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Peter Cook, Mal Lees, Sandeep Sharma

1. DEVELOPING THE PROJECT

1.1 Introduction

The foundation for the CO2CRC Otway Project was established as long ago as March 1998, when it was first proposed to the Board of the then Australian Petroleum Cooperative Research Centre (APCRC) that a programme be established to look at the opportunities in Australia for "geologically disposing" of carbon dioxide, with an initial focus on high-CO_2 natural gas, but with the intention to also look at the opportunities for applying the technology more broadly, to address what was perceived as Australia's looming greenhouse gas issue. In 1998, this was not an issue of broad community or political import and therefore it was not possible to get funding from the CRC Programme, despite attempts to do so. Nonetheless the Board continued to support the concept. A workshop was held in Perth, Western Australia to discuss geosequestration in late 1998, under the aegis of Chevron (who was at that stage increasingly interested in the technology for the proposed Gorgon Project) and subsequently, a number of oil and gas companies (BHPB, BP, Chevron, Shell, Woodside), together with the Australian Greenhouse Office, agreed to provide some funding to get work underway.

In 1999, the GEODISC (Geological Disposal of CO_2) Project was initiated by the APCRC, with the specific objective of assessing on a continent-wide basis, what the opportunities were likely to be for the geological storage of carbon dioxide in Australia (Cook et al. 2000). In order to make that assessment, a team of earth scientists was assembled by the Centre, drawing on the original participants in the APCRC (CSIRO, Curtin University, University of NSW, University of Adelaide), together with new members of the team from Geoscience Australia. The outcome of that work, which extended over 4 years, was to convincingly show that there were indeed opportunities to apply the technology in Australia and, as part of the GEODISC Project, a very preliminary analysis of the storage potential of Australia was undertaken, the first such exercise attempted for an entire continent. The results, which were summarised in a series of publications and APCRC reports, clearly suggested that Australia did indeed have the potential opportunity to apply what was then known as geosequestration (carbon capture and storage, or CCS) on a large scale. By 2001–02, greenhouse gas concerns in government and the community at large were increasingly evident and the GEODISC findings had a

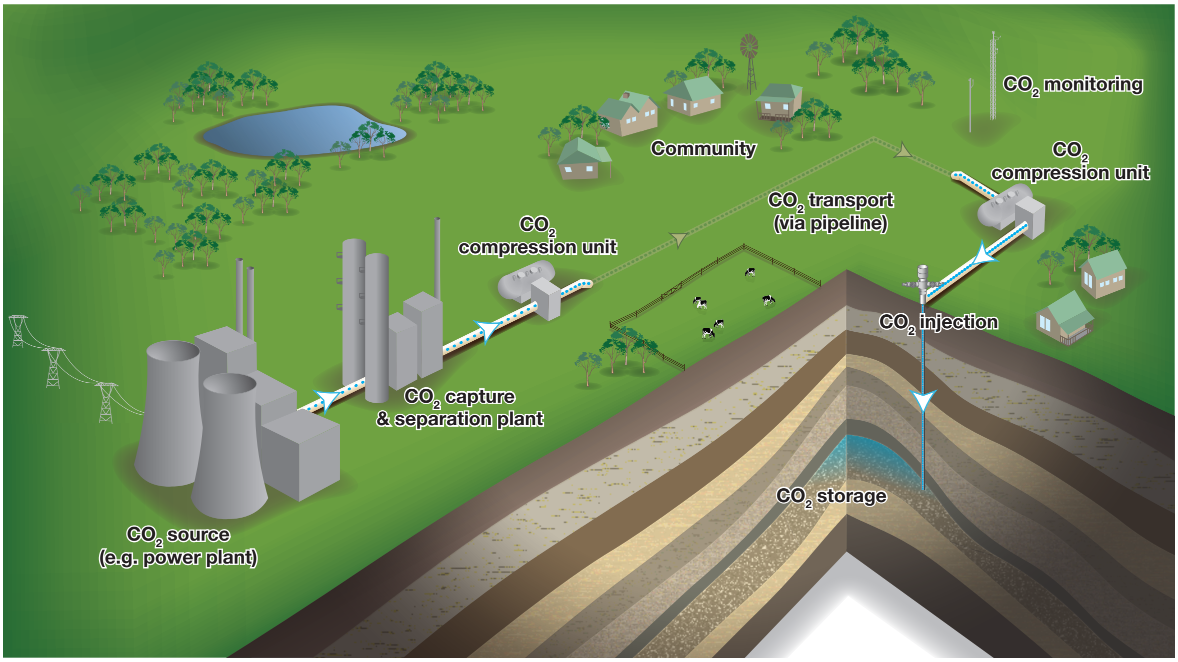

Figure 1.1: A simplified overview of carbon capture and storage.

major impact on government thinking on the possible options for decreasing emissions.

In 2003, a new Centre, the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) was formed out of the APCRC, to undertake applied research into the capture and geological storage of carbon dioxide. The support base was broadened to now include the oil, gas, coal, power and service industries initially through Australian Coal Research, BHPBilliton, BP, Chevron, Rio Tinto, Shell, Stanwell Corporation, Schlumberger, Woodside and Xstrata Coal, with subsequent support from Anglo American, Conoco Phillips, Sasol, Solid Energy and Total. Unlike GEODISC, which was only concerned with the geosciences, a much wider range of CCS science and engineering was brought into the CRC via expertise within CSIRO, Curtin University, Geosciences Australia, GNS New Zealand, Monash University, University of Adelaide, University of New South Wales and the University of Melbourne, as well as the Australian Greenhouse Office, together with several small enterprises (Cansyd, Process Group, URS). Close and much valued links were also developed with Lawrence Berkeley National Laboratory.

Right from the start it was recognised that a key element of the new CRC had to be to not just talk about geological storage of CO_2, but to actually demonstrate it, if possible with the complete CCS chain of capture, transport and storage as shown conceptually in Figure 1.1. Geological storage of CO_2 was already underway in 2003 through the Sleipner Project in offshore Norway and also at Weyburn in Canada as part of an enhanced oil recovery (EOR) project. Plans were well advanced for the Frio Brine Project in Texas and a number of other demonstration projects were also at the planning stage, though none in Australia at that time. Therefore in 2003, CO2CRC started to look at the feasibility of a small-scale CCS project in Australia.

1.2 Developing an Australian project

1.2.1 The first practical steps

The concept of an Australian demonstration/pilot project was first developed by CO2CRC around the technical

