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High Tide: News from a Warming World
Six Degrees: Our Future on a Hotter Planet

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The God Species

How Humans Really Can
Save the Planet

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CHAPTER ONE

The Ascent of Man

Three large rocky planets orbit the star at the centre of our solar system: Venus, Earth and Mars. Two of them are dead: the former too hot, the latter too cold. The other is just right, and as a result has evolved into something unique within the known universe: it has come alive. As Craig Venter and his team of synthetic biologists have shown, there is nothing chemically special about life: the same elements that make up our living biosphere exist in abundance on countless other planets, our nearest neighbours included. But on Earth, these common elements – carbon, hydrogen, nitrogen, oxygen and many more – have arranged themselves into uncommon patterns. In the right conditions they can move, grow, eat and reproduce. Through natural selection, they are constantly changing, and all are involved in a delicate dance of physics, chemistry and biology that somehow keeps Earth in its Goldilocks state, allowing life in general to survive and flourish, just as it has done for billions of years.

Why the Earth has become – and has remained – a habitable planet is one of the most extraordinary stories in science. Whilst Venus fried and Mars froze, Earth somehow survived enormous swings in temperature, rebounding back into balance whatever the initial cause of the perturbation. Venus suffered a runaway greenhouse effect: its oceans boiled away and most of its carbon ended up in the planet's atmosphere as a suffocatingly heavy blanket of carbon dioxide. Mars, on the other hand, took a different trajectory. It began life warm and wet, with abundant liquid water. Yet something went wrong: its carbon dioxide ended up trapped for ever in carbonate rocks, condemning the planet to an icy future from which there could be no

return.¹ The water channels and alluvial fans that cover the planet's surface are now freeze-dried and barren, and will remain so until the end of time.

Part of the Earth's good fortune obviously lies in its location: it is the right distance from the sun to remain temperate and equable. But the distribution of Earthly chemicals is equally critical: our greenhouse effect is strong enough to raise the planet's temperature by more than 30 degrees from what it would otherwise be, from -18°C to about 15°C today on average – perfect for abundant life – whilst keeping enough carbon locked up underground to avoid a Venusian-style runaway greenhouse. Ideologically motivated climate-change deniers may rant and obfuscate, but geology (not to mention physics) leaves no room for doubt: greenhouse gases, principally carbon dioxide (with water vapour as a reinforcing feedback), are unquestionably a planet's main thermostat, determining the energy balance of the whole planetary system.

This astounding 4-billion-year track record of self-regulating success makes the Earth unique certainly in the solar system and possibly the entire universe. The only plausible explanation is that self-regulation is somehow an emergent property of the system; negative feedbacks overwhelm positive ones and tend to push the Earth towards stability and balance. This concept is a central plank of systems theory, and seems to apply universally to successful complex systems from the internet to ant colonies. These systems are characterised by near-infinite complexity: all their nodes of interconnectedness cannot possibly be identified, quantified or centrally planned, yet their product as a whole tends towards balance and self-correction. The Earth that encompasses them is the most complex and bewilderingly successful system of the lot.

One of the pioneers in understanding the critical regulatory role of life within the Earth system was the brilliant scientist and inventor James Lovelock. Lovelock's original Gaia theory – that living organisms somehow contrive to maintain the Earth in the right conditions for life – was a stunning insight. But his idea of the Earth as being alive, perhaps as a kind of super-organism, only holds good as a metaphor. Self-regulation comes about not for the benefit of any

component of the system – living or non-living – but by dint of the overall system's long-term survival and innate adaptability.

An important characteristic of the Earth system is that its main elements move around rather than all ending up in one place. Water, for instance, cycles through rivers, oceans, ice caps, the atmosphere and us. An H_2O molecule falling in a snowstorm on the rocky peak of Mount Kenya may have been exhaled in the dying gasps of Queen Elizabeth I: water, driven by energy, is always circulating. Nitrogen, oxygen, phosphorus, sodium, iron, calcium, sulphur and other elements are also perpetually on the move. Carbon is perhaps the most important cycle of all, because of the thermostatic role played by its molecular state; particularly in its gaseous form as CO_2 , but also in combination with other elements, such as with hydrogen as CH_4 (methane). It was the failure of the carbon cycle that doomed Venus and Mars, yet here on Earth various feedbacks have kept the system in relative balance for billions of years – even altering the strength of the greenhouse effect to offset the sun's increasing output of radiation over geological time.

