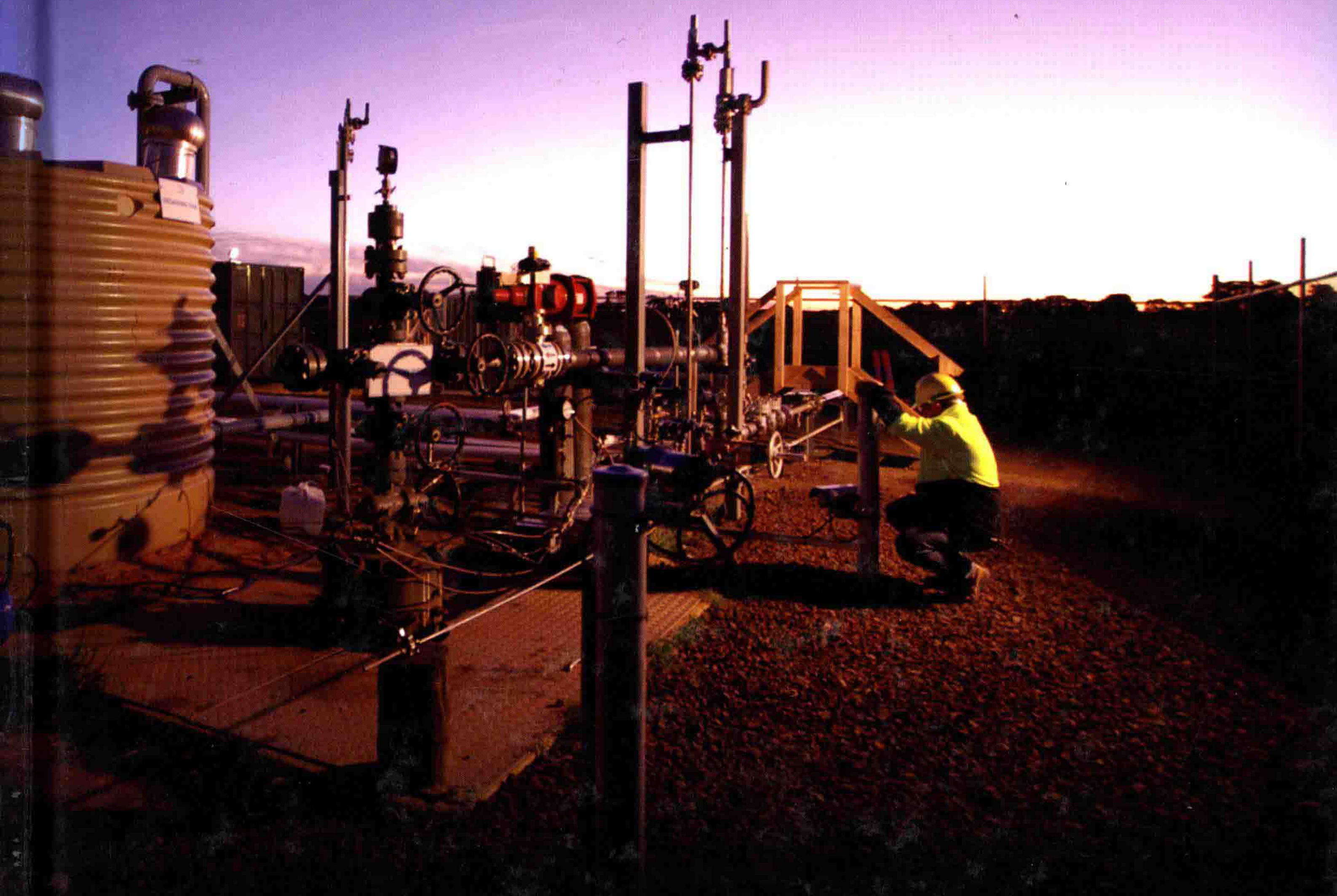
GEOLOGICALLY STORING CARBON

LEARNING FROM THE OTWAY PROJECT EXPERIENCE



EDITOR: PETER J COOK

WILEY

GEOLOGICALLY STORING CARBON

LEARNING FROM THE OTWAY PROJECT EXPERIENCE

EDITOR: PETER J COOK

CSIRO PUBLISHING

WILEY

Published exclusively in Australia and New Zealand by

CSIRO Publishing
150 Oxford Street (PO Box 1139)
Collingwood VIC 3066
Australia

Email: publishing.sales@csiro.au
Web site: www.publish.csiro.au

Published in the Americas, Europe and Rest of the World (excluding Australia and New Zealand) by

John Wiley & Sons Ltd
The Atrium, Southern Gate
Chichester, West Sussex
PO19 8SQ United Kingdom

Email: customer@wiley.com
Web site: www.wiley.com

For distribution in the rest of the world other than Australia and New Zealand.

