Praise for *Challenged by Carbon*:

"The author's enthusiasm leaps out of every page and the result is a very readable, jargon–free and informative book on climate change. As a geologist he sets the present in the context of past changes. Anecdotes, personal reminiscences and clear science will captivate and inform the general reader and may well offer new insights to the specialist. A really good read."

Lord Oxburgh, House of Lords Science and Technology Committee

"As a geologist Lovell gives an authoritative insider's view of the oil industry's various approaches to climate change and the contribution industry can make through carbon capture and storage. Enlivening the book with geological insights, he also maps out the government frameworks needed to meet the climate challenge."

Sir Mark Moody-Stuart, former Chairman of Royal Dutch/Shell and Anglo American plc

"Bryan Lovell's voice is a new one on the climate change stage. Compelling, lucid, and enjoyable – this book demystifies geology for the non-specialist and elucidates how geologists and the oil industry can contribute solutions to the problem of global climate change."

Professor Robert Socolow, Princeton University

"Bryan Lovell has produced a remarkable book which draws on a lifetime of experience in the oil industry to identify new and creative ways of dealing with the challenge of global warming. This is a book which deserves the widest audience not just within the scientific community and the energy industry but also at the highest levels of policy making."

Nick Butler, University of Cambridge and Senior Policy Adviser, 10 Downing Street

"Bryan weaves a compellingly entertaining story – the Oil Industry's change in attitude to carbon is well documented, as is the capability for 'putting the carbon back'. The book then highlights the author's frustration at the continued absence of an international regulatory regime that is capable of addressing the real objective function."

Dr David Jenkins, Director of BHP Billiton plc and former Director Technology BP plc

"The central theme of *Challenged by Carbon*, that the oil and gas industry is a vital part of the solution as we transition slowly to a lower carbon energy future, is one that I heartily endorse."

Professor Scott W. Tinker, University of Texas at Austin, State Geologist of Texas and former President of the American Association of Petroleum Geologists

Challenged by Carbon: The Oil Industry and Climate Change

Is there a low-carbon future for the oil industry?

Faced with compelling new evidence from the rocks that lie at the heart of its business, the petroleum industry is no longer able to ignore the consequences of climate change brought on by consumption of its products. Yet across the globe we will continue to need to burn fossil fuels as we manage the transition to a low-carbon economy.

As a geologist, oil man, academic and erstwhile politician, Bryan Lovell is uniquely well placed to describe the tensions accompanying the gradual greening of the petroleum industry over the last decade. He describes how, given the right lead from government, the oil industry could play a crucial role in stabilising emissions through the capture and underground storage of large volumes of carbon dioxide.

Lovell challenges entrenched prejudice on both sides of the debate between the environmentalists and the oil industry, giving a glimpse of oil barons as prospective environmental saviours rather than traditional stage villains. Ultimately he assigns major responsibility to us as consumers and to our elected governments, highlighting the need for decisive leadership and urgent action to establish an international framework of policy and regulation.

BRYAN LOVELL holds B.A. and M.Sc. degrees in geology from the University of Oxford and a Ph.D. from Harvard University. Following 12 years as a lecturer in geology at the University of Edinburgh and as a consultant to the oil industry, he worked for BP Exploration from 1981 to 1996, joining as Chief Sedimentologist, and subsequently holding positions as Exploration Manager and General Manager Ireland, International Exploration Manager with special responsibility for Middle East, and Head of Recruitment, BP Group. He is currently a Senior Research Fellow in Earth Sciences at the University of Cambridge, working on controls exercised by mantle convection on the elevation of Earth's surface, and continues to provide consultancy advice to the oil industry. Dr Lovell was the Scottish Liberal Party energy spokesman from 1978 to 1979 and ran as a parliamentary candidate in 1979, finishing third out of five behind Michael Ancram and Gordon Brown. He was awarded an OBE in 1989 for services to Anglo-Irish relations and has recently been elected President-designate of The Geological Society of London (2010–2012).

Challenged by Carbon

The Oil Industry and Climate Change

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Acknowledgements

Young geologists learn by looking at rocks in the company of older geologists. Older geologists keep learning about rocks by looking at them in the company of young geologists. All geologists learn by looking at rocks with people who aren't even sure what geology is. So over the years I have become indebted to many people, several of them characters in the story told here: thanks to all of you.