Over million-year timescales, the carbon cycle balances out between the weathering of rocks on land, which draws carbon dioxide out of the air, and its emission from volcanoes. Carbon is deposited in the oceans and then recycled through plate tectonics, as oceanic plates subduct under continental ones, providing more fuel for CO_2 -emitting volcanoes. The process is self-correcting: if volcanoes emit too much carbon dioxide, the Earth's atmosphere heats up, increasing weathering rates and drawing down CO_2 . If carbon dioxide levels fall low enough for weathering to cease – as perhaps was the case during the early 'snowball Earth' episodes, when global-scale ice caps put a stop to the weathering of rocks – volcanic emissions continue uninterrupted, allowing CO_2 to build up until a stronger greenhouse effect melts the ice and allows balance to be restored. The system is stable but not in stasis: the geological record shows tremendous swings in temperature and carbon dioxide concentrations over the ages, though always within certain boundaries.

Perhaps one of the strongest arguments against the Gaia concept is the fact that even if the planet in general remains habitable, things do

sometimes go badly wrong. Over the last half-billion years since complex life began there have been five serious mass extinctions, the worst of them wiping out 95 per cent of species alive at the time. Most appear to have been linked to short-circuits in the carbon cycle, where volcanic super-eruptions led to episodes of extreme global warming that left the oceans acidic and depleted in oxygen, and the land either parched or battered by merciless storms. And yet, over millions of years, new species evolved to fill the niches vacated by extinguished ones, and some kind of balance was restored. Over the last million years, recurrent ice ages demonstrate how regular cycles can lead to dramatic swings in temperature, as orbital changes in the Earth's motion around the sun lead to small differences in temperature, which are then amplified by carbon-cycle and ice-albedo (reflectivity) feedbacks. Our planet may be self-regulating, but it is also extraordinarily dynamic.

GOD SPECIES OR REBEL ORGANISM?

Life is now an important component of most of the planet's major cycles. The majority of carbon is locked up in calcium carbonate (limestone) rocks, laid down in the oceans by corals and plankton. The appearance of photosynthesis was perhaps one of life's most miraculous innovations, allowing microbes – and later, green plants – to use atmospheric carbon dioxide as a source of food. Water is an essential part of the process: in cellular factories called chloroplasts, plants split water into hydrogen and oxygen, combining the hydrogen with carbon from the air to form carbohydrates, and releasing oxygen as a waste product. The process opened up an opportunity for the evolution of animals, that could eat the carbohydrates as a food source and recombine them with oxygen (forming CO₂ and water), thereby generating energy and closing the loop.

Evolution of life is a critical part of the process of planetary self-regulation, because it allows organisms to change to take advantage of new opportunities and learn from failures – evolution is self-correction in action. Just as the build-up of oxygen in the air allowed animal life to appear, so the accumulation of any waste is an

opportunity for new species to evolve to take advantage of it. Evolution is very different from mere adaptability, because it allows new life-forms to appear rather than old ones to adapt, leading to much greater transformations. A species may, for example, be able to adapt to a shift in its food supply by moving, but over many millennia an entirely new species may thereby come into being, able to exploit a whole new niche in the ecosystem. Think of polar bears, likely descended from an isolated population of brown bears in an ice age, but which evolved white fur and an ice-based lifestyle to become the pre-eminent hunter of the far north.