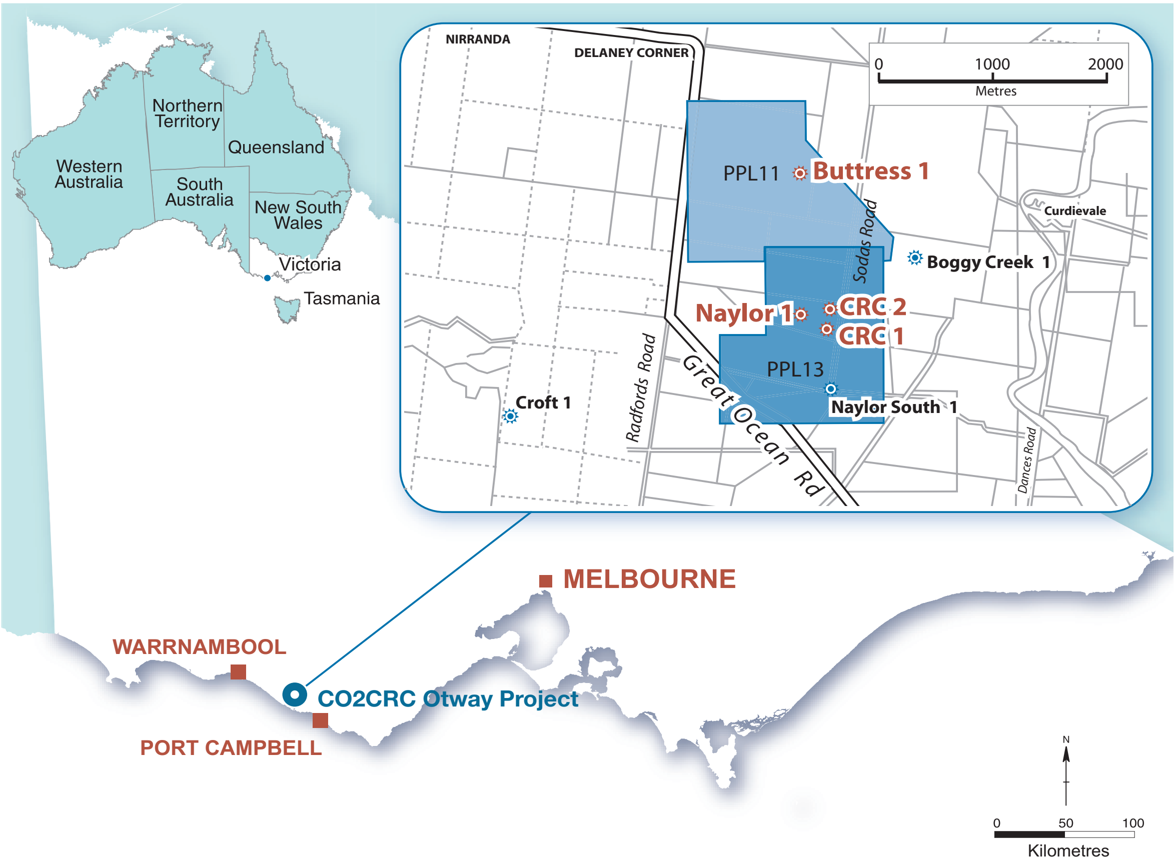

Figure 1.2: Location of the petroleum tenements in the Otway Basin that ultimately provided the basis for the Otway Project.

components embedded in Figure 1.1, with all aspects of the CCS chain to be demonstrated at a commercially significant scale. It soon became apparent that this was an impractical aspiration for a small-scale project in the short to medium term. One of the key constraints on a number of the proposed overseas small-scale injection projects was the lack of CO_2 and as a result of this it was necessary for some projects to buy food grade CO_2 at high cost, which in turn limited the scale of the injections to just a few hundred to a few thousand tonnes in many cases. If an Australian pilot project was to be undertaken at the commercially significant scale the CO2CRC wanted, it was important to ensure that there was ready access to an affordable source of CO_2 at sufficient scale (around 100,000 t of CO_2) and that it was available now. While CO2CRC had plans for also undertaking a pilot capture project, there was no prospect of using a power station or an industrial plant as the source of CO_2 for at least 5 years and possibly longer. It was therefore necessary to have a "surrogate" for the major CO_2 source shown in Figure 1.1.

It was decided to focus on securing a natural gas-related source of CO_2, whether a high CO_2 natural gas such as is found in the Cooper Basin or relatively pure geological CO_2 such as is found in the Otway Basin. After considering a number of possible options, attention soon turned to the Otway Basin, a natural gas-producing basin in western Victoria, where a number of natural CO_2 accumulations were known to exist in tenements licensed to the Santos-Beach JV (Figure 1.2). In 2004 CO2CRC made a visit to the Santos data room visit and examined PPL-11 (known to have a high CO_2 content in the Buttress well) as a potential source and with prospects for an injection site.

Options short-listed for injection and storage included the Croft and Naylor depleted gas fields (Figure 1.3). The Buttress Field had been logged and cased by Santos, but not perforated and tested, before it was suspended as a potential CO_2 producer (Frederickson 2002). Based on the available data, there was a reasonable level of confidence that it could provide the 100,000 t of CO_2 required for a small-scale storage project.

In 2004, Santos decided to sell its entire portfolio of onshore Otway gas fields, including the above options, to Origin Energy (OE). In early 2005 OE acquired 90% of the Santos share in all these tenements; with the Santos/Origin sale there was a related purchase agreement outlining that PPL-11 would be sold to the CRC and funds from the sale would flow back to Santos. If that were not to happen, Santos indicated it would find an alternate buyer for PPL-11. Through subsequent discussions, it became evident that OE were willing to sell only the Naylor depleted gas field to CO2CRC (up until that time, CO2CRC was also interested in the Croft depleted gas field as a CO_2 storage site). The Naylor Field was a small depleted gas field with original gas in place estimated at 170 million standard cubic metres (6 billion standard cubic feet). From May 2002 to February 2004, Naylor-1 produced a total of 112 million standard cubic metres (3.965 billion standard cubic feet) of natural gas from the Waarre "C" and "A" units. The well was suspended in 2004 after the well started to produce water and the field was considered depleted (Bowden and Rigg 2004). As a potential sink site based on the volumes of natural gas produced, Naylor was deemed to be adequate for a storage project. However because of the wish of OE to retain the Croft Field, PPL-10 needed to be partitioned in order to separate the holdings of the two fields, Croft and Naylor. Accordingly, a new PPL-13 was defined (Figure 1.3).

Therefore CO2CRC now had the essential components for a pilot or demonstration storage project. Through the purchase of the Petroleum Production Licence PPL-11, it had an unproduced natural gas well (Buttress-1) known to be high in carbon dioxide (95,000 t of CO_2 at the P90 level, 250,000 t at the P50 level and 950,000 t at the P10 level).

What was not then known (because the well had not been produced up to that time) was the actual composition of the natural gas. However as the well was close to the Boggy Creek gas field, which produced CO_2 for the food industry, it was considered likely that the composition of the gas (by weight) would be of the order of 90% CO_2 and 10% methane. In the event, the composition was closer to 80%:20%. Nonetheless this provided the basis for using the Buttress Field as the source of CO_2.

In addition, CO2CRC (initially through CMPL, subsequently through CPPL—see Section 1.3) was in a position to purchase PPL-13, which included the depleted gas field, Naylor-1, which was seen as a suitable site for testing the geological storage of CO_2. A significant amount of residual methane remained in the field but a preliminary assessment by CO2CRC suggested that the abandoned Naylor structure would provide a suitable storage site for up to 100,000 t of CO_2 and also that it might be possible to use the existing Naylor well as a monitoring well.

What was not clear at that stage was how the PPLs would be held by CO2CRC or how a project of the scope envisaged, would be undertaken by CO2CRC. It meant that CO2CRC, a research consortium, was potentially taking on responsibilities and risks akin to those of a small oil and gas company. This clearly needed careful consideration particularly as each member of the CO2CRC had a different attitude to risk. Nonetheless, despite these uncertainties, the opportunity offered in the Otway Basin was seen to be so important to the future of CO2CRC that it was decided to go ahead with the purchase of the two properties, PPL-11 and PPL-13, from Origin Energy. It was also decided at that time to develop a more appropriate corporate structure for CO2CRC that would meet the needs of the proposed project and address any related concerns of the members of the joint venture.

1.2.2 Naming the project

At first glance, the naming of a project would seem to be a relatively unimportant issue, but this is not necessarily correct, for the name becomes a unique identifier through which the project becomes widely known and with which the scientists, the engineers and other staff identify. Therefore getting the right name was important.

