systems evolve and can be locked into trajectories by incumbent industries, unless strong pressures force a change in course. These strands of economics are crucial to understanding the energy–climate nexus and policies for transformation. The economics mainstream is still largely in thrall to the idea that competitive markets drive innovation, but liberalization of the energy sector destroyed UK energy research and development. The energy literature explains why, but Stern hardly touches on this and thus misses a chance to help to educate fellow economists.

Stern's real speciality is displayed most in his discussion of the ethics of how to weigh costs and benefits over time, as well as broader issues in moral and political philosophy. The first is technical, but is at the heart of the post-Stern review debate: prevalent economic tools 'discount' almost anything more than a few decades ahead. Critics often cite philosopher David Hume to support arguments that we should weight impacts on future generations on the basis of 'revealed preference' in markets. To these critics, Stern cites Hume on the need for "governors and rulers" to overcome the "impatience" of individuals. Stern maps out his case with a precision reminiscent of philosopher and mathematician Bertrand Russell. He demolishes economists who, trying to avoid explicit ethical debates, forget the ethical assumptions of their discipline.

Towards the end, Stern distils his thoughts on the international climate scene. Although he overlooks some key respects in which a binding treaty — the Kyoto Protocol — was crucial in forming European climate policy,

huge value remains in his wisdom and his experience of international debates.

However, Stern's coverage of lessons from economic history and theory is messier. It meanders through market failures, policy uncertainties, the European Union's emissions-trading system, the debate over reserves of fossil fuels that must be left unburnt to satisfy emissions targets, shale gas, the German nuclear phase-out, failed Chinese dams and more. There are trenchant points about six market failures and the six areas of policy required to address them, but little structure behind the tales, and no compelling narrative on how policy failures might have been overcome. Instead, Stern embarks on a demolition of his critics. The integrated assessment models beloved of many technical analysts come in for particular ire. Stern views them as "simplistic attempts to shoehorn the deep and dynamic issues into inappropriate or narrow models", noting that many "can be profoundly misleading", and evoking John Maynard Keynes' old punchline: "It is better to be roughly right than precisely wrong."

Most seriously, Stern has misdiagnosed the major obstacles to climate action as a failure of policy-makers to understand the scale of the risks, to grasp that delay is dangerous or to appreciate the feasibility of and potential for low-carbon paths. These are not the root of the problem, and Stern never gets to it, despite providing much of the intellectual material.

Most policy-makers accept the need for action. Ignorance, inattention and ideology have all played a part in the waiting game, but it also springs from microrealities of politics

and economics. Stern is a big thinker, used to the broad sweeps of economic development and global issues. But the crux is local people and businesses. Voters might like the idea of clean energy, but oppose wind farms next door; back emission reductions and profess support for market-based solutions, but oppose increased energy prices. There is little on energy prices in *Why Are We Waiting?*, but climate policy in Brussels and Washington DC is concerned with little else.

The real challenge in controlling climate change is many-layered, but must include attempts to align global need for transformation with the old adage that all politics is local. A brief reference to border measures, to deter industries from migrating to escape carbon controls, signals a shift in Stern's thinking; but the argument is not developed further.

Stern deserves much credit for moving the economics debate on so far in a decade. But *Why Are We Waiting?* is a depressing reminder of the sheer size of the elephant. The complexities of climate change are beyond the ken of any individual, even such a big thinker as Stern. Developing the institutions, intellectual frameworks and impact channels required for effective 'solution science', matched to the sheer range and scale of the problems and opportunities, remains very much a work in progress. ■

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GENETICS

We are the 98%

Nathaniel Comfort unpicks the metaphors in a trio of books exploring the 'junk'–ridden genome.

The language of DNA is a veritable cornucopia of metaphor and cliché. Since James Watson and Francis Crick solved the double helix, biologists have imagined DNA as an information-storage device: magnetic tape, a computer program or, most commonly, a book that contains the instructions for making a cell's proteins. In multicellular organisms, this precious tome is secured in the vault of the nucleus, the membrane of which isolates and protects nature from nurture.

But if a genome is text, it is badly edited. Most DNA is gibberish, full of stutters, snippets of doggerel from other species, and echoes of quiescent viruses. In humans, only

about 2% of the genome encodes proteins. Much — but not all — of the remaining 98% is evolutionary detritus. In the 1960s, researchers learned that non-coding DNA can serve vital functions, such as regulating gene action and building ribosomes. The remainder they began to call junk.

Today, junk DNA is at the heart of the most radical transformation of how we understand the genome since the information metaphor. Three books — *The Deeper Genome* by John Parrington, *Junk DNA* by Nessa Carey and *Biocode* by Dawn Field and Neil Davies — present a vision of the twenty-first-century genome. Their relative success hinges on metaphor and imagery, both in how they

Biocode: The New Age of Genomics

DAWN FIELD AND NEIL DAVIES
Oxford Univ. Press: 2015.