Library of Congress Cataloging-in-Publications Data
A catalogue record for this book is available from the British Library and the Library of Congress.
ISBN: 9781118986189

Front cover image: Rebecca Jones, CO2CRC
Back cover image: CO2CRC

Set in Adobe Garamond Pro
Cover design by James Kelly
Text design by Roslyn Paonin
Typeset by Roslyn Paonin, Jo Ashley, Matthew Harris
Index by Indexicana
Printed in China by 1010 Printing International Ltd

Original print edition:
The paper this book is printed on is in accordance with the rules of the Forest Stewardship Council®. The FSC® promotes environmentally responsible, socially beneficial and economically viable management of the world's forests.

FSC www.fsc.org MIX Paper from responsible sources FSC® C016973

GEOLOGICALLY STORING CARBON

For our children and grandchildren

FOREWORD 1

Carbon dioxide capture and storage (CCS) is one of the most important approaches for achieving large and rapid CO_2 emission reductions. Pioneering projects initiated in the 1990s demonstrated that CCS could be safe and effective at an industrial scale. With growing concerns about global climate change, and encouraged by these early successes, governments, industry and academia in Australia, Europe, Japan and North America initiated research programs to accelerate bringing this technology to the global scale needed to make substantial reductions in CO_2 emissions.

The Otway Project, Australia's premier CO_2 storage demonstration project, has identified and tackled the most pressing issues needed to bring this technology to scale. Some of these challenges are purely technical, such as the need for improving site characterisation and monitoring methods. To address these issues, the Otway Project assembled a world-class team of geologists, geochemists, geophysicists, hydrologists and reservoir engineers. Together they designed and implemented a large-scale demonstration project that would provide a replicable model for how to decide which sites are suitable for CO_2 storage and to develop methods for monitoring the fate and transport of injected CO_2. They worked closely with regulators to ensure that the data would satisfy their requirements and leveraged industry capabilities to bring state-of-the-art tools and know-how to the Project. Having successfully demonstrated that this suite of measurement and modelling tools are up to the job, they then went one step farther. They developed an entirely new approach for quantifying the extent of residual gas trapping—an important secondary trapping mechanism that increases storage security over time. On the strength of these contributions alone, the Otway Project is second to none.

Importantly, however, many new and unforeseen issues emerged as the ambitious project ploughed new ground—cutting across the traditional boundaries of business, law and the social sciences. What is the appropriate business model for public–private partnerships for one-of-a-kind demonstration projects? Who is responsible if something goes wrong? How do you communicate and work cooperatively with the local community? Here, more than any other project, the Otway Project shines light on the full spectrum of challenges and then offers solutions for moving this technology forward.

There are so many unique contributions from this project, from business models to regulatory frameworks, from public engagement to communications research, and from site characterisation to fundamental research on trapping processes. This extraordinary book documents these contributions, with over 40 authors from four continents who provide a rich and detailed account of all aspects of the Project. They generously share more than a decade of learning. This book provides invaluable contributions to advancing the state-of-the-art and practical know-how about CO_2 storage. I thank the authors for this wonderful book and the countless hours of hard work, scientific inspiration, and the fortitude that brought this project to fruition. In the future, our children and grandchildren will also thank them for pushing this important technology for reducing CO_2 emissions forward.

Professor Sally Benson
Director, Global Climate and Energy Project
Stanford University, USA

FOREWORD 2

This book documents the amazing journey of applied research undertaken by the CO2CRC Otway Project over the past decade, involving industry, researcher and government collaboration, local community engagement and political and international interaction. All of this is against a backdrop of rapidly increasing global fossil fuel emissions and growing scientific insights into global warming. CCS promises to be a vital part of any serious global response to climate change and the Otway Project has made and will, no doubt, continue to make a significant contribution to this unfolding endeavour.

The Otway Project is important to Australia as the nation's large fossil fuel reserves are potentially affected in a future requiring substantial emission reductions. Victoria is particularly vulnerable with its substantial but high emission brown coal resources and related energy production. In a world that will ultimately see CCS widely deployed, the Otway Project will be seen to have made a significant contribution to the emerging new discipline of subsurface carbon storage technology; all the more so because of this book.

For Australia, the safe storage of more than 60,000 tonnes of CO_2 serves as a clear example of the practicability of this new technology, while giving added confidence to communities and regulators alike. The storage of CO_2 in a depleted gas field in the Otway Basin combined with a strict encompassing scientific and monitoring regime, has established an outstanding international reputation for the Project. The lessons and insights are set out comprehensively in this volume, from the project design and engineering to the community and regulatory processes. Most importantly it brings together the scientific insights and technologies for carbon storage, building a new discipline on the well-established knowledge and principles of subsurface engineering and geoscience from the oil and gas industry.