Initially, without giving the matter a great deal of thought, the project was called the Otway Basin Pilot Project. This was

Figure 1.3: Partitioning of PPL-10 into a new PPL-13 and a reduced PPL-10.

soon abbreviated to OBPP, which the scientists were quite comfortable using, but which meant absolutely nothing to anybody other than those closely acquainted with the Project. It was therefore decided to call it the CO2CRC Otway Project, sometimes used in full, particularly when used for the first time, but then abbreviated to the Otway Project, which for many people immediately identified the area where it was being undertaken. This then was the name that entered into general use.

A nomenclatural complication arose in 2006–07: by this time it was evident that the site offered the opportunity to undertake other field experiments and activities beyond the initial activity of storing CO_2 in the Waarre Formation. It was therefore decided to retain the name Otway or Otway Project, but to add Stage 1 to the initial project and Stage 2 to the proposed second project, with the further option of a Stage 3 and a Stage 4, etc., at the Otway site. However, this became further complicated by the need to divide Stage 2 into 3 phases leading to the need to have Stages 2A, 2B and 2C. Table 1.1 summarises the nomenclature and the activities undertaken. For the most part, this book is concerned with Otway Stage 1 although a number of chapters make reference to Stage 2A or Stage 2B. Stage 2C is only mentioned briefly. There are no firm plans for a Stage 3, although options are under consideration.

A further nomenclatural issue which arose was whether to refer to the Project as a demonstration project or a pilot project? There is in fact no definition of these terms and they are often used interchangeably. Notionally the

Table 1.1: The various phases of the Otway Project 2003–13.

CO2CRC Otway Project	
Stage 1	Injection of 66,000 t of CO_2-rich gas into the Waarre Formation at the CRC-1 well and related monitoring (completed)
Stage 2A	Drilling of new injection well CRC-2 into the Paaratte Formation and site characterisation (completed)
Stage 2B	Injection of 140 t of pure CO_2 into the Waarre Formation and determination of residual saturation (completed)
Stage 2C	Injection of up to 30,000 t of CO_2-rich gas into the Paaratte Formation with related seismic monitoring (planned)
Stage 3	Under consideration

term "pilot" could perhaps be reserved for projects of less than 10,000 t of CO_2 and "demonstration" for projects of 10,000–100,000 t, but there is no agreed convention. Because of the wish to inject up to 100,000 t (an amount arrived at somewhat arbitrarily) at Otway, the apt but perhaps somewhat vague term "commercially significant" was often used to distinguish it from, say, a small injectivity experiment, where only tens of tonnes of CO_2 were injected. The IEAGHG programme in its recent review of storage projects (Cook et al. 2013) used the term "small-scale" for projects of less than 100,000 t. More recently the 100,000 t quantity has acquired greater significance in that it is the upper limit set within EU legislation for the size of projects that could be dealt with under research-related legislation rather than under the much more onerous regulations relating to large (commercial) scale injection of CO_2. There obviously continues to be a degree of arbitrariness about these terms. The issue was avoided in the case of the Otway project by not including "Pilot" or "Demonstration" in the name of the Project, not least because this made it possible to have a continuum of projects in the future, with a range of scales and objectives all referred to under the name of the Otway Project.

One final nomenclature issue was whether to refer to the gas injected from the Buttress Field as CO_2 or CO_2-rich gas or Buttress gas. As already mentioned and as discussed in greater detail in Chapter 4 and subsequently, the gas injected was approximately 80% CO_2. Therefore while 66,000 t of "gas" was injected, the amount of pure CO_2 actually injected was approximately 60,000 t. Nevertheless throughout the Project (and in this book), for the sake of brevity, the course followed was to refer to the total amount of gas injected, as "CO_2". This was a reasonable course to follow, given that the methane was totally miscible in the CO_2 and within the pressure and temperature conditions encountered in the Project, it had no significant impact on the behaviour of the CO_2.

1.2.3 Developing the science programme

In first putting forward an Otway Project to funding agencies in the Federal and State systems in 2004, the objectives were spelt out in a largely non-scientific way, namely "to demonstrate that CO_2 capture and storage is a viable, safe and secure greenhouse gas abatement option in Australia". This objective was then underpinned by several sub-objectives needed to achieve this overriding objective, namely:

- "effectively separating and capturing CO_2
- safely transporting CO_2 from source to sink
- safely storing CO_2 in the subsurface
- safely abandoning the facilities and restoring the site
- communicating with all stakeholders
- conducting the project within approved time and budget
- capturing all research outcomes".

It was of course the last point which highlighted that research was to be done at the site, and the fact it was put last did not in any way reflect a lack of importance. Rather, its position reflected the reality of a funding climate focused on practical outcomes rather than the research needed to provide those outcomes. Nonetheless it was recognised by all involved that innovative high quality research was really what the proposal was all about.

Throughout the negotiations to obtain PPL-11 and PPL-13, the underpinning driver was the science that CO2CRC proposed to undertake. By 2001–02, Sleipner and other projects in Europe and North America had demonstrated the viability of underground geological storage of CO_2, but they were limited in number and none were in Australia. By 2003, with significant funding available to CO2CRC, there was the potential opportunity to demonstrate that CO_2 could be geologically stored under Australian conditions. The scientists were confident that it could be, based on overseas experience, but it really was not sufficient to tell stakeholders, or the community at large, that "it has worked in Texas and therefore it will work in Australia". There was a need to demonstrate that it could work under Australian conditions and to provide people with the opportunity to "kick the tyres"! In other words, an important initial driver related to communications and demonstrating that the technology could and would work. However, this should not then be misconstrued as primarily a "public relations exercise" for CCS, in that right from the start it was recognised that there had to be world-class science underpinning all aspects of the project.

CO2CRC already had access to leading scientists through its predecessor organisation, the APCRC, and the related

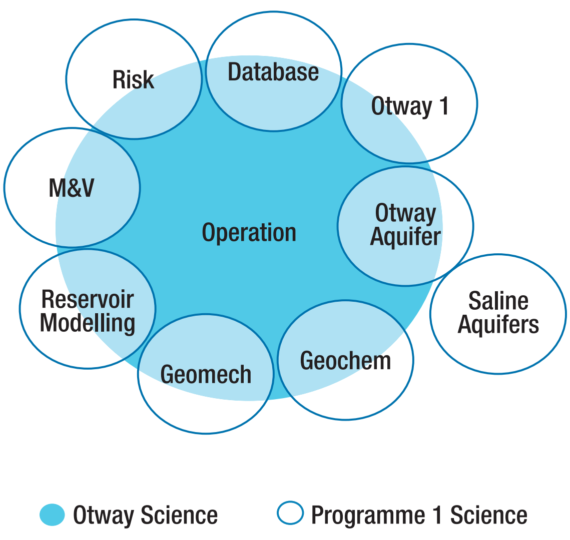

Figure 1.4: Relationship between Otway science and activities within the broader CO2CRC programme.

GEODISC programme. Researchers, together with the CO2CRC Executive, started to develop the detailed research proposal for what was to become the CO2CRC Otway Project Stage 1. The key scientific drivers for the Project were to demonstrate under Australian conditions:

- safe geological storage of CO_2 at a "commercially significant" scale (defined as up to 100,000 t)
- the successful application of a range of monitoring techniques to confirm effective geological storage of CO_2
- to undertake all of the above with no adverse environmental consequences.

To meet these objectives required the application of a range of scientific, engineering and organisational skills. A number of these were already available within the broader range of activities undertaken by CO2CRC; some of the expertise was only deployed in the Otway Project for a limited time; some was deployed virtually full time (Figure 1.4).