Then there are those who have helped quite specifically with the preparation of this book, through some combination of encouragement, advice, gift of materials and warnings. My thanks go to: Francisco Ascui, Claire Budd, Nick Butler, Andy Chadwick, Anthony Cohen, Harry Elderfield, Susan Francis, Gardiner Hill, James Jackson, David Jenkins, Jeremy Leggett, Heather Lovell, Dan McKenzie, Mark Moody-Stuart, Ted Nield, Richard Norris, Heather Poore, Robert Socolow, Bob White, Nicky White and Eric Wolff.

We geologists prefer to spend most of our time outside, looking at rocks in many places and in all weathers. When measuring sandstones on an exposed cliff and recording their special features in a field notebook, it is a big help to have a resolute companion with neat handwriting. It is even better if she can see beyond the cliff. This book is for Carol.

Preface

Within the last decade the scientific case for anthropogenic climate change has become significantly more plausible. New observational science offers crucial support for the computer-based speculations of those creating models of climate change. The record of Earth's past climates recorded in rocks and ice can now be measured with far greater definition than before: divided into thousands rather than millions of years. This major breakthrough means that changes in climate that took place long ago can now reasonably be compared with those seen in the recent past.

One of these past changes in climate is a particularly important guide to present-day concerns: a dramatic warming event that took place 55 million years ago (55 Ma). Comparison of the volume of carbon released to the atmosphere 55 million years ago and the volume we are now releasing ourselves strongly suggests that we are indeed facing a major global challenge. We are in danger of repeating that 55 million-year-old global warming event, which disrupted Earth for over 100 000 years. That event took place long before *Homo sapiens* was around to light so much as a campfire. Now we have no excuses, we are here and we are aware of our capacity to precipitate major inimical changes to our habitat on this planet. We can cope, but only by adopting a new intellectual framework for energy policy that is based on that awareness.

This is an unusual challenge to the established order, comparable to the greatest periods of political and social change.

Successful resolution will require an unusual degree of cooperation between all sorts of tribes: academic, social, financial, industrial, political and national. This kind of cooperation was the real value of the 1997 Kyoto Protocol and is the hope for the crucial successor meeting in Copenhagen in 2009. The Kyoto agreement was never going to be a sufficient answer in itself to coping with climate change, but it was a sign that the global community has the capacity to edge towards the scale of cooperation that is required.

That cooperation clearly has to embrace China and India. These two countries are moving along paths of development that emulate those followed previously in the developed world, with heavy reliance on fossil fuels – especially coal. If the source of energy for development in China and India remains as it is now, the per-capita emission of carbon in those countries will continue to increase rapidly. On a planet with a forecast increase in human population measured in billions during this century, per-capita measurements become ever more significant. At the beginning of the twenty-first century the per-capita emissions in China and India were an order of magnitude lower than those in North America, Europe and Russia: now that gap is closing. Can the developing countries be helped to achieve their aspirations for rapid development while maintaining a low per-capita output of fossil carbon? Can the developed countries maintain the confidence of their consumers and voters while reducing per-capita output of fossil carbon?

Here the oil companies may have a chance of redemption from their classical role as the villains of climate change, by giving a positive response to being challenged by carbon. In principle they could capture and then store safely underground a good part of the fossil carbon released to the atmosphere through their agency – and that of the coal industry – although the price in energy and dollars of that capture and safe storage is still not clearly defined.

Emissions of greenhouse gases by the oil companies may be divided into those resulting from their own operations (a little over 10 per cent of the total), and the remaining quantity (approaching 90 per cent of the total) that is released by the use of

their products by their customers. The oil companies have made considerable efforts in recent years to control greenhouse gas emissions from their own operations, not necessarily to their commercial disadvantage. Responsibility for coping with the far greater quantity of emissions resulting from the use of oil company products by customers has yet to be assigned.

At this stage, a series of broad questions may be framed, by no means complete, but an indication of the scale of change required:

Can the major international non-state oil companies, who control only a few per cent of the world's reserves of oil and gas, persuade their shareholders to keep investing when they seek to make money by disposing of fossil carbon (in the form of anthropogenic carbon dioxide), as well as profit by pumping it out of the ground (in the form of oil and natural gas)?

Can the major state oil companies, who control the greater part of the world's reserves of oil and gas, persuade their governments that part of their role should be the safe disposal of carbon dioxide?

Can political, economic and financial institutions adapt to a global imperative to regard the safe capture and disposal of carbon dioxide as an activity as important as taking fossil fuels out of the ground?

Can cutting demand for energy be given similar emphasis to ensuring supply?