All this sounds comforting. The Earth, and life, will always prevail. But the self-regulating system contains a flaw, one that can seriously damage or even destroy it. This flaw is the gap in time between a perturbation and the ensuing correction: instabilities can happen very fast, whilst the correcting process of self-regulation typically takes much longer. The gap between the advent of an oxygen-rich atmosphere and the appearance of animal life was a long one: a good hundred million years if not more. Major volcanic eruptions may release trillions of tonnes of carbon dioxide over just a few thousand years, outstripping the capacity of the Earth system to mop up the additional CO₂ via rock weathering and other processes of sequestration, and leading to extreme global warming events. Mass extinctions happen because changing circumstances outstrip the adaptability of existing species before evolution can work its magic. Over millions of years new species can appear, but only from the diminished gene pool of the survivors – and a return to true pre-extinction levels of biodiversity may take much longer, if it ever takes place at all.

This time-lag effect was cleverly demonstrated in a modelling simulation undertaken by two British researchers, Hywell Williams and Tim Lenton (both at the University of East Anglia; Lenton is a member of the planetary boundaries expert group).² In a computer-generated world – entirely populated by evolving micro-organisms living in a closed flask – Williams and Lenton found that the closing of nutrient loops emerged as a robust property of the system nearly every time the model was run. As in the real world, the emergence of self-regulation came about because evolution allowed new species to

appear that could use the waste of one species as food for themselves, recycling nutrients and leading to a stable state. Moreover, the more species that evolved, the greater the amount of recycling and the greater the overall biomass the system could support. 'Flask world' had discovered the value of biodiversity.

But this world also had a dark side, for several simulations illustrated that the flaw in self-regulation – the time gap between a disturbance and the evolved correction – might occasionally be fatal. In just a few model runs, an organism appeared that was so spectacularly successful in mopping up nutrients that its numbers exploded and its wastes built up to toxic levels before other organisms were able to evolve a response. Williams and Lenton dubbed these occasional rogue species 'rebel organisms'. They were unusual, but their impact was invariably catastrophic: the explosive initial success of the rebels changed the simulated global environment so suddenly and dramatically that their compatriots were killed, and – with no other life-forms around to recycle their wastes – they were themselves condemned to die too. As the last lonely rebels perished, their whole biosphere went extinct, evolution ceased, self-regulation failed, and life wiped itself out.

Like Lovelock's Gaia, Flask world – and its rebel organisms – might just be a clever idea, more of a metaphor than a true representation of reality. But the parallels with our species are unsettling. We have transformed our environment within just a few centuries in ways that are wiping out other life-forms at a shocking speed – the changes so rapid that evolution has no time to adapt and thereby allow other organisms to survive. Like a rebel organism, our species discovered a colossal new source of energy, which had lain hidden and undisturbed for millions of years, and which no previous life-form had found a use for. It is the sheer rapidity in the rise of the waste from the exploited new energy source of buried carbon – largely in the form of gaseous carbon dioxide – plus the other combined wastes and environmentally transformative impacts that fossil fuels allowed humanity to achieve, that have now begun to overwhelm the self-regulatory capacity of the Earth system. This single element holds the key to a possible future mass extinction.

Flask world is now our world. Consider that our wastes are accumulating so fast in the oceans that no species can consume them; instead, massive dead zones are spreading around the world's coasts, from China to the Gulf of Mexico, where the recent BP oil spill adds to the toll. We have produced novel organic chemicals and synthetic polymers that no microbes have yet learned to digest, and which are poisonous to most organisms – often including ourselves. And we are steadily eating our way through global biodiversity – from fish to frogs – consuming voraciously, and moving on to the next species when one is extinguished. Those species that are not edible we ignore and displace, whilst those that threaten or dare to compete with us we pursue mercilessly and annihilate. Thus is our rebel nature revealed.

There is a paradox however. Even as a putative rebel organism, humanity is a product of Darwinian evolution, like every other naturally generated life-form sharing our planet today. Moreover, we did not evolve the biological capacity to eat coal and drink oil – the energy from these abundant 'nutrients' is combusted outside the body rather than metabolised within it. Why us, then? Our mastery of fire was a product of the adaptability and innovativeness with which evolution had already equipped us long before, and that no other species had heretofore possessed. Humanity's Great Leap Forward was not about evolution, but adaptation – and could therefore move a thousand times faster.