With increasing confidence in the imminent purchase of the Otway tenements PPL-11 and PPL-13, the scientific planning was able to be more clearly defined. One of the major benefits of purchasing the tenements was that a great deal of information was acquired on prior gas production, subsurface geology, seismic reflection profiles and so on from the previous operators. It was now known what sort of geology would be encountered, the presence of a potentially suitable reservoirs and their depths (Figure 1.5), the potential rates of injection, the likelihood of an effective seal, the capacity of the structure and the presence of faults. In other words, it was possible to start the high level characterisation of the site (Dance et al. 2009) and on this basis, start to develop the full science programme.

In particular it was now possible to gain a better idea of the feasibility of the original concept of injecting up to 100,000 t of CO_2 and of monitoring the behaviour of the CO_2 plume. The operational concept was quite straightforward in that it involved producing CO_2 from the Buttress well, treating that CO_2 as necessary, transporting by pipeline to an injection well (CRC-1) and then injecting

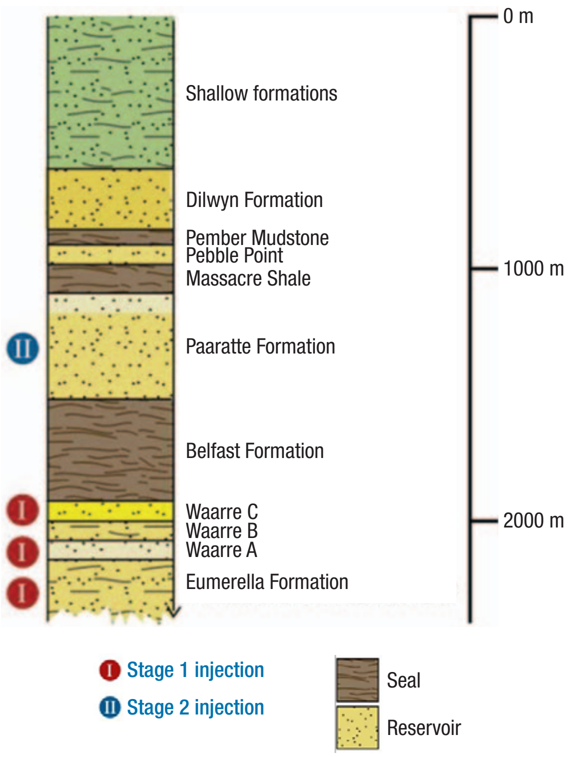

Figure 1.5: Preliminary stratigraphic column available for the Otway site. More definitive stratigraphy was obtained by drilling the CRC-1 well (see Chapter 5).

and storing the CO_2 in a suitable geological formation, within the depleted Naylor gas field (Figure 1.6). The CO_2 would also be monitored, using suitable technologies. Although superficially quite straightforward, there were of course many scientific unknowns, which needed to be addressed if the objectives were to be satisfactorily addressed by CO2CRC research.

There were two key objectives (discussed in detail in Chapter 9) in monitoring the CO_2, namely to monitor whether or not stored CO_2 was remaining within the reservoir interval (integrity monitoring) and to monitor with a view to ensuring that the community and the regulators could be confident that CO_2 was not leaking into aquifers or into the atmosphere (assurance monitoring). This required surface or subsurface systems that would monitor the deep storage formation (the reservoir), the overlying seal, the aquifers, the soils and the atmosphere. These are discussed in detail in Chapters 10–14 and also by Jenkins et al. (2011), Dodds et al. (2009) and Hennig et al. (2008). It was also necessary to devise programmes that would ensure that the site was well characterised (Chapter 5), that the seals would be suitable (Chapter 6), the geomechanical properties were known and understood (Chapter 7) and that any risk were clearly defined (see Chapter 8 and later in this chapter). Integral to all of these was the need to develop a programme of reservoir modelling and monitoring (Chapter 16). Finally it was also necessary to ensure that these programmes could be integrated not only in terms of the science but also in terms of the practicality of undertaking then in a timely and effective manner, which meant of course that the operations team and the science team had to work very closely together (discussed later in this chapter). By 2008, all of these objectives were achieved.

Given the nature of research and researchers, the Otway Stage 1 Project was not completed before consideration started to be given to using the undoubted science potential of the Otway site to address other questions of importance to CCS. It was of course essential from a research management perspective to ensure that enthusiastic researchers did not start running off to undertake the next exciting research project before the current one was successfully completed! At the same time, it was not realistic to expect a research programme to run until everything was finished and only then start to plan for a new phase and obtain the new funding. One of the key reasons why this would have been quite unrealistic for the Otway site (and probably for most other long-term CCS research projects) is that, whether any research was done at the site or not, it cost of the order of $1 million a year to maintain the site, ensure it was secure, undertake maintenance of equipment, and so on. Therefore from this perspective alone there was a compelling reason to have a rolling programme of research at the site if at all possible. The other problem that would have arisen, had there been a significant hiatus between Stage 1 and Stage 2, was that much of the expertise assembled to undertake Stage 1 would have been lost, with a major adverse impact on Stage 2.

Therefore in 2006, proposals for a new phase of Otway science, to be known as Otway Stage 2, were developed initially as a funding proposal to the Federal government