Can a representative democracy accept as an overriding basis for policy an intellectual framework that demands a perspective of fifty years rather than five?

Can both governments and governed come to regard activities that restrain per-capita output of carbon as a social good, on a par with provision of health services and education?

It is claimed in this book that all this could be achieved, given a widespread deep conviction that there really is a problem to be solved. We already have to hand the technology to give ourselves breathing space. So the six questions posed above hinge on yet another question: how can that depth of conviction be achieved? It is argued here that the study of rocks can provide, from observational science rather than from computer-based

models, the necessary depth of intellectual conviction that there is a problem in the first place. Then the significant role that subsurface storage of carbon dioxide could play in resolving that problem is assessed, with particular reference to the future of the oil industry.

This book is written from the individual perspective of a geologist with a range of experience in universities, industry and politics. Specifically it is based on a working knowledge of the rocks in which oil is found and in which carbon dioxide could be stored. Broadly it is based on the expertise of those I have been lucky enough to have as teachers, colleagues and students. This large debt is acknowledged throughout the narrative. In that respect, readers familiar with operations in the oil industry might now anticipate a homily on team behaviour. They can relax a little: the need for intense cooperation between different tribes to cope with climate change should be obvious enough from the story itself.

Lying between mainland Europe and the UK is the source of much late-twentieth-century prosperity: the North Sea. The story told in this book has this oil province and those working there as a recurrent theme. It was among those with experience in the North Sea that much of the crucial change in thinking took place. For environmentalists and oil folk alike it is an important source of evidence and ideas. The many Earth scientists who are involved in energy and the environment have a common meeting place, Burlington House in Piccadilly, London. There the Geological Society of London belies the age of its building, and its status as the world's oldest geological organisation, by mixing academics and industrialists in politically alert discussion and debate on topics of contemporary public significance. Reports of innovative activity on climate change are published by the Society for the benefit of its Fellows: these reports are gratefully drawn on here for presentation to a wider audience.

There has been an apparent contrast with the story in North America, a distinction now happily fading. Until recently an environmentally alert European visitor to Alberta and Texas would have found disappointingly little concern within the oil community that their industry might be a significant part of a serious and

developing problem with climate change. Fossil carbon was taken from the ground with increasing enthusiasm from ancient wells in the Permian Basin of Texas at times of rising prices and was cheerfully passed to the customer for eventual release to the atmosphere as carbon dioxide. Canadian tar sands were mined using a deal of water and energy to release the sticky oil, with thoughts of profit apparently running well ahead of environmental concerns. These attitudes have until recently been reflected in the leadership and policy of professional organisations such as the American Association of Petroleum Geologists (AAPG). Those of us involved with both the AAPG and the Petroleum Group of the Geological Society in London have had plenty of contrasting literature to consider and debate over the last decade.

The key issues of climate change will eventually be resolved in one way or another on a global scale, not just in Europe and North America. Fortunately a natural virtue of the oil industry is that it is obliged to be international. Oil and gas are not distributed evenly on this planet and most of the remaining reserves lie outside the North American and European homelands of the major non-state oil companies. Only part of Earth was covered by the ancient Tethys Oceans, the geological evolution of which led to the concentration of oil in what is now the Middle East. Will the oil industry be able to seize the advantage of its global perspective to bring general environmental benefit to its customers, while protecting its own profits? We have long relied on the oil folk to use their ingenuity to supply us with their mighty handy products: now we need their inventiveness to help us manage our transition from that dependency.

Is the industry prepared to help? The scale of the problem is certainly recognised. The view of Shell was given by their Vice President CO_2, Mr Bill Spence, in a public lecture at the Geological Society in London on 4 November 2008 (Spence, 2008). By the middle of this century we shall need to supply a much larger global population, aspiring to greater wealth, with double the amount of energy used today. All that energy will have to be supplied while emissions of carbon dioxide are severely restricted: the huge numbers involved are the subject of much of this book. The tribes will certainly need to combine to

tackle this extraordinary task. Not least of those tribes is the oil industry.

Before we take these issues further, one important matter needs to be faced. Is the earnest enquiry set out in this book entirely misplaced from the very start? Are we already too late? Should we be concentrating on how to cope with the apocalypse, because we have little hope of avoiding it?

