Ten Technologies to Fix Energy and Climate

‘Goodall’s book contains much of the information you’ll need to follow the energy debates in years to come’, *The Herald* (Glasgow)

‘Rewarding and essential, *Ten Technologies* combines rigorous research and an accessible tone.’ BBC Green

‘Books about climate change can be depressing, so three cheers for Chris Goodall’s latest, *Ten Technologies*, for its positive, pragmatic message. Best of all, you don’t need science qualifications to understand it. Written in an accessible, engaging style … Small wonder, perhaps, that this timely, thoughtful book was recently chosen as one of the *Financial Times* Books of the Year. It provides some fascinating, carefully analysed insights into where we might go next.’ *Oxford Times*

CHRIS GOODALL is a writer and broadcaster on climate change issues, and editor of the website, Carbon Commentary. His previous book, *How to Live a Low-Carbon Life*, won the 2007 Clarion Award for non-fiction and was described by *New Scientist* as 'the definitive guide to reducing your carbon footprint'. He spends his free time turning off household appliances at the mains socket.

REVISED AND UPDATED

Ten Technologies to Fix Energy and Climate

Chris Goodall

*Green*Profile

To my father and mother

This revised and updated paperback edition published in 2009

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Author’s note

Units of energy

This book uses the kilowatt as the base for its descriptions of the power of the various technologies. A kilowatt is the amount of electrical energy necessary to light ten old-fashioned 100-watt incandescent light bulbs, or about a third of the power used in an electric kettle.

One kilowatt of power continuing for sixty minutes is called a kilowatt-hour.

The other units used in this book are megawatts (1,000 kilowatts), gigawatts (1,000 megawatts) and terawatts (1,000 gigawatts). To illustrate the scale of these figures, here are some comparisons. The typical European home uses about 4 megawatt-hours (or 4,000 kilowatt-hours) of electricity per year. A US household uses approximately twice as much. A big fossil fuel power station generates a gigawatt or more. The UK consumes about 350 terawatt-hours of electricity every year and the US about ten times that amount.

The book offers approximate figures for the cost of producing low-carbon energy. To put these figures in context, broad estimates of the price of fossil fuel electricity are as follows. Over the last few years the wholesale price of electric power in the UK has tended to be about 5 pence per kilowatt-hour or £50 per megawatt-hour, although it is somewhat higher at the moment (summer 2008) because of unprecedented fuel prices. The retail price of electricity sold to domestic homes is about twice this figure, covering the cost of distributing the power, maintaining the grid and billing the customer. Prices in Europe are about the same as in the UK, but those in the US are typically somewhat lower.

At times of peak demand or when the electricity system encounters a sudden problem, such as a malfunction in a big power station, the wholesale price of power can suddenly spike upwards to a level several times higher than average, as power stations that are standing idle are offered high prices to persuade their owners to start producing electricity. At present, the wholesale price at which it becomes profitable for the owner of a power station to start producing electricity mainly depends on the cost of coal and natural gas, today's principal fuels for electricity generation.

I am focusing here on electricity because a future low-carbon world will probably use more electric power than at the moment and less oil, gas and coal. Using renewable sources, such as wind or photovoltaic panels, we can generate electricity without producing large amounts of greenhouse gases and policy-makers around the world are keen to encourage a switch away from fossil fuels and towards clean electric power.

A note about greenhouse gases

This book regularly refers to carbon dioxide, the most important man-made climate-changing gas. Carbon dioxide emissions are the major part of the world's greenhouse emissions, which also include methane, nitrous oxide and several other gases which are primarily used for refrigeration or some industrial processes.

A molecule of carbon dioxide consists of one atom of carbon and two of oxygen – hence its formula CO_2. Confusingly, we sometimes talk about the weight of greenhouse gases in terms of carbon and sometimes in terms of carbon dioxide. The crucial thing is that a molecule of carbon dioxide weighs 3.667 times more than an atom of carbon. I have tried to be clear in the text as to whether I am referring to the weight of carbon dioxide or just to carbon.