The Project is unique because of its scale, its significant in-situ CO_2 reserves, a supportive local community and the established constructive relationship with local regulators. Importantly, the more work that has been done on the site, the better characterised it has become. The rich data sets of subsurface geology, geochemistry, geomechanics and geophysics make it increasingly valuable as a test bed for the study of new techniques and technologies.

Ultimately it has been the people and organisations with vision and drive that have made this Project and its outstanding science a reality. The planning and execution of the experiments, approvals processes, funding, governance, community engagement and analysis and interpretation of results, has required a dedicated team of people with a wide array of experience and skills. The Project has seen the direct and indirect involvement of many experts from industry and some of the world's leading scientists in the field. One person that deserves particular mention is Peter Cook for his leadership, vision and unfailing enthusiasm to make a difference. He has led an outstanding team setting up and running the Project. It has been an inspired personal quest for him, from the time he started the Project, to the effort put into the delivery of this book. Both will be seen as a monumental legacy in the field of CCS.

Dr Richard Aldous
Chief Executive, CO2CRC

PREFACE

A great many scientists, policy makers, environmentalists and the community at large are concerned about the potential climatic impact of increasing concentrations of greenhouse gases in the atmosphere, particularly CO_2. And even those not convinced of a CO_2–climate link, that argue there is too much uncertainty to warrant action, must surely recognise that if we are not certain of the impact, we should stop emitting CO_2 to the atmosphere in ever-increasing quantities. In other words, should not the Precautionary Principle apply? Many point to the importance of renewable energy in mitigating CO_2 emissions and it is certainly true that renewables, along with greater energy efficiency and switching to low intensity fuels, all have a part to play.

But it is unrealistic to believe that the world can completely switch to renewable energy almost overnight. Such a transition will take decades and will require much improved technologies to be developed, critically including far better systems for energy storage. Also, the cost of mitigation and of the move to clean energy cannot be ignored; we cannot spend all of the world's wealth on addressing greenhouse concerns when there are so many other problems needing resolution. Wealthy countries may choose to spend a high proportion of their GDP on clean energy, but some countries, particularly developing countries, may have no alternative but to continue to use fossil fuels for energy because they cannot afford the high cost of alternative energy, or because fossil fuels are their only practical option. In other words there is little prospect of moving totally away from fossil fuels anytime soon. Some may see this as a defeatist view but I see it as a realistic view that should be the starting point for any sensible mitigation strategy.

The International Energy Agency, the IPCC, NGOs, government organisations and many leading scientists, have pointed to the critical importance of deploying CCS (carbon capture and geological storage of carbon dioxide) in a carbon constrained world. Despite the increasing application of renewable energy, the use of fossil fuels continues to grow worldwide. Coal is the fuel of choice of many countries because it is cheap and abundant, but it does inevitably result in increasing emissions of CO_2. In many developed countries gas is seen as the future fuel of choice with the benefit of producing lower carbon emissions, but obviously it too produces significant CO_2 emissions, albeit less than coal produces. Therefore whether the energy fuel of choice is coal or gas, for as long as we continue to use fossil fuels, CCS is the only technology available for making deep cuts in the emissions arising from that use. But despite this, CCS has yet to be widely deployed.

So why is CCS not being widely deployed? The argument is often advanced that CCS is too expensive at an industrial scale. The reality is that CCS is more expensive than some renewable technologies that are in use, but less expensive than others. It is therefore vital to keep CCS in the mix of clean energy technologies, while at the same time working to bring down the cost of CCS and particularly the cost of capture. The claim is also frequently made that CCS is "unproven". The reality is that separation and capture of CO_2 is used extensively in large scale gas processing and tens of millions of tonnes of CO_2 are injected into the subsurface every year as part of enhanced oil recovery operations. There are also thousands of kilometres of CO_2 pipelines already in existence. In other words many parts of the CCS chain are already in operation. What is not yet in operation is integrated CCS applied to large scale coal- or gas-fired electricity generation, although power plants with CCS that are under construction in Canada and the USA will go some way to addressing this criticism.