There are those, notably that doyen of the environmentalists, Dr James Lovelock (2006, 2009), who consider that we have abused the planet beyond hope of redemption. In this gloomy view of our prospects, all we can do is prepare to act defensively as climates change dramatically, sea-level rises, and mass migrations and the collapse of societies test our species to the limit. Possible defensive actions taken in these dire circumstances would differ in significant respects from the actions humankind might take to prevent the very occurrence of such disasters: seeking a balance between mitigation and adaptation (Bierbaum, Holdren, MacCracken, Moss and Raven, 2007; Hunt, 2009) would no longer be a priority.

Whatever the merits of considering a range of defensive actions at this stage, one would have to be very sure that disaster was inevitable before ceasing to try to avoid it. A premise of this book, based on a reading of the reality written in the rocks, is that we cannot be confident that we have gone beyond Lovelock's point of no return. If across the globe we now unite in wise action, we can still turn back from the edge; if not to stability, at least away from the apocalypse.

This book attempts to explain in plain language how this relative optimism arises from the study of rocks. We geologists, like doctors and lawyers, seek to protect our income by using obscure language to describe quite ordinary things. I hope that such jargon is not obvious in this book, or that at least it is explained where it does creep in. For those who wish to study the scientific papers to which I refer, a word of warning. Jargon rules the day in some of these publications, although access to the largely comprehensible abstracts should in most cases be easy enough; I recommend simply typing the names of the authors into Google or Google Scholar, with the year of publication and a key word or two from the title.

A key point underpins this book: you can't argue with a rock. We can simply try to understand rocks by examining them carefully in the field and laboratory, using our wits and our imagination. Rocks are tangible objects that humans find useful for many purposes, including the provision of energy and the disposal of waste. So there is reality in rocks that we should strive to grasp.

In that spirit, Chapter 1 describes how a few refreshingly jargon-free geologists had a key influence on the relationship between the oil industry and the environmental movement at the crucial time of the Kyoto climate summit in 1997. Following that bit of modern history, we go way back in time. Chapter 2 shows how 55-million-year-old rocks record the reality of a warming event that is a salutary guide to our present concerns on climate change. This account draws on the emerging detailed understanding of that 55 Ma warming event on a human timescale. That 55 Ma perspective was available to participants in a 2003 international scientific conference that is considered in the last of the three introductory historical chapters; Chapter 3 has at its core the illuminating transcript of the March 2003 Geological Society debate in London on *Coping with Climate Change*, featuring two of the several Vice Presidents of BP and ExxonMobil. From a strict environmentalist's perspective this could be seen as a discussion between the damned and the devil, but here it is interpreted as the beginning of an important convergence across an earlier Atlantic Divide in the oil industry – a convergence that continues apace.

With the historical scene now set, Chapter 4 examines the strategic options open to the oil industry in reacting to today's growing scientific and political interest in climate change. The restraint imposed by rocks on all parties is identified. But do we have an intellectual framework within which this recent carbon challenge to the oil industry may be embraced in a new strategic outlook? Chapter 5 claims that we do have such a framework, and summarises a largely Princeton University-generated integration of engineering, economics and social science within which the oil industry can consider its strategic options. Carbon capture and storage (CCS) is picked out as a potentially significant contribution that the oil industry can make to controlling our release of

carbon to the atmosphere, by putting back underground the carbon that the oil and coal industries have taken out for our eager use.

Can CCS be readily implemented by petroleum geologists and engineers? For them the principles and practice of CCS set out in Chapter 6 are second nature. Finally, how could CCS be made to happen? Chapter 7 places the onus firmly on government to set a framework of carbon policy and regulation, within which such vital activity as CCS can take place without beggaring everybody involved. This global regulatory framework for coping with the imminent carbon crisis should be well within the range of world leaders hardened by the financial crisis that began in 2008.

Chapter 8, 'The proof in the puddingstone', is a personal coda, connecting various events 55 million years ago to us. Puddingstone is an exceptionally hard rock, with a tough silica cement that probably formed as a result of the intense heat at Earth's surface during the 55 Ma warming event. The recent discovery of a hitherto elusive Roman puddingstone quarry north of London triggers a series of connections, including links to the 55 Ma reservoir sandstones at Forties field in the UK North Sea and to the carbon released to the atmosphere by our use of Forties oil.

For the Roman invaders of Britain settling in the Thames Valley a couple of thousand years ago, puddingstone was to become a key element in an essential technology: grinding corn. That particular imperial legacy now consists only of beehive querns and a few angular fragments of rock. This book says that our use of carbon cannot be allowed to become a millstone round the necks of our grandchildren – and it does not have to be. Our governments should give the putative environmental villains of the oil industry the chance to become carbon heroes: challenged by carbon yet not found wanting.