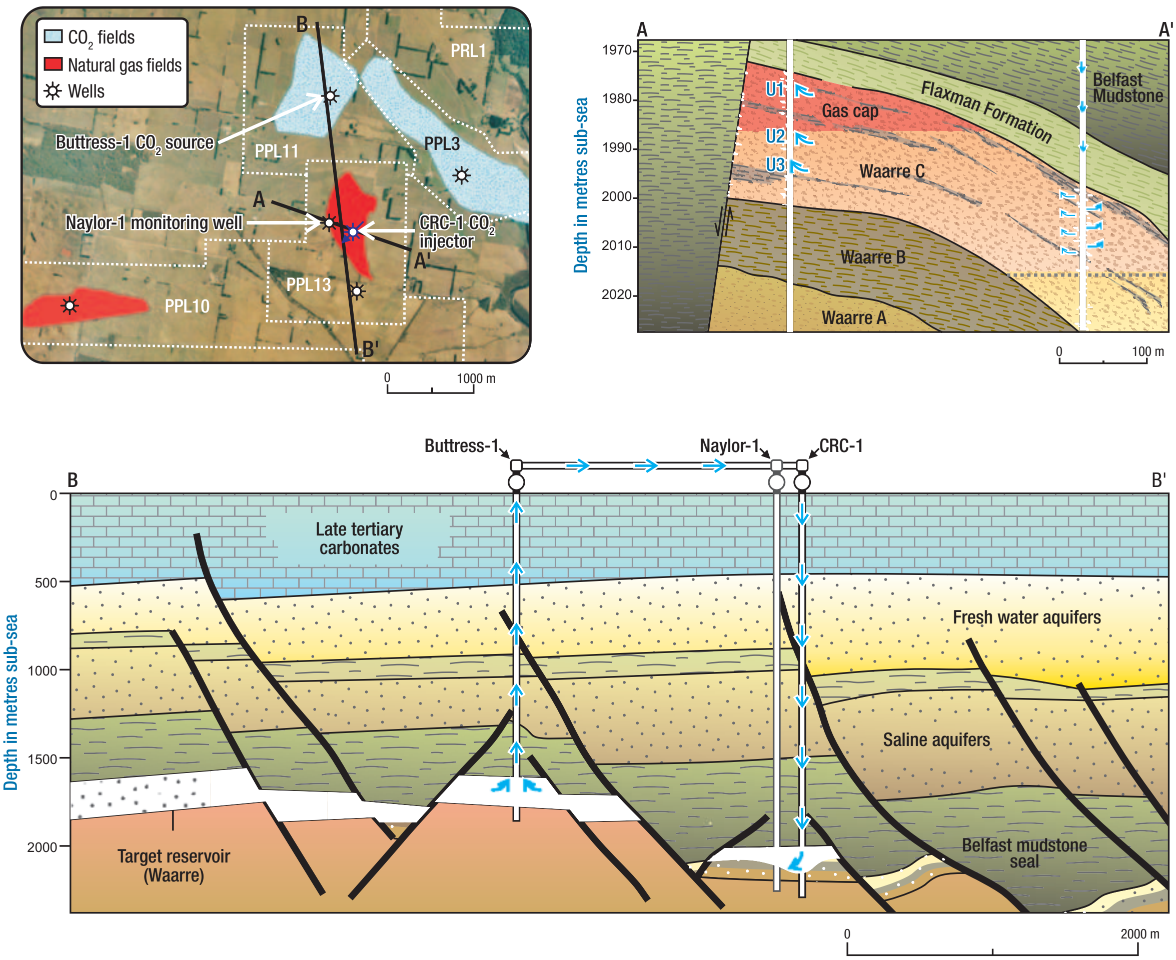

Figure 1.6: North-south cross-section through the fault-bound CO_2 source and sink intervals overlaying seals and aquifers (after Jenkins et al. 2011).

CRC programme for supplementary funding. Stage 1 involved injection and storage of CO_2 in a depleted gas field. This is a significant storage option (Underschultz et al. 2010; Cook et al. 2011) but volumetrically is regarded as much less important as a storage option than saline aquifers (IPCC 2005). However, while trapping of CO_2 and related gases in a closed geological structure (such as Naylor) is relatively well understood, storage in a saline aquifer is not. In particular the trapping of the CO_2 is dependent on residual capillary trapping and dissolution trapping (IPCC 2005).

With this in mind, the main objective of the Stage 2 proposal was to investigate residual capillary trapping (Zhang et al. 2011). Because Otway Stage 1 was within a depleted gas field with abundant residual methane, it was not suitable for investigating residual trapping of CO_2. Therefore Stage 2 had to include the drilling of a new well to provide access to a saline aquifer with no residual hydrocarbons. The interval chosen was the Paaratte Formation, which was somewhat shallower than the Waarre Formation (Figure 1.5) and relatively poorly investigated (largely because of its lack of hydrocarbons). Therefore an important aspect of the study had to be to first geologically characterise the poorly known Paaratte Formation, before the investigation of residual trapping could be carried out. The need to inject CO_2 into a saline aquifer was also seen as an opportunity to investigate the use of seismic imaging to establish the distribution of CO_2 within a saline aquifer.

Closer investigation of the research objectives showed them to be sound but the research to achieve them needed significant modification for several reasons. First it was concluded that it would be difficult to do the necessary Stage 2 field experiments using Buttress gas because of the presence of methane; it was therefore decided to use food-grade CO_2, which added significantly to the costs. Because of this, it was decided to only inject a small quantity of CO_2 (around 140 t). This work (Stage 2B) is discussed in detail in Chapter 17. This decision meant that it would not be possible to detect such a small quantity of CO_2 using seismic methods. Therefore what had by this stage become known as Stage 2C required a new injection of Buttress gas (up to 30,000 t) into the Paaratte Formation via CRC-2. All of these considerations led to a reassessment of the scientific methods to be deployed and also a sharper definition of the scientific objectives, which could be summarised as:

- geologically characterise a saline aquifer (in this case the Paaratte Formation) in detail
- establish residual gas saturation of CO_2 in a saline aquifer via a single well huff and puff-type test using various measurement options
- verify numerical simulations and predictions by field measurements
- establish the distribution of CO_2 within a saline aquifer by remote measurements
- use time-lapse seismic anisotropy to verify pore-pressure change, fluid migration and saturation
- develop a multi-level monitoring system.

Chapter 17 clearly indicates that the first three objectives were met through Stages 2A and 2B. Stage 2C has yet to be undertaken, but the research team has confidence that the remaining objectives can be met.

Is there to be a Stage 3? Possibly, with the uncertainty inevitably arising because of funding uncertainties! However what is not in doubt is the potential to use the Otway site and the Project facilities to answer a range of other important CCS-related questions, such as developing a better understanding of the impact of CO_2 on pre-existing faults or the potential for induced seismicity, or the opportunities for remediation if leakage were to occur. The likelihood of such events taking place is very small, but nonetheless it is prudent to investigate them to be able answer community concerns if they were to occur. The Otway site offers that opportunity.

1.3 Developing a suitable corporate structure

The initial structure of CO2CRC developed in 2002 (Figure 1.7), was in the form of a conventional unincorporated joint venture (JV). In common with many other joint ventures, two other incorporated entities were formed to provide services to the JV. The first entity, CO2CRC Management Pty Ltd (CMPL), was a management company set up to handle finance and accounting, employ staff, and generally deal with financial governance issues. The other entity, Innovative Carbon Technologies Pty Ltd (ICTPL), subsequently renamed CO2CRC Technologies Pty Ltd (CO2TECH), was established primarily to hold intellectual property (IP) rights on behalf of the members and to provide a vehicle to commercialise IP arising from the work of CO2CRC. Both companies were proprietary non-reporting entities. By 2003, membership of CO2CRC stood at 11 industry and government participants, each with a seat on the JV

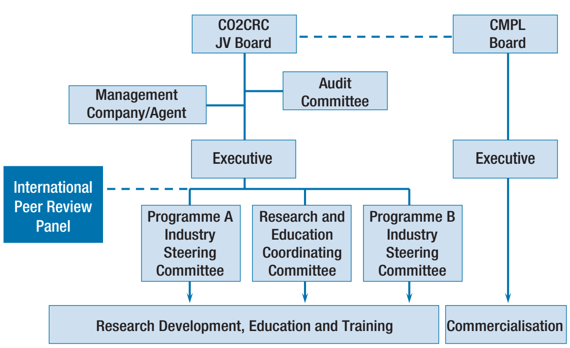

Figure 1.7: Initial structure of CO2CRC and related entities in 2003.

Board and eight Research Participants who were represented as a group by three elected JV Board members. The Chief Executive was also a Board member and there was an independent Chair. The Board of CO2TECH was similar but not identical in its composition (not all members of the JV wished to be involved in commercialisation) but the CEO, the Chair and several Directors were common to both Boards. The Board of CMPL, the management company, was significantly smaller. Again there was some commonality of Directorship with other Centre Boards.

This structure remained largely in place throughout the first term of the CO2CRC with only minor changes. The principal change to the JV was an amendment to the Corporations Regulations to allow unincorporated CRCs to allow up to 50 partners (previously limited to 20). This was important to CO2CRC as its membership grew significantly after 2003.

However, as pointed out previously, a joint venture did not provide the best structure for managing the new responsibilities of CO2CRC. One of the objectives of the CO2CRC was not only to carry out research but to take that research to an applied level by practical demonstration of CCS. The medium-scale field demonstration envisaged was at semi-industrial scale which would:

- demonstrate the engineering technology to safely store carbon dioxide but also research and measure many aspects of the sequestration process
- involve governments in the formation of the statutory and regulatory framework necessary for the industrial application of the technology
- provide a practical example to the community of a successful application of the technology and thereby enhance community acceptance.

These requirements were seen as likely to have a significant impact on the structure of CO2CRC and require the establishment of an operating entity.