However much of the challenge to the widespread deployment of CCS lies in a lack of knowledge of storage technology which in turn breeds "fear of the unknown", that in turn can translate into an unwillingness on the part of individuals, communities and governments to countenance CCS as a mitigation option. The town of Barendrecht in Holland is an example of a community living safely and confidently above a large accumulation of natural gas for many years, but unwilling to consider using that same geological structure to store CO_2. Some governments, for example Germany, have banned underground onshore storage of CO_2 because of perceived risks and uncertainty and because of community opposition. There is really only one way to address these concerns and that is by actually undertaking CCS and clearly and convincingly demonstrating in an open and transparent manner, that CO_2 can be safely, securely and effectively stored, and that it is a credible option for addressing greenhouse concerns. Ideally this would be done at a scale needed to make significant cuts in emissions now, and there are examples of this, for example the Sleipner Project in the North Sea, the Weyburn Project and soon the Boundary Dam Project in Canada, but such projects are often constrained by commercial concerns or logistics that inhibit them from providing open access. Similarly they cannot be expected to be used as sites for a wide range of fundamental research into CO_2 storage when they have commercial imperatives that have to be addressed.

For these and other reasons, smaller scale demonstration or pilot projects are often chosen as the way forward. Their cost is modest compared to a large-scale project; they can be undertaken within a reasonable time frame; and they provide an excellent low cost opportunity to undertake research that will in turn address uncertainties that may confront large scale projects. Crucially they also provide the opportunity not only for scientists and engineers to see and test CCS technology under field conditions, but also the chance for politicians, NGOs, regulators and members of the community to see CCS for themselves. The opportunity to "kick the tyres"; the chance to hear firsthand from the scientists how they know what is happening in the subsurface and why they are confident that the CO_2 will not leak to the surface or contaminate aquifers.

It was with all of these issues in mind, that in 2003 I first set about trying to persuade people that we should undertake a CO_2 storage project in Australia at a commercially significant scale. Given Australia's reliance on fossil fuels there was a compelling case for getting a project underway as soon as possible. But as is so often the case with "first of a kind" projects, it was to take several years before the first molecule of CO_2 could be injected. That project was of course the CO2CRC Otway Project.

This book outlines the progress and achievements of the CO2CRC Otway Project, Australia's first CO_2 storage project, over the period from 2003 to 2013. From a personal perspective, the genesis of the Project and this book can be traced back more than 20 years. I was Director of the British Geological Survey at that time and first became interested in geological storage of CO_2 through some of the early work of BGS on North Sea storage opportunities. This in turn led me to initiate the GEODISC Project in Australia in 1998, and then in 2003 as Chief Executive of CO2CRC, to develop the idea of undertaking an actual storage project. But it is one thing to develop the "vision" and it is entirely another thing to turn that vision into the reality of a successful project; that is the part that requires the hard work! The 45 authors of this book were of course a critical component of the Otway team that has achieved so much over the past 10 years.

Geologically Storing Carbon provides a detailed account of the CO2CRC Otway Project, one of the most comprehensive demonstrations of the deep geological storage of carbon dioxide undertaken anywhere. This book of 18 comprehensive chapters written by leading experts in the field is concerned with outstanding science. But it is not just a collection of scientific papers and indeed much of the science has already been published in peer-reviewed journals, which is as it should be. What this book is about in particular is "learning by doing". It describes the organisational, governance and decision-making processes that were used, and outlines how the storage site was chosen and what was done to prove its suitability. It also describes how and why the Project went about securing a source of CO_2 and the various options for processing the gas.

The book also provides insights into the operational details of the Project, including risk assessment and ensuring that the site was geologically suitable for taking the Project forward. A major program of scientific investigation was undertaken, which involved activities as diverse as obtaining fluids from 2 km down a well and 500 m in a water well; sampling a few centimetres in the soil and sampling in the atmosphere. How the samples were obtained and how they were analysed is described in some detail. Monitoring and verification were critical to the Project and a wide range of methods were employed; the book describes how some methods worked well while others did not, and how results were processed and interpreted.

In addition to the technical details, *Geologically Storing Carbon* outlines how the Project was regulated and what it cost, as well as the experience of successfully communicating with the local community and the community at large. While it does not pretend to provide all the answers, hopefully it will assist others who want to develop a demonstration of geological storage, up to the size of perhaps a 100,000 tonne injection. It is a book for geologists, engineers, regulators, project developers, industry, communities, indeed anyone who wants to better understand how a carbon storage project really "works". It is also for people concerned with obtaining an in-depth appreciation of one of the key technology options for decreasing greenhouse emissions to the atmosphere.

Each storage project will have its own particular challenges depending not only on the geology, but also the expertise of the team, the availability and composition of the CO_2 stream and of course the availability of funding. In addition and crucially, the objectives of each project will vary. For some the prime objective will be to just demonstrate storage and certainly that was initially the main objective of the Otway Project and the one discussed in the greatest detail in this book. However as our knowledge at Otway increased, so did our recognition of what we did not know or understand. Therefore as the work progressed, so too did our aspirations to undertake more research and provide more answers. I suspect that other projects will show a similar aspirational progression. This detailed knowledge in turn will hopefully serve to provide the community, industry, government, and stakeholders, with the confidence to progress the deployment of CCS and make deep cuts in the emissions of CO_2 from large energy and industrial sources.