I don't want to oversimplify: the Stone Age did not end in 1764 with James Watt's invention of the steam engine. Clearly great leaps in human behaviour and organisation took place over preceding millennia with the advent of language, trade, agriculture, cities, writing and the myriad other innovations in production and communications that laid the foundations for humanity's industrial emergence. But I would argue that the true Anthropocene probably did begin in the second half of the eighteenth century, for it was then that atmospheric carbon dioxide levels began their inexorable climb upwards, a rise that continues in accelerated form today. This date also marks the beginning of the large-scale production of other atmospheric pollutants and the planet-wide destabilisation of nutrient cycles that also characterise this new anthropogenic geological era.

Take population. When humans invented agriculture, some 10,000 years ago, the global human population was somewhere between 2 and 20 million³. There were still more baboons than people on the planet. By the time of the birth of Christ, the globe supported perhaps 300 million of us. By 1500, that population had increased to about 500 million – still a relatively slow growth rate. A global total of 700 million was reached in 1730. Then the boom began. By 1820 we numbered a billion. That total rose to 1.6 billion by 1900, and the growth rate continued to accelerate. By 1950 we were 2.5 billion strong, and by 1990 had doubled again to more than 5 billion. In 2000 the 6 billion mark was passed. At the time of writing, in late March 2011, we number an astonishing 6.88 billion individuals.⁴ Through the process of writing this book, another 225 million people were added to the total – just under half the entire world population of 500 years ago, now appearing in just three years.

But this still doesn't answer the puzzle: Why us? And why were buried stores of carbon the 'nutrients' that allowed our species to proliferate so explosively? A satisfactory response requires a brief digression into the evolutionary origins of this remarkable hominid, for it is our past that holds the key to our present and future. This is the story of a species whose biological characteristics combined with an accident of fate to have world-shattering consequences. And it is a story that might shed some light on the central question of this book – whether we are rebel organisms destined to destroy the biosphere, or divine apes sent to manage it intelligently and so save it from ourselves.

Perhaps the environmentalist and futurist Stewart Brand put it best when he wrote these words: 'We are as gods and have to get good at it.'⁵ Amen to that.

THE DESCENT OF MAN

Listening to some environmentalists talk, it is easy to get the feeling that humanity is somehow unnatural, a malign external force acting on the natural biosphere from the outside. They have it wrong. We are as natural as coral reefs or termites; our inherited physiology is

entirely the product of selective pressures operating over millions of years within living systems. Our inner ear, for example, was once the jawbone of a reptilian ancestor. Babies in the womb begin life with tails, expressing in the earliest stages of life genes that illustrate our long evolutionary history. Our key biological characteristics – including those that have allowed us to emerge as 'sapient' beings – exist only because they conferred on our ancestors some selective advantage as they ate, fought, played and reproduced over millions of years within the natural biosphere.

The actual origin of life – how animate organisms assembled themselves out of inanimate chemicals without a Dr Venter to supervise affairs – remains a mystery. Perhaps the first self-replicating amino acids were formed in some primordial soup by a charge of lightning or a volcanic eruption. Or maybe, given the right environment and ingredients, life can spontaneously appear. Some suggest that extraterrestrial microbes may have hitched a lift onto the early Earth from passing meteors or comets. Either way, the first microbes appeared about 3.7 billion years ago, evolving into 'eukaryotic' cells – with a proper nucleus, cell walls and the capacity to metabolise energy – a billion and a half years later. These cells were probably made up of a symbiotic union of several bacteria, which is why mitochondria in our body cells today still have their own DNA. (Symbiosis, by the way, is quite as much part of the story of evolution as red-in-tooth-and-claw competition.)

Some of these early microbes, the cyanobacteria, learnt to use photons from the sun to split water and carbon dioxide in photosynthesis. They are probably Earth's most successful organisms, for cyanobacteria are still prolific today. As eukaryotic cells learned to combine to form multicellular organisms, the stage was set for a major proliferation of life – though still only in the oceans – in an event dubbed the 'Cambrian explosion' by palaeontologists. During the Cambrian, from 540 million years ago, recognisable ancestors of many of today's animal groups appeared. These include arthropods (insects, spiders and crustaceans), molluscs (snails, oysters, octopus), and even early vertebrates – the first fish. An evolutionary arms race kicked off, as predators evolved ways to catch, grip and swallow, whilst

prey developed speed or armour to reduce their chances of being eaten.