Introduction

Two or three email newsletters drop into my inbox every week promising spectacular returns if I invest now in green technologies. The overexcited claims of dubious stockbrokers suggest that the battle against climate change will be won as easily as the DVD took over from video cassette. The technologies promoted in these newsletters often have a disturbing reliance on breaches of the hitherto unassailable laws of physics.

This book is more restrained. It does not claim that the world will painlessly escape from the shackles of fossil fuel dependence, quickly and cheaply building a low-carbon economy. But I hope it demonstrates that, however difficult the transition might be, the world has the tools it needs to tackle climate change. The book identifies and explores ten separate ways in which we could significantly reduce emissions or extract large volumes of carbon dioxide from the atmosphere. It also suggests that, once we have successfully switched away from coal, gas and oil, we will find that energy costs are no higher than they are today, and perhaps considerably lower. There are huge technological improvements to come that will reduce the price of low-carbon energy to a fraction of what it is today. The earlier we start a systematic programme of investment in new technologies that don't use fossil fuel, the sooner we will see the costs decline to the level of today's fossil-fuel prices.

The following chapters steer a line between the technophiles who believe that free markets will naturally bring about the growth of alternatives to oil, coal and gas and the growing number of environmental pessimists who think that the world is hurtling towards catastrophe at increasing speed. Most of the technologies discussed are still in their infancy and, although their prospects seem bright, none will advance rapidly without large amounts of risk capital, consistent and expensive support from governments (and therefore also from their electorates in democratic societies), and continued scientific advances. And I hope it goes without saying that these technologies are not a substitute for improvements to energy efficiency across industry and domestic life. The world needs a mix of technical advances and complementary reductions in energy use – including substantial lifestyle changes – if we are to stop and eventually reverse the rise in greenhouse gas concentrations in the atmosphere. Investment now in alternative technologies will also release us from reliance on oil and gas supplies imported from a small number of countries, not all of whom bear the West much goodwill.

Some of the ten technologies in this book will fail, and it is a reasonable bet that a clear majority of the innovative companies that I briefly profile will not even exist in ten years' time. This shouldn't particularly concern us. All that matters is that those technologies which do eventually succeed are rolled out on a massive scale. Even the global warming pessimists should recognise that the world's entrepreneurs, venture capitalists and scientists are devoting unprecedented amounts of ingenuity and hard work to the greatest challenge of our age. This is a global effort, and the following pages look at people and companies in places as diverse as China, the US, Ireland, Spain, Korea, India and Australia. If the world fails to solve its climate change and energy security problems, it won't be because these individuals didn't try hard enough.

The second glass problem

When speaking in public, almost all specialists engaged in the climate change debate offer a positive and hopeful view of the world's ability to tackle climate change. They know that if they say that the situation is too awful and frightening they will lose the sympathy of the audience. Speakers have to be relentlessly upbeat, stressing the capacity of the world to reduce its use of fossil fuels while still improving prosperity around the globe. With a few exceptions, the public stance of climate-change experts is that global warming is within our control, at least for the next few years.

There is often a reception after the speech and the scientist or politician speaker will stay to chat to the people who came to the talk. Glasses of indifferent wine are passed around and the conversation moves to the actions the world needs to undertake to avert the potential of unmitigated catastrophe. I have been to many of these events, and I have noticed the same thing happen on almost every occasion. Winding down after the talk, the speaker sips the first glass and continues to say that the climate problem is within the capacity of the world to solve. But as he or she reaches for a second glass, and the alcohol starts to loosen inhibitions, the speaker begins to offer a less cheerful view. The slow pace of change in attitudes among the world's political elite is witheringly dissected. (I would use the word 'glacial' to describe the rate of progress, but since some Greenland glaciers now move several kilometres a year this adjective is far too generous.) The speaker notes the mounting evidence that the relatively small increases in average temperature we have already seen are having surprisingly dramatic effects. The Arctic will probably have ice-free summers within a decade, major Asian rivers are likely to dry up for several months a year, biodiversity is declining at an accelerating rate, and increases in crop yields are slowing as drought, rising salinity and increasing temperatures affect vulnerable plants. The speaker now says what he or she really believes: the world is not yet ready to make the adjustments necessary to control climate change.