Many people have played a key role in the Otway Project and in the publishing of this book. The acknowledgements section of the book lists many of the key contributors—individuals, researchers, support and technical staff, organisations, companies, governments and others, without whom the Otway Project and this book would have never happened. Because they all played an essential role, one way or the other, and because there are literally hundreds of people who have contributed to the Otway Project and this book in one way or another, it is difficult to pick out particular people to acknowledge, but nonetheless let me do just that from a personal perspective.

During my time as Chief Executive of the APCRC and then CO2CRC, I have been most fortunate in the Chairmen with whom I have worked—the late Dr Alan Reid OA was enthusiastic about pursuing the far-out (for that time) idea of storing Australia's emissions underground. Mr Tim Besley AC, the founding Chair of CO2CRC, was extraordinarily supportive as we took the Otway Project from an idea to reality; his successor, Mr David Borthwick, PSM, subsequently continued that support and Dr Mal Lees, Chair of CPPL, was outstanding in dealing with the practical complexities of undertaking a first-of-a-kind project. The various CO2CRC Boards provided me with the leeway, the freedom of action and the backing that is so essential for a project such as Otway. The CO2CRC Executive was extraordinarily supportive throughout the decade; in the early days of the Project, the efforts of the late David Collins and Andy Rigg and later Sandeep Sharma, were particularly notable. Most recently, my successor as Chief Executive, Dr Richard Aldous, has been extremely supportive of my aim to publish a comprehensive volume on the Otway Project. Finally, from a personal perspective, this book was only possible because of the willingness of my wife Norma to put up with my absences in the field, my need to rush off to yet another meeting, my preoccupation with getting the Project successfully underway and my many evenings and weekends spent writing (and most recently editing) this volume.

Professor Peter J Cook CBE FTSE
University of Melbourne, Australia
Chief Executive, CO2CRC 2003–2011


CO_2
CAT

AUTHORS

Dr Colin Allison
CSIRO Marine and Atmospheric Research
Aspendale, VIC 3195, Australia
colin.allison@csiro.au

Ian S Black, AGR
Address now: ExxonMobil, Melbourne, Australia
ian.s.black@exxonmobil.com

Dr Chris Boreham
Basin Resources Group, Geoscience Australia
GPO Box 378, Canberra, ACT 2601, Australia
chris.boreham@ga.gov.au

Dr Mark Bunch
Australian School of Petroleum
The University of Adelaide, SA 5005, Australia
mark.bunch@adelaide.edu.au

Dr Eva Caspari
Department of Exploration Geophysics
Curtin University, GPO Box U1987
Perth, WA 6845, Australia
eva.caspari@curtin.edu.au

Professor Peter J Cook
Peter Cook Centre for CCS Research
University of Melbourne
Melbourne, VIC 3010, Australia
pjcook@co2crc.com.au

Ms Tess Dance
CSIRO Earth Science and Resource Engineering
26 Dick Perry Ave, Kensington, WA 6151, Australia
tess.dance@csiro.au

Dr Patrice de Caritat
Geoscience Australia
GPO Box 378,Canberra, ACT 2601, Australia
patrice.decaritat@ga.gov.au

Mr Thomas M Daley
Geophysics Department, Earth Science Division
Lawrence Berkeley National Laboratory
1 Cyclotron Rd, Berkeley, CA 94720, USA
tmdaley@lbl.gov

Dr Richard (Ric) Daniel
Australian School of Petroleum
The University of Adelaide
Adelaide, SA 5005, Australia
richard.daniel@adelaide.edu.au

Mr Craig Dugan, Process Group
Address now: Optimal Group Australia Pty Ltd
175 Wellington Road, Clayton, VIC 3168, Australia
craig.dugan@optimalgroup.com.au

Dr Jonathan Ennis-King
CSIRO Earth Science and Resource Engineering
Clayton, VIC 3168, Australia
jonathan.ennis-king@csiro.au

Dr David Etheridge
CSIRO Marine and Atmospheric Research
Aspendale, VIC 3195, Australia
david.etheridge@csiro.au

Dr Paul Fraser
CSIRO Marine and Atmospheric Research
Aspendale, VIC 3195, Australia
paul.fraser@csiro.au

Dr Barry M Freifeld
Hydrogeology Department, Earth Science Division
Lawrence Berkeley National Laboratory
1 Cyclotron Rd, Berkeley, CA 94720, USA
bmfreifeld@lbl.gov