Of all the technical novelties evolution called into existence, from scales to jaws, perhaps the most interesting is the development of sight. The eye may have been the innovation sparking this intense burst of Cambrian competition, for both predators and prey would have had an equally powerful reason to evolve vision. The fossil record demonstrates that sight evolved independently in different groups of animals, though in a remarkably similar way. The octopus, for example, has an eye much like ours, with a lens and a retina behind it, yet our common ancestor was probably some kind of sightless worm. All the higher animals that survived the Cambrian could see.

The oceans now had a fully developed food web, and it may have been to escape the marine killing fields that some of the less well-armoured fish first ventured onto land – already colonised, from about 450 million years ago, by plants and insects. Fins gradually morphed into limbs, though the hybrid water–land transition is still repeated in the life cycles of today's amphibians, hundreds of millions of years later. As some of these early amphibians grew more accustomed to onshore life, they evolved into reptiles, with leathery skins to hold in moisture and eggs with watertight shells that could be laid on dry land rather than in ponds.

We are now up to 300 million years ago in geological time – nearly to the appearance of mammals, for our mammalian line is surprisingly ancient, if rather insignificant for most of its existence. The sail-back reptile *Dimetrodon* displayed many mammal-like features: its sail was probably a way to regulate temperature, perhaps demonstrating an early attempt at warm-bloodedness. Its teeth had differentiated into molars and canines, just as ours still do. Its descendants developed fur, modified – like the feathers of birds – out of reptilian scales, also as a way to control its body temperature. By the late Triassic, true mammals appeared, and were present on Earth throughout the entire age of the dinosaurs, though as very junior partners indeed. For the next 135 million years – during the entire Jurassic and Cretaceous periods – our ancestors stayed in the shadows, living furtive existences as the dinosaurs dominated the planet.

Mammals then were tiny, most no bigger than rats. They could dart out under the cover of darkness, snatching insects and worms as *Tyrannosaurus* slept. But there was an evolutionary tradeoff. Without the luxury of laying masses of eggs, and confined to burrows and crevices, mammals evolved sophisticated ways of nurturing their young: live births and lactation. Their specialised teeth enabled them to chew and grind up food, yielding more energy. In contrast the bulky dinosaurs wolfed their meals down whole. But the most outstanding adaptation of the mammals to their subordinate status was far more important than milk or molars. It was the evolution of intelligence. Contrary to popular myth, dinosaurs had big brains – not because they were smart, rather because they were big animals. But it is not brain size per se that counts for intelligence; more important are the relative proportions of brain and body, and in the diminutive mammals, this relationship was beginning to change. As one evolution textbook puts it: 'The pint-sized mammal was the intellectual giant of its time.'⁶

So why did selective pressures force this shift? Most likely, the shadowy existence of mammals demanded very different skills from those of the daytime excursions of dinosaurs. The mammalian world was one of sound and smell as much as sight, demanding more subtle skills of deduction and reasoning. The smell of a predator, for instance, could mean danger if the killer is soon to return – or safety if it is gone. All would need to be kept in memory for retrieval later. Similarly, to interpret sound on a dark night would require consulting a mental map of some complexity, adding further evolutionary pressure for larger brains. The result was the neocortex, a completely new brain structure found only in mammals. This is our 'grey matter' – vital for all higher functions that we collectively define as 'intelligence', such as sensory perception, spatial reasoning and conscious thought.

The age of mammals dawned, with spectacular suddenness, 65 million years ago. Perhaps aggravated by extensive volcanic eruptions and consequent global warming, a mass extinction tore through the planetary biosphere when a large asteroid ploughed into the sea off modern-day Mexico. Once the dust had settled, the dinosaurs were gone – along with half of life on Earth. Why mammals made it