky — they consider that the value of smallpox to a terrorist lies not in its lethality but in its ability to panic the public.

The Life and Death of Smallpox explains why. It starts by describing the recorded impacts of the disease in ancient times, and how it replaced plague as an epidemic killer. The book's focus then shifts to the immunological attack on the virus, with the appearance of Lady Mary Wortley Montagu. She was an early promoter in England of variolation — the deliberate infection of the young with smallpox from a mild case — having seen it in operation in Turkey.

Jenifer Glynn is a historian, so although the account of Lady Mary is somewhat anglocentric, it contains nice touches. Lady Mary lost her eyebrows after an attack of smallpox that damaged her beauty and, no doubt, stimulated her interest in the disease. And we learn of her elopement with Edward Wortley Montagu to avoid an arranged marriage with Clotworthy Skeffington. But the overall account of variolation is certainly not anglocentric. As the book records, variolation persisted right up to the end of natural smallpox, changing from a practice that had some merit in the eighteenth century (its mortality was lower than that of randomly acquired disease) to one that helped the wild virus to persist in the mid-1970s.

Edward Jenner is the hero of the book, of course. Most of the chapters are devoted to describing his introduction of vaccination, its spread and its successes, finishing with the eradication campaign, which depended on it. More generally, the trials and tribulations of vaccination also feature in the book. Britain is currently having trouble with its immunization policy, for example. Because of a perception that the combined measles–mumps–rubella vaccine may be linked to autism, some parents are rejecting it, leaving their children unprotected. Others are opting for unofficial alternatives. *The Life and Death of Smallpox* provides an excellent account of similar events a century and more ago. A group of people opposed to vaccinations was active then and, in 1898, compulsory vaccination in England was abandoned — 'conscientious objectors' to vaccination could apply for an exemption certificate.

As a historical account of smallpox, the Glynns' book is excellent. It attends to vaccination controversies and personality clashes in a masterly fashion. Virus-related policy events in the aftermath of the terrorist attack of 11 September 2001 are covered well. But those who look for a definitive account of the origins of vaccinia, the vaccine virus, will be disappointed. To virologists this will be no surprise, because its history is shrouded in mystery and its molecular genealogy is puzzling. As a former poxvirologist, I was a little disappointed not to read more about the molecular and cell biology of the virus itself, but its virological quirks and peculiarities, and those of its relatives, are striking and complex enough for another book. This one is for the general reader. ■

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