Professor Boris Gurevich
Department of Exploration Geophysics
Curtin University and CSIRO, GPO Box U1987
Bentley, Perth, WA 6845, Australia
b.gurevich@curtin.edu.au

Professor Ralf Haese
Peter Cook Centre for CCS Research
University of Melbourne
Melbourne, VIC 3010, Australia
ralf.haese@unimelb.edu.au

Ms Allison Hortle
CSIRO Earth Science and Resource Engineering
26 Dick Perry Ave, Kensington, WA 6151, Australia
allison.hortle@csiro.au

Dr Charles Jenkins
CSIRO Earth Science and Resource Engineering
Black Mountain, Canberra, ACT 2601, Australia
charles.jenkins@csiro.au

Professor John Kaldi
Australian School of Petroleum
The University of Adelaide, SA 5005, Australia
jkaldi@co2crc.com.au

Dr Anton Kepic
Department of Exploration Geophysics
Curtin University, GPO Box U1987
Perth, WA 6845, Australia
a.kepic@curtin.edu.au

Dr Dirk Kirste
Department of Earth Sciences
Simon Fraser University
8888 University Dr, Burnaby, BC V5A 1S6, Canada
dkirste@sfu.ca

Mr Paul Krummel
CSIRO Marine and Atmospheric Research
Aspendale, VIC 3195, Australia
paul.krummel@csiro.au

Dr Maxim Lebedev
Department of Exploration Geophysics
Curtin University, GPO Box U1987
Perth, WA 6845, Australia
m.lebedev@curtin.edu.au

Dr Malcolm J Lees (retired)
Chief Advisor Technical
RioTinto Coal Australia
Brisbane, Queensland

Dr Ray Leuning
CSIRO Marine and Atmospheric Research
Black Mountain, Canberra, ACT 2601, Australia
ray.leuning@csiro.au

Dr Zoe Loh
CSIRO Marine and Atmospheric Research
Aspendale, VIC 3195, Australia
zoe.loh@csiro.au

Dr Ashok Luhar
CSIRO Marine and Atmospheric Research
Aspendale, VIC 3195, Australia
ashok.luhar@csiro.au

Dr Lincoln Paterson
CSIRO Earth Science and Resource Engineering
Clayton, VIC 3168, Australia
lincoln.paterson@csiro.au

Dr Roman Pevzner
Department of Exploration Geophysics
Curtin University, GPO Box U1987
Perth, WA 6845, Australia
r.pevzner@curtin.edu.au

Dr Matthias Raab
CO2CRC, School of Earth Sciences
University of Melbourne, VIC 3010, Australia
mraab@co2crc.com.au

Ms Namiko Ranasinghe
Department of State Development, Business
and Innovation
121 Exhibition Street
Melbourne, VIC 3000, Australia
namiko.ranasinghe@dsdbi.vic.gov.au

Dr Ulrike Schacht
Australian School of Petroleum
The University of Adelaide, SA 5005, Australia
uschacht@co2crc.com.au

Mr Sandeep Sharma
Schlumberger Carbon Services
256 St Georges Terrace, Perth, WA 6000, Australia
sharmass@bigpond.com

Dr Valeriya Shulakova
CSIRO Earth Science and Resource Engineering
Bentley, WA 6102, Australia
valeriya.shulakova@csiro.au

Dr Anthony Siggins
CSIRO Earth Science and Resource Engineering
Clayton, VIC 3168, Australia
tony.siggins@csiro.au

Mr Rajindar Singh
CO2CRC, School of Earth Sciences
University of Melbourne, VIC 3010, Australia
rssingh@co2crc.com.au

Mr Darren Spencer
CSIRO Marine and Atmospheric Research
Aspendale, VIC 3195, Australia
darren.spencer@csiro.au

Dr Linda Stalker
CSIRO Australian Resources Research Centre
26 Dick Perry Avenue
Kensington, WA 6151, Australia
linda.stalker@csiro.au

Dr Paul Steele
CSIRO Marine and Atmospheric Research
Aspendale, VIC 3195, Australia
paul.steele@csiro.au

Mr Tony Steeper
CO2CRC, 14–16 Brisbane Avenue
Barton, Canberra, ACT 2600, Australia
tsteeper@co2crc.com.au

Dr Eric Tenthorey
Geoscience Australia
GPO Box 378, Canberra, ACT 2601, Australia
eric.tenthorey@ga.gov.au

Dr Milovan Urosevic
Department of Exploration Geophysics
Curtin University, GPO Box U1987
Perth, WA 6845, Australia
m.urosevic@curtin.edu.au

Dr Maxwell N Watson
CO2CRC, School of Earth Sciences
University of Melbourne, VIC 3010, Australia
mwatson@co2crc.com.au

Mr Steve Zegelin
CSIRO Marine and Atmospheric Research
Black Mountain, Canberra, ACT 2601, Australia
steve.zegelin@csiro.au

ACKNOWLEDGEMENTS

The CO2CRC Otway Project was made possible through a range of contributions from many Australian and international researchers, research organisations, universities, companies, government bodies, officials and government ministers, regulators, stakeholders, landholders, contractors, administrative staff and management. The contributions were as diverse as the provision of expertise, the sharing of information and knowledge, the provision of access to farmland, and of course funding. In so many ways the Otway Project was a team effort (with every member and associate of CO2CRC a part of that team) and therefore it is the team rather than individuals that ensured success. Nonetheless it is appropriate to highlight a number of contributors and contributions.