In May 2004 a draft proposal was submitted to the CO2CRC Joint Venture participants. At this stage the proposed structure for carrying out the project consisted of a Project Steering Committee coordinated and managed by CO2CRC. It envisaged that an operator would need to be appointed to deal with day-to-day operations, while the CO2CRC would undertake the research activities. It envisaged that operational liability would be managed by insurance and long-term liability would be borne by the State Government. A funding requirement of some $12–13 million was envisaged at that time (see Section 1.4). As a holding operation CO2CRC's incorporated commercial entity, CMPL, was used to sign some of the preliminary agreements including service agreements to undertake a well test on the CO_2 well, but this was not seen by the Board as the best option for the long-term.

Initially it was hoped that an experienced operating company would agree to manage the envisaged Otway Project on behalf of CO2CRC, for a fee. However, the fee that the companies required to undertake the project was far greater than the amount of funding that CO2CRC believed it had available. In retrospect, it is clear the costs envisaged by the operating companies were more realistic than the early estimates of CO2CRC. Even more significantly, in all the options considered, the operating company was required to take on all risks and liabilities associated with the Project and no single company was willing to do this. In hindsight, such an arrangement, even if it had been possible, would probably have not met the needs of the JV or the Project and most likely would have unduly inhibited the research aspirations of CO2CRC.

It was apparent that the undertaking of the Project was going to expose the CO2CRC joint venture to operational and financial risks, potential exposure to long-term liability, and the usual obligations associated with ownership and operation of petroleum tenements. An unincorporated JV was legally not able to unilaterally accept these risks on behalf of its members and in subsequent joint venture discussions it became apparent that the nature of the Project was such that not all joint venturers would be prepared or be allowed to participate in such a project. Core participant research organisations and industry bodies such as ACARP were unable to assume any exposure to potential liabilities because of their structure or charter.

In the period mid-2004 to mid-2005 there was slow progress in acquisition of the interest in tenements PPL-13 and PPL-11 with ownership, pre-emptive rights issues and possible operatorship of the project all intertwined issues.

By March 2005 the prospect of forming a new entity to take on the Project (referred to at that stage as the Otway Basin Pilot Project or OBPP) was floated and industry members were polled to see which ones were prepared to accept such a role. The responses were mixed and reflected traditional legal advice from company lawyers. Discussions continued in an attempt to resolve various issues, legal advice was sought on the nature of the appropriate entity, and this culminated in a formal proposal at the subsequent June JV Board meeting (Figure 1.8) based on legal advice, detailing options for the formation of an entity to manage the operation of the Project. This included incorporated and unincorporated options but the recommendation was to proceed with the formation of an incorporated entity to carry out the Project.

A new special purpose company was recommended for the following reasons:

- administratively simple
- structure, ownership and responsibilities clear
- works well with existing CO2CRC entities
- no presumptions on operator
- provides maximum flexibility
- limited liability from having a separate legal entity
- shares risk equitably (but only by the members of this entity).

There appeared to be no adverse tax implications from such an option. The risk sharing was subsequently the subject of much discussion and much later became an issue relevant to the transition to CO2CRC Ltd. The Board of CO2CRC was asked to consider immediate formation of the company so that negotiations with governments could be successfully concluded and the Project could get underway.

Following this CO2CRC Board meeting, it became apparent that most of the industry participants supported the formation of an incorporated entity to carry out the project. These members became known as "The Coalition of the Willing"—or COW for short! However, there were varying views on several issues including the mechanisms to handle project liability, especially the long-term liability (LTL) associated with sequestered CO_2. The process of establishing a formal company proceeded slowly and therefore in the interim it was necessary for the COW to informally take on advisory role in moving the project forward. It was apparent by this time that the members of the "COW" would essentially be comprised of the coal

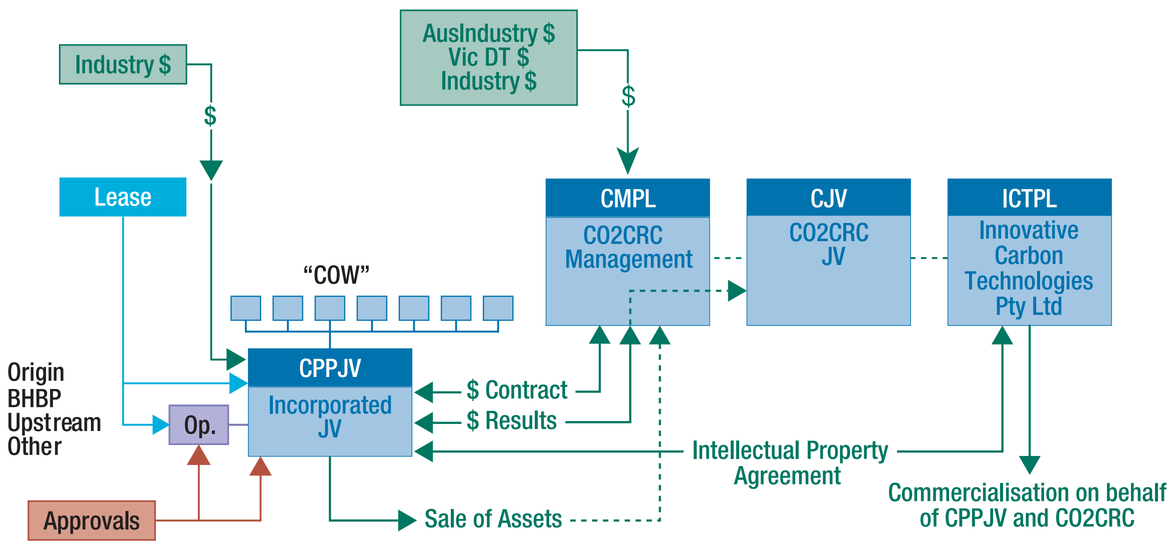

Figure 1.8: 2005 incorporated option proposed for the undertaking of the Project.

and oil/gas industry participants in the CO2CRC JV. Other participants would not or could not participate and insisted that when the new incorporated OBPP vehicle was formed it should be independent to the extent that no liability for operational activities or long-term storage could flow to the CO2CRC JV. This meant that the Project company could not be an agent for the JV. That role had to continue to be fulfilled by CMPL.

There were many meetings of the COW led initially by an oil industry representative and later by a coal industry person. Some of the issues that were prominent in the COW discussions were driven by the criteria these members needed to resolve in order to sell the proposition to their respective companies. These issues included:

- dealing with operational liability issues including cost overruns and defining a mechanism to handle this
- dealing with long-term liability (LTL) issues surrounding storage of sequestered CO_2
- determining what criteria might be required prior to a decision to inject gas for sequestration
- establishing operational controls appropriate to the Project. It was clear that the company needed to control its own destiny and required a complete mandate to operationally manage the Project and all site activities. Other issues included
  - details and specification of the scientific research was to remain the domain of the CO2CRC JV but site activities were to be under the control of the Project company
  - defining the statutory and regulatory regime under which the sequestration would be carried out
  - determining who would be the operator of the project and under what terms and conditions
  - establishing the company Constitution and Member's Agreement
  - defining the relationship between the Project company and the CO2CRC JV.

Legal advisors were commissioned to prepare draft criteria for the incorporation of a not-for-profit company, limited by guarantee, to be known as CO2CRC Pilot Project Ltd (CPPL). There were many meetings of the COW in which "Term Sheets" covering the various issues were debated and for the most part were resolved. The process was tedious because the various members of the COW were companies whose legal advisors and head office processes were widely scattered and held differing criteria for approvals for entry to such a project. By December 2005 there was resolution of issues to the point where the company could be incorporated and the first Members formally join. The expectation was that there would be 10 Members—broadly five from each of the coal and oil/gas sectors.