The Deeper Genome: Why There Is More to the Human Genome Than Meets the Eye

JOHN PARRINGTON
Oxford Univ. Press: 2015.

Junk DNA: A Journey Through the Dark Matter of the Genome

NESSA CAREY
Icon: 2015.

conceive the genome and in the writing itself.

In September 2012, the ENCODE (Encyclopedia of DNA Elements) consortium announced that its multi-year international effort to catalogue the various types of DNA sequence had assigned "biochemical function" to 80% of the human genome. Incautious reporters began shouting that junk was bunk, even though scientific consensus maintains that most genomes contain large amounts of it. The subsequent debate upregulated public interest in non-coding DNA — but how do we talk about DNA now?

The title *Biocode* forestalls any doubt ▶

► that the authors hew to the information metaphor. Breathlessly, Field and Davies survey the greatest hits and promises of genomics, including *Jurassic Park*-style reanimation of extinct species, the microbiome and environmental engineering. The thin chapters blurt out strings of recent findings, each capped with a crescendo of sensational speculations that mostly rehearse familiar ethical questions. Critical distance is achieved with the time-honoured double negative: “Might a lawyer one day argue that deliberately *not* giving [our children] the best genes available is a form of abuse? It is not inconceivable to imagine a world where natural reproduction would seem primitive and even barbaric.” It concludes by exhorting us to set our sights on a global genome project to understand “the software that shapes our living planet”. The biocode is Gaia plus DNA. But two clichés do not make a right. *Biocode* simply extends the text metaphor to the macrocosm.

The old metaphor is not wrong; it is incomplete. In the new genome, lines of static code have become a three-dimensional tangle of vital string, constantly folding and rearranging itself, responsive to outside input. The roots of this idea run deep. In her 1983 Nobel lecture, geneticist Barbara McClintock called the genome a “sensitive organ of the cell”. McClintock, who discovered mobile genetic elements in the 1940s, had named them controlling elements because she thought they composed the regulatory system that governed gene action. In 1980, Ford Doolittle and Carmen Sapienza proposed that transposons were molecular parasites, jumping into genomes to propagate themselves. Parasitic transposons are now textbook knowledge, but McClintock’s larger point holds: the genome is dynamic, full of regulatory elements that respond to environmental cues.

The Deeper Genome is the only book of the three that credits McClintock as a progenitor of the three-dimensional genome. A scientist and journalist, Parrington covered the ENCODE story for *The Times* in 2012; his book enriches those accounts with historical and scientific context. The science is better than the history. He provides a fine discussion of recent support for McClintock’s often-overlooked late work on how stress can activate transposition, but he perpetuates the

myth that at first no one thought transposition was real. The contested point was actually McClintock’s interpretation of mobile elements as controllers of gene action. Parrington’s strongest chapters survey the emerging view of gene regulation, including DNA folding, epigenetics and regulatory RNA. Overall, this is a faithful, engaging portrait of the twenty-first-century genome.

Finally, *Junk DNA*, like the genome, is crammed with repetitious elements and superfluous text. Bite-sized chapters parade gee-whizz moments of genomics. Carey’s *The Epigenetics Revolution* (Columbia University Press, 2012) offered lucid science writing and vivid imagery. Here the metaphors have been deregulated: they metastasize through an otherwise knowledgeable survey of non-coding DNA. At one point, the reader must run a gauntlet of baseball bats, iron discs, Velcro and “pretty fabric flowers” to understand “what happens when women make eggs”. The genome seems to provoke overheated prose,

unbridled speculation and Panglossian optimism. Junk DNA produces a lot of DNA junk.

The idea that the many functions of non-coding DNA make the concept of junk DNA obsolete oversells a body of research that is exciting enough. ENCODE’s claim of 80% functionality strikes many in the genome community as better marketing than science.

Still, as with McClintock, the larger point holds: the genome is more than a set of rules and parts descriptions. Finding apt imagery to replace the dead metaphor of the ‘instruction book of life’ could enable us to break free of the cliché of nature versus nurture. It could usher in a more democratic conception of life, in which all the world’s a cell, and all the genes and genomes merely players. ■

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NEW IN
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Highlights of this
season’s releases

Neanderthal Man: In Search of Lost Genomes

Svante Pääbo BASIC 2015

Pioneer of ancient-DNA studies Svante Pääbo was inspired in his youth by ancient Egyptian history. Feeling that this field moved too slowly, he decided to study medicine instead, and went on to sequence the first full Neanderthal genome in 2010. Here he details the technicalities of his life’s work and the incremental discoveries, such as genetic intimations that modern humans and Neanderthals had mixed, which generated our theories of human evolution. (See Henry Gee’s review: *Nature* **506**, 30–31; 2014.)