Member companies of the CO2CRC Joint Venture contributed not only funding and in-kind support but also technical, legal and organisational advice. They included Anglo Coal, Australian Coal Research (now Australian National Low Emissions Coal Research and Development—ANLEC R&D), BHP Billiton Petroleum Pty Ltd, BP Developments Australia Pty Ltd, Chevron Australia Pty Ltd, ConocoPhillips, Inpex Browse Ltd, Origin Energy Ltd, QER Pty Ltd, Rio Tinto (through Technological Resources Pty Ltd), Sasol Petroleum International Pty Ltd, Schlumberger Oilfield Australia Pty Ltd, Shell Development (Australia) Pty Ltd, Solid Energy New Zealand Ltd, Stanwell Corporation Ltd, Total S.A., Woodside Energy Pty Ltd and Xstrata Coal Pty Ltd (now Glencore).

Over and above their responsibilities as Members of the CO2CRC Joint Venture, a number of companies also took on the added role of being Members of CO2CRC Pilot Project Ltd (CPPL), with responsibilities not only for operational and related issues, but also for holding some of the potential liabilities associated with the Project. The companies who were Members of CPPL were Anglo Coal, BHP Billiton Petroleum Pty Ltd, BP Developments Australia Pty Ltd, Chevron Australia Pty Ltd, Rio Tinto, Schlumberger Oilfield Australia Pty Ltd, Shell Development (Australia) Pty Ltd, Solid Energy New Zealand Ltd, Woodside Energy Pty Ltd and Xstrata Coal Pty Ltd.

Governmental Members of CO2CRC included the New Zealand Foundation for Research Science and Technology, NSW Department of Primary Industries, Queensland Department of Employment, Economic Development and Innovation, Victorian Department of Primary Industries and the WA Department of Mines and Petroleum.

Research Members of CO2CRC included the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Geoscience Australia, Curtin University, Institute of Geological and Nuclear Sciences, Korean Institute of Geoscience and Mineral Resources (KIGAM), Monash University and the Universities of Adelaide, Melbourne, New South Wales and Western Australia.

There were several Associate Members of CO2CRC; the Lawrence Berkeley National Laboratory in particular was a very major research contributor to the Otway Project. A number of small to medium enterprises contributed their expertise, including the Process Group, Cansyd and URS Australia. EnergyAustralia (previously TRUenergy) provided access to geomechanical data from the Iona Gas Storage Facility. AGR Ltd provided many operational services at the Otway site. Santos Ltd assisted with establishing the suitability of the Otway site.

Funding of site activities and research was obviously critical to being able to undertake the Otway Project. The single largest financial contributor to the Project was the Australian Government through the CRC Program, AusIndustry and the Australian Greenhouse Office. Major funding from the Victorian Government was also critical to the financial viability of the Project. Financial assistance provided through the Australian National Low Emissions Coal Research and Development (ANLEC R&D) which is supported by Australian Coal Association Low Emissions Technology Limited and the Australian Government through the Clean Energy Initiative, was also a vital part of the financial support base. Industry and government Members of CO2CRC listed above were very important financial contributors to the Project; Members of CPPL listed above also provided additional funding over and above that of the other Members. The Otway Project was also financially supported by the GEO-SEQ Project for the Assistant Secretary for Fossil Energy, Office of Coal and Power Systems through the National Energy Technology Laboratory of the U.S. Department of Energy, under LBNL contract DE-AC02-05CH11231. Financial support was also provided by the Carbon Capture Program.

While direct financial support was obviously crucial to undertaking an expensive research project, in-kind support was also very important indeed to the success of the Otway Project. All of the Research Members and the Associates listed above contributed very significantly through their in-kind contribution, particularly through the provision of researcher time, but also including equipment, analyses and other services. The Australian National University, the University of Calgary, Simon Fraser University and the University of Canberra also provided analytical services. Also a number of companies made software available to the Project, including Halliburton (Landmark), Schlumberger (Petrel, Eclipse), CGG (Hampson-Russell), dGB (OpenDTect), Ikon Science (RokDoc), and DECO Geophysical SK (RadExPro).