1.4 Formation of CO2CRC Pilot Project LTD

On 28 November 2005, CPPL was formally incorporated with the broad purpose outlined in the Constitution to:

- undertake the CPPL Project
- operate, or engage others to operate, facilities to undertake the CPPL Project.

Although a Pty Ltd option was considered, the structure of a public company limited by guarantee was seen to have several advantages:

- the structure was typical for non-profit entities
- facilitates entry and exit—no need to buy or sell shares
- perhaps more amenable to tax exemption.

The Member's Agreement and Constitution defined the detail but the COW had resolved the following issues:

- Each Member had equal accountability to share operating liability and any potential cost overruns. It was recognised that, despite the best endeavours, a real operating situation (such as an emergency) may require utilisation of resources that exceeded the capacity of the CO2CRC JV to support

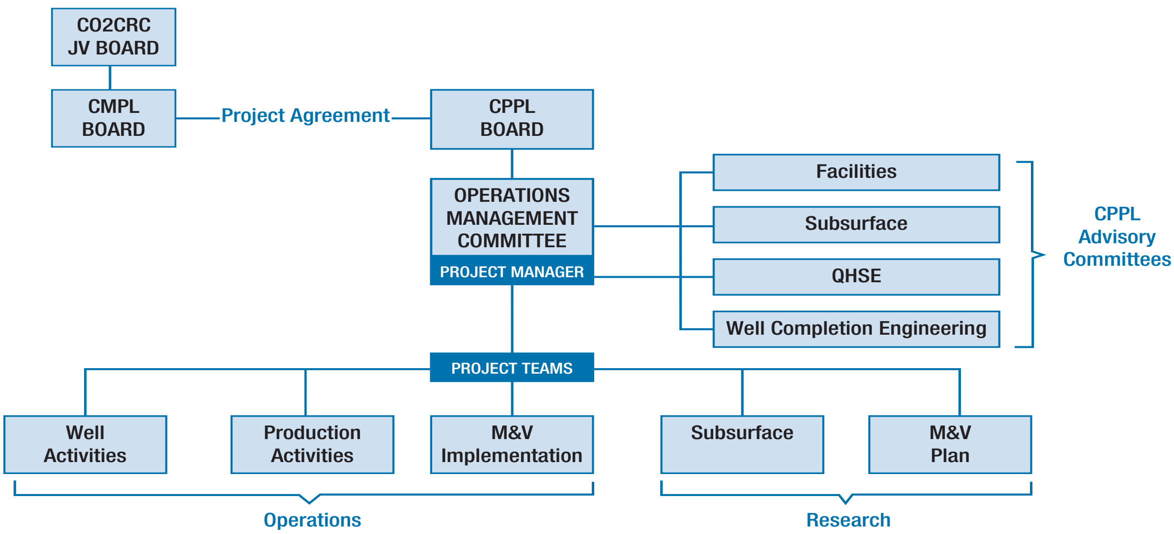

Figure 1.9: The CPPL organisational chart.

technically and/or financially. However, the expectation was that these issues could be managed with traditional risk assessment and careful planning. Reputational risk issues were discussed at length and were a key consideration.

- The issue of how to deal with long-term liability of sequestered CO_2 could not be resolved at the time and the COW's expectation was that this liability should be accepted by the State or Federal Government. In order to move the project forward the COW resolved to defer this decision by putting a special clause defining that it must be a unanimous decision of the Board to proceed to injection. In practical effect, this meant that each Director would need to satisfy the Member Company of this decision and effectively made it a Member's decision at a future point in time. The Company (CPPL) also would own the tenements and have the right to manage all activity on those tenements including appointment of operator and operational staff and be able to develop and install any necessary systems required for the Project.
- A Project Agreement would be put in place with CO2CRC Management Pty Ltd (CMPL as agent for the CO2CRC JV) which detailed the contractual arrangement to carry out the programme of works. Implicit in this arrangement was an understanding that all funds required for the project activity had to be identified and available (from CMPL) prior to commitment of those funds by CO2CRC Pilot Project Ltd. Injection of CO_2 required consent of both CMPL and CPPL before any injection would take place.

These concepts were embodied in the various legal documents such as the Constitution, Member's Agreement, and the Project Agreement between CPPL and CMPL. The relationship between CPPL and the CO2CRC entities is shown in Figure 1.9.

The first meeting of the Company (CPPL) was held in early December 2005 and at that time there were five Members. Other participants were seeking approval to join but due to geographic diversity and different approval systems it was to take another 12 months before all 10 Members were in place.

At the initial meeting the industry representative that had been leading the meetings of the COW was elected Chairman. At that time it seemed that the path forward would be for the Chairman role to move to a petroleum industry representative because of the relevance of petroleum skills. This proved to be a wrong assumption because in practice the skills required to get the project established were more related to statutory and regulatory approval, land use and landholder issues, local government and community arrangements and cultural heritage. These skills were just as relevant in a mining background as they were for the petroleum industry.

Early tasks for CPPL included the appointment of a Project Manager. In conjunction with the Project Manager the Board then established the operating structure for CPPL as shown in Figure 1.9.

This structure also defined the interface with the research activity to be undertaken by the CO2CRC JV. Figure 1.9 shows a line management structure within CPPL which included an Operations Management Committee. The members of this committee included the Project Manager and various people with relevant skills seconded from the Members. The committee typically had three or four members and people who had skills appropriate for the work activity at any particular time were seconded. This committee had delegated authorities in excess of the Project Manager and could meet at short notice to provide support and advice and if necessary commit funds and resources to an agreed level. Beyond that level referral was to the Chairman and Board. However, it is important to note that CPPL required the CO2CRC JV to provide those funds via CMPL before they were committed by CPPL. In other words, for the most part, CO2CRC JV continued to be the vehicle for raising funds to undertake the research programme, to develop the research programme (and provide the researchers to undertake that research), and obtain the funds to enable CPPL to undertake the Otway operations.

The Board of CPPL had 10 Directors including the Chairman. This Board was a good size and contained a good spread of technical, operations, project management and financial skills and also provided an avenue to access skills and resources to support the various aspects of the Project through the Members. While there was some turnover in representation there was a stable nucleus of Directors throughout the period of the Stage 1 Project. The CEO and the Chair of CO2CRC JV attended the meetings of the CPPL Board to ensure close coordination between CO2CRC science and CPPL operations.

Four Advisory Committees were established by CPPL to provide advice and support to the Project Manager but these committees did not have any line management function or authority to commit funds or resources. Again membership of these committees came from people in both the Members and researchers who had appropriate skills. One of the principal early tasks was to establish a HSE (health, safety and environment) system for the project in conjunction with the appointment of an operator.

In the early period there were many activities running in parallel. CPPL in its formative stages and after incorporation had a significant role in all of the following activities:

- purchase, ownership and management of the two petroleum tenements
- establishing the regulatory regime in conjunction with the various levels of government and government authorities, including establishing the appropriate legal path to accomplish a regime satisfactory to CPPL and its Members
- establishing the company systems including safety, financial, project budgeting, project management and project controls and financial audit. In this area it shared resources with the CRC utilising the CRC Business Manager as Company Secretary
- establishing lease agreements and compensation agreements with landholders
- establishing contracts for the provision of services including drilling and construction activities
- managing statutory requirements such as compliance with the requirements of the Federal EPBC, State Environmental and Rural Water authorities and Cultural Heritage legislation
- managing access to site by contractors, researchers and visitors and the HSE requirements of the site.