Many in the climate change debate have, understandably, moved on to a metaphorical second glass of wine. They have become deeply pessimistic about human society's capacity to change course quickly enough. They despairingly note that global carbon dioxide emissions appear to be rising at a faster rate than in any of the scenarios envisaged by the reports of the Intergovernmental Panel on Climate Change. The recent economic recession depressed oil and gas demand but the moment growth picks up, energy demand will race ahead. Few countries have begun the process of decoupling the growth in their economies from increasing fossil fuel use. Among policymakers, the pessimists point out, self-delusion abounds. The British government loudly claims success in beginning to stabilise greenhouse gases, for example, but it ignores the emissions from aviation and those 'embedded' in the ever-growing number of products imported from China.

It isn't that the world doesn't recognise that global warming is a problem. When asked, a large majority of people around the world say that human activity is causing changes in the climate. And people are concerned about these changes. In an international survey conducted by HSBC in 2007, 60 per cent of Indians said that climate change was one of their biggest worries. Global-warming sceptics still exist in large numbers but the majority of people, perhaps observing the increasingly obvious evidence from the natural world, accept that rapid and unpredictable climate variations are happening around them. Forests are more vulnerable to fire, storms are increasing in intensity, icepacks and tundra are melting and drought is causing starvation in water-stressed countries.

When individuals are asked whether climate change can be successfully controlled by humans, we see large differences between countries. People in the developing world are much more inclined to believe that the global community can successfully arrest global warming. In India, 45 per cent of respondents said we can control temperatures, but in France the figure was less than one in ten. The inhabitants of rich countries, usually responsible for a disproportionate share of greenhouse emissions, are generally not optimistic about mankind's ability to solve the carbon dioxide problem.

So who's right? Are the attitudes that come to the surface when sipping the second glass of wine reasonable, or are there good grounds for the optimism that is widespread in India, Brazil and China? Is it too late, or perhaps just too technically difficult, to reduce our economic reliance on fossil fuels?

This book argues that there is reason for very considerable optimism. Each of the ten chapters looks at a technology or technique that could reduce CO_2 emissions by at least 10 per cent of the annual world total. All of them are comfortably within our scientific and technological reach. So, to use that ugly phrase, we should be able to 'decarbonise the economy' at an affordable price.

In fact, many of the technologies in this book, such as zero-till farming or improved home insulation, can be implemented today with no permanent increase in costs. They will improve incomes, make agricultural yields more reliable or reduce household expenditure. Other technologies, including second-generation biofuels, and tidal energy, will probably be more expensive than their fossil fuel equivalents for some years or decades to come. But every chapter concludes that with reasonably predictable technological progress we can expect that our energy sources will eventually be no more expensive than at present. Importantly, I also suggest that carbon sequestration – ensuring that CO_2 is permanently stored – is a readily available option, albeit at some cost. This is very good news.

Nevertheless, I don't want to suggest for one second that phasing out fossil fuels is going to be easy. After all, when I give talks on climate change I always refuse the second drink after the speech, for fear I will let my own worries show. We should accept that some of the technologies in this book require the world to make wrenching changes to the way we do things. At the moment, for example, we power our cars with petrol or diesel. The fuel we need is available at many thousands of filling stations at the side of the roads across the world. Liquid fuels are convenient and give us unparalleled flexibility. But from a climate change point of view, it makes eminent sense to move to a world in which we all use electric vehicles powered by batteries charged with energy from renewable sources.