In addition to the support from organisations, the support of individuals was extraordinarily important to the success of the Otway Project and amongst the most important of these were the farmers who provided access to their land, other local stakeholders and participants in the Community Reference Group. These included John McInerney, Delcie Dumesny, Peter Dumesny, Corey Couch, Karin Couch, Gavin Couch, Ron Brumby, Sue Blake, Andrew Straker, Gillian Blair, Jenny Porteous, Ken Gale, Terry O'Connor, Andrew Gosden and Oliver Moles. Especially important to ensuring effective and productive relations with the local community was the untiring work of Josie McInerney, the Community Liaison Officer for the Project.

A number of officials at the State level played a vital role in regulating the Project in a practical and consultative manner, including John Frame (Environment Protection Authority), Terry McKinley, Geoff Collins and Namiko Ranasinghe (Department of Primary Industries), Bala Balendran (Energy Safe Victoria), Martin Kent, Mick Fennessy, Lynda Hardy (Southern Rural Water) and Peter Greenham (Department of Infrastructure). Other officials who contributed greatly to the Otway Project, by facilitating State support, included Dale Seymour, Richard Aldous and Cliff Kavonic (Department of Primary Industries). The enthusiasm of the then Victorian Minister for Primary Industries, Mr Peter Batchelor, was an important element in enabling the Project to go ahead.

Many officials at the Federal level similarly played a vital part in helping the Project to go forward including Tania Constable, John Hartwell, John Ryan, members of the CRC Program (Department of Industry) and Gerry Morvell (Australian Greenhouse Office). The Federal Minister for Industry, the Honourable Ian Macfarlane MP, has been a strong and much valued supporter of the Project, as has the Honourable Martin Ferguson MP.

The external review of the Otway Project coordinated by John Gale of the IEA Greenhouse Gas Programme and including Sally Benson, Susan Hovorka and Malcolm Wilson, was much appreciated by the members of the Project.

The contribution and dedication of Board members, too many to name individually, and the untiring efforts of the Board Chairs—the late Alan Reid (APCRC, 1991–2003), Tim Besley (2003–2010), David Borthwick (2010 to present) and Mal Lees (CPPL, 2005–2010) have been especially valued by the Centre. Members of the CO2CRC Executive who have played a major role in the Otway Project include Sandeep Sharma, Matthias Raab, Andy Rigg, John Kaldi, Barry Hooper, the late David Collins, Carole Peacock, and since August 2011 Richard Aldous (CEO).

Perhaps the most difficult part of this Acknowledgement is to attempt to do justice to the efforts of so many dedicated scientists, technicians and many other specialists involved in the Otway Project. The 45 authors of this volume of course deserve special mention and are listed elsewhere in the book and in the individual chapters. A great many other CO2CRC people contributed to the Project in a variety of ways and their names can be found at www.co2crc.com.au. There are others who contributed to the Otway Project and deserve mention, who were not officially part of the Project or who have now moved to other organisations. These include in geology and geochemistry—Lynton Spencer, Frank La Pedalina, Catherine Gibson-Poole, Ernie Perkins, Claire Rogers, Sandrine Vidal-Gilbert, Peter van Ruth, David Dewhurst, Thomas Berly, Dennis van Puyvelde, Jürgen Streit, Jacques Sayers, Myles Regan, Simon Mockler, Alex Moisis, Mark Pavloudis, Dominic Pepicelli, Piotr Sapa, Peter Tingate, Adrian Tuitt, Mario Werner, Dae Gee Huh and his colleagues at KIGAM. In reservoir engineering—Qiang (Josh) Xu, Geoff Weir, Martin Leahy and Jim Underschultz. In geophysics—Kevin Dodds, Jonathan Ajo-Franklin, Brian Evans, Andrej Bóna, Aleksander Dzunic, Christian Dupuis, Ruiping Li, David Lumley, Donald Sherlock, Aline Gendrin, Shoichi Nakanishi, Allan Campbell, Les Nutt, Shujaat Ali, Vladimir Tcheverda, Evgeny Landa, Yusouf Al-Jabri, Putri Wisman and Faisal Abdulkader Alonaizi. In communications—Carmel Anderson. In atmospheric monitoring—Scott Coram, Ray Langenfelds, Rebecca Gregory, David Thornton, Mick Meyer and Dale Hughes. In risk assessment—Adrian Bowden and Donna Pershke.

Finally, thanks to Jo Ashley, Roslyn Paonin and Matthew Harris for their graphic design skills and Julia Stuthe and Tracey Millen of CSIRO Publishing and their colleagues at Wiley for helping to make this book a reality.