In parallel with these responsibilities, the CO2CRC JV had the responsibility for:

- identifying the research priorities for the Otway Project
- seeking the necessary funding for the scientific and operational aspects of the Project

- liaising with funders and other stake holders to enable the Otway Project to progress
- staffing and undertaking the research activities
- developing the monitoring and verification regime that would both meet the scientific objectives of the Project and enable CPPL to meet its statutory obligations
- communicating outcomes from the Otway Project via the scientific literature, the media and other outlets.

During this period it was clear that neither the Federal Government nor the Victorian Government were prepared to accept outright liability associated with injected CO_2. However under the arrangements with the Victorian Government, it became evident that should the Project meet all of the Agreed Statutory requirements, then normal processes for ultimate relinquishment of the tenements would apply.

At the CPPL Board level, extensive Risk Assessment was undertaken prior to the injection phase to assure the Members that the activity would be carried out safely and without liability or reputational damage. This was summarised on one page that effectively became the final check list. On the basis of this assessment the decision was made to proceed with injection under the terms of the relevant agreements with the Members and CMPL.

Obviously it was essential that CO2CRC JV and CPPL worked together as seamlessly as possible to achieve the objectives of the Project. This was achieved in part by having joint membership/attendees of the various Boards. On occasions there were inevitable tensions arising from the competing priorities of operational needs and research aspirations, but these were minor and the collaborative arrangement worked well.

CO2CRC operated under this structure for approximately 5 years during which time the Otway Stage 1 Project was successfully carried out. The large amount of effort establishing the structure and systems was well justified and the Project was completed within the financial constraints and without any lost time injury to contractors or research staff.

Following the completion of Stage 1 of the Otway Project in 2008, CO2CRC took early steps to seek an extension for a further funding term beyond 2010 under the CRC Programme. The Government advisors had earlier stated a preference for any extension to be carried out under an incorporated entity rather than an unincorporated joint venture. Also there was recognition of the inevitable complexities of having four entities—CO2CRC JV, CMPL, CO2TECH and CPPL—all with a range of responsibilities. In the case of CPPL those responsibilities were solely to the Otway Project, but in the case of the other three entities the responsibilities covered not only Otway but also a wider range of storage activities, capture activities, CCS economics, education, training and commercialisation. Nonetheless the question needed to be asked—was there a more cost effective way to handle the affairs of Otway and the other CCS activities, using a simpler corporate structure?

CPPL had been set up as a special purpose vehicle to demonstrate CO_2 storage at Otway and clearly it had achieved that purpose. Under the original arrangements, the intention was to close activities at Otway once statutory obligations had been completed and then disband CPPL. Up to 2008–09, the members of CPPL had carried project risk on behalf of all participants of the CO2CRC Joint Venture (which now numbered around 30 participants) and they considered that any future burden should be more equally shared amongst all participants. By this time, CO2CRC had already been successful in obtaining supplementary funds to undertake Otway Stage 2 (see later) and therefore there was recognition of the need by CPPL and CO2CRC more broadly, to consider longer term arrangements. In addition, in 2009, CO2CR was successful in obtaining new funding for a further 5 years of research for the period 2010–15.

Various options for the incorporation of the new phase of CO2CRC were proposed, but the only option that addressed all requirements, including the concerns of the Members of CPPL regarding liability, was either the currently unincorporated JV (CO2CRC) became incorporated, or CPPL becoming the incorporated entity for the period beyond 2015. It was decided to take the latter course (Figure 1.10).

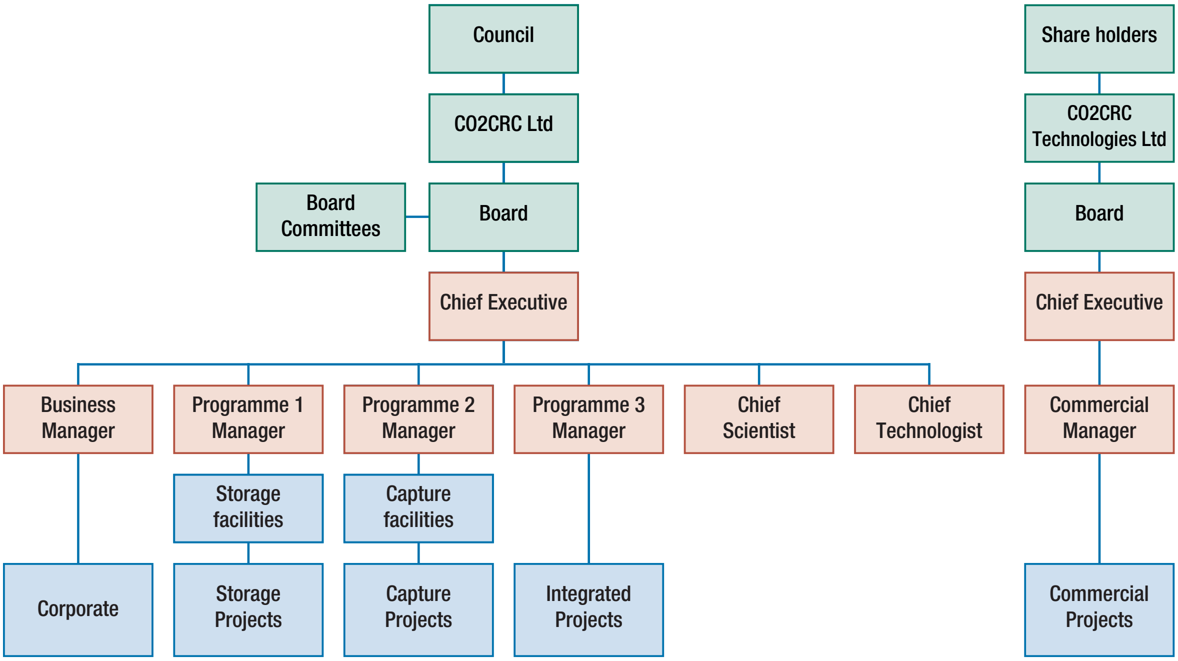

Figure 1.10: The CO2CRC corporate structure used from 2010 onwards.

There were many practical reasons for this decision, including substantial savings in the cost of transfer of assets and agreements. Also, CPPL was the formal holder of the petroleum tenements, held leases and agreements with Landholders and Governments, and had established systems for the financial, operational, and safety requirements that would be necessary for the proposed future activities of CO2CRC, both in storage and capture. This change also facilitated the establishment of a new and more effective Board structure for the CRC, with only 9 to 11 Directors (a number that had proved very effective in CPPL), rather than the 20 or more directors under the JV constitution. At the same time all of the CRC participants would be assimilated as shareholder members.

From the point of view of CPPL Members it also provided the basis for other CRC participants to join the company and to equally participate in risk sharing for future project activity. It also provided the opportunity to establish a much simpler structure for the new CRC since the combined roles of CPPL, CMPL and the original JV could all be achieved through a single entity, by making some changes to the Constitution and Member's Agreement and then renaming CPPL as CO2CRC Ltd. However, there was an ongoing need at that time for CO2TECH in terms of management of IP and therefore this entity was retained (Figure 1.10).

These changes were put into effect following the success of the rebid for the CO2CRC 2010–15 extension and the first meeting of CO2CRC Ltd was held in early 2010.

1.5 Funding the project

When the original CO2CRC bid for funding was lodged with the Federal Government's CRC Programme in 2001 (with funding proposed to start in 2003), there was every intention to undertake a pilot or demonstration storage project, and this was flagged in the proposal. The original funding did allow for researcher costs, but no request was made for funding an actual field project at that time. There were two reasons for this: first, a pilot storage project was an aspiration and in 2001–02 there was no clear idea of how and where such a project could be undertaken (such a project had never been undertaken in Australia before). Second, there was a ceiling on the