Eventually, battery-powered electric cars will be cheaper and easier to maintain than the dinosaurs of the internal combustion era. But shifting the world's car fleet to running on electrons rather than petrol is not a trivial task. Batteries need substantial improvement in cost, the speed with which they charge, and their capacity to store enough power to drive the car for hundreds of miles. Although the first all-electric sports cars are appearing on the road to excited reviews, this does not mean that batteries will rapidly become the main means of automobile propulsion. We need entrepreneurs and corporations to take huge risks in moving away from petrol. Governments must offer support and fiscal encouragement. Car users will need to be tolerant of the flaws of the first generation of electric vehicles. But once we have got over the humps in the road, everybody will wonder why we took so long to switch to pollution-free, easy-to-maintain, super-efficient battery cars.

Almost all of the other technologies described in this book will go through similar phases: an expensive and inconvenient

An early US wind turbine

introduction; a troubling period in which enthusiasm wanes and improvements appear to be slow; gradual acceptance by sceptical purchasers; and, eventually, a dawning sense that we really can do without the fossil fuel alternative.

There is one particularly easy way to attack my restrained optimism: point to the experience of the early 1970s. Then, as now, the price of oil had accelerated upwards at a dizzying rate. Governments and companies around the world were eager to rid themselves of dependence on the oil cartel. Research and development (R&D) programmes tried to find the best way of commercialising low-carbon technologies. Many of these R&D efforts went into precisely the same set of technical opportunities promoted in this book. The US government put money into biofuels, the Chinese invested heavily in anaerobic digestion, the UK began research into wave power, and governments in Europe backed combined heat and power plants. They are doing exactly the same today. Unfortunately, however, they are often spending a smaller percentage of our national incomes than they did thirty-five years ago.

In many cases, as the cynics never cease to remind us, the earlier attempts to speed the development of new energy-generating techniques were complete failures. Costs remained high, the technology immature and consumer interest limited, despite the investment of billions of dollars of public money. Generally declining fossil fuel prices in the three decades after the oil shock of the early seventies caused governments to lose interest and most research efforts faded away. It is one of the great ironies of the last few years that some of the scientists involved in the 1970s alternative-energy drive have been brought out of retirement to restart the same R&D programmes that were abruptly shut down decades ago. The people who came closest to finding an industrial-scale technology for making diesel fuel from growing and then crushing algae are back in the labs they left thirty years ago.

Some of the other early pioneers of low-carbon technologies, perhaps conscious of the transience of the interest of government and investors, have decided to move on. Salter's Duck, one of the first wave-power collecting devices, was designed in 1974, just after the oil shortages of the preceding year. It was a genuine advance and its efficiency in capturing the energy in waves has scarcely been bettered since. Professor Stephen Salter, its South African-born inventor, now has the pleasure of watching wave power finally being commercialised. But in the interim, after decades of minimal official interest in renewable power, Professor Salter has switched focus. He and his colleagues are now investigating a technology to increase low-level cloud cover over the oceans. Since low clouds block the sun's rays, Salter's scheme might help limit global warming. This is one of the ten or so 'geoengineering' projects that the more pessimistic among the scientific community are investigating in the hope of dealing with the consequences of the carbon dioxide build-up, rather than trying to avert it. The concluding section of this book looks sceptically at how we might employ some of these schemes in a climate emergency.

Given the rapid fall in enthusiasm for alternative energy two or three decades ago, why should we believe that the current level of interest will be any more persistent? Is it not simply naive for us to think that the nascent technologies of solar power, fuel cells and advanced biofuels will ever be competitive with fossil fuels? Three forces bolster my optimism.

First, many of the technologies that looked good in 1973 but failed commercially have experienced significant and sustained reductions in price since then. Many important low-carbon technologies – most obviously wind power – have come down in cost with almost predictable regularity. Consistent with the well-understood theory of the 'learning curve', manufacturing costs have gone down by a similar percentage every time the number of units produced has doubled. If the experience of almost every single manufacturing industry in the world is any guide, the next doubling of the accumulated volume of wind turbines will reduce costs by approximately the same percentage. Even though the recent headlong rush into wind power caused a sharp spike in equipment prices, underlying costs will continue to fall as manufacturers gain knowledge of how to build turbines more cheaply. By contrast, as the world pumps more oil from its increasingly depleted stocks, the price will almost certainly tend to go up. Although we continue to see far more money invested in oil exploration than in the development of alternative energies, the number of barrels found per million dollars spent is still declining. At some point, perhaps soon, the financial returns to investment in low-carbon technologies will exceed those from drilling for oil and gas. At that point, costs of new technologies are likely to sharply dip.

Second, the world is now concerned about climate change. With the exception of a few peculiarly far-sighted scientists, no one was worried about global warming in the early 1970s. This means that low-carbon technologies are more likely to garner the long-run support and subsidy that they need.

Third, opinion leaders around the globe have an increasingly strong sense that the world is beginning to run out of minerals, or at least failing to keep up with the increase in demand. The recent simultaneous increases in the prices of metal ores, fossil fuels, and fertiliser sources such as phosphate created awareness – not before time – that the globe cannot be indefinitely mined. It now seems painfully obvious that future economic growth cannot be based on unlimited supplies of raw materials, available for little more than the cost of extracting them from the ground. This is a sharp about-turn from the attitudes of even five or ten years ago when pessimism about the long-run availability of raw materials was confined to a few inveterate doom-mongers. Even if we did not need to reduce fossil energy consumption for climate change reasons, there are compelling reasons to find ways of living without continuous recourse to scarce and increasingly expensive materials extracted from a thin layer of the earth's crust. Low-carbon energy sources have the advantage of working with the grain of this important change in the *zeitgeist*.

Obstacles to the ten technologies

Just because a technology is good and its financial advantages clear does not mean that it will be seamlessly and quickly incorporated into widespread use. In each of the ten chapters of this book, I try to note the chasms that have to be crossed – technical and financial – before we see truly widespread adoption of the most promising of low-carbon opportunities. I have done this partly to rebut the accusation that the chapters of this book are little more than public relations on behalf of the new industry on which I am commenting. I also suspect that we will go through several cycles of elation and disappointment before the full outlines of a low-carbon society become clear. It is better to recognise early that the road is not going to be easy.

Loss of convenience

One of the main obstacles to the adoption of new technologies is the ubiquity of the existing infrastructure that enables us to use fossil fuels cheaply and conveniently. Thousands of billions of dollars have been spent building natural gas pipelines and storage tanks, electricity distribution grids, huge coal- and gas-fired power stations that operate safely and reliably, mostly with few hours each year of unscheduled maintenance, and networks of oil refineries and filling stations. It won't be easy to switch away from the pipes, wires, buildings and machines that have been so expensively built up over the last century or so and have served the inhabitants of prosperous countries so well.

It is true that some alternative energy products can be fitted into the existing infrastructure. Cellulosic ethanol can, for example, be mixed with conventional gasoline without requiring new cars, filling stations or oil refineries. But other technologies require new distribution systems. Wood-based community heat and power plants, for example, rely on the installation of hot water pipes around urban areas. The large companies at the centre of the fossil fuel economy – electricity generators, oil companies and pipeline operators – have the human and financial resources to invest in projects of this scale. Few institutions have the financial capacity or skills to do the same in the low-carbon world.

Moreover, our lives are currently structured around instant and consistent access to energy. For example, the electricity system in advanced countries offers nearly universal access and reliability. Even a brief power loss in a developed nation can prompt startled front-page newspaper headlines. It would be naive to expect that low-carbon technologies could match this reliability, and replace all the other advantages of fossil fuels, within a few short years. We will go through periods when the new technologies fail, provide only intermittent supply, and cost more than their fossil fuel equivalents.

Archive films from around 1900 show many spectacular, and often very funny, failures of prototype airplanes to get off the ground. Low-carbon research will throw up similar disasters. The last few years have offered several good examples. In one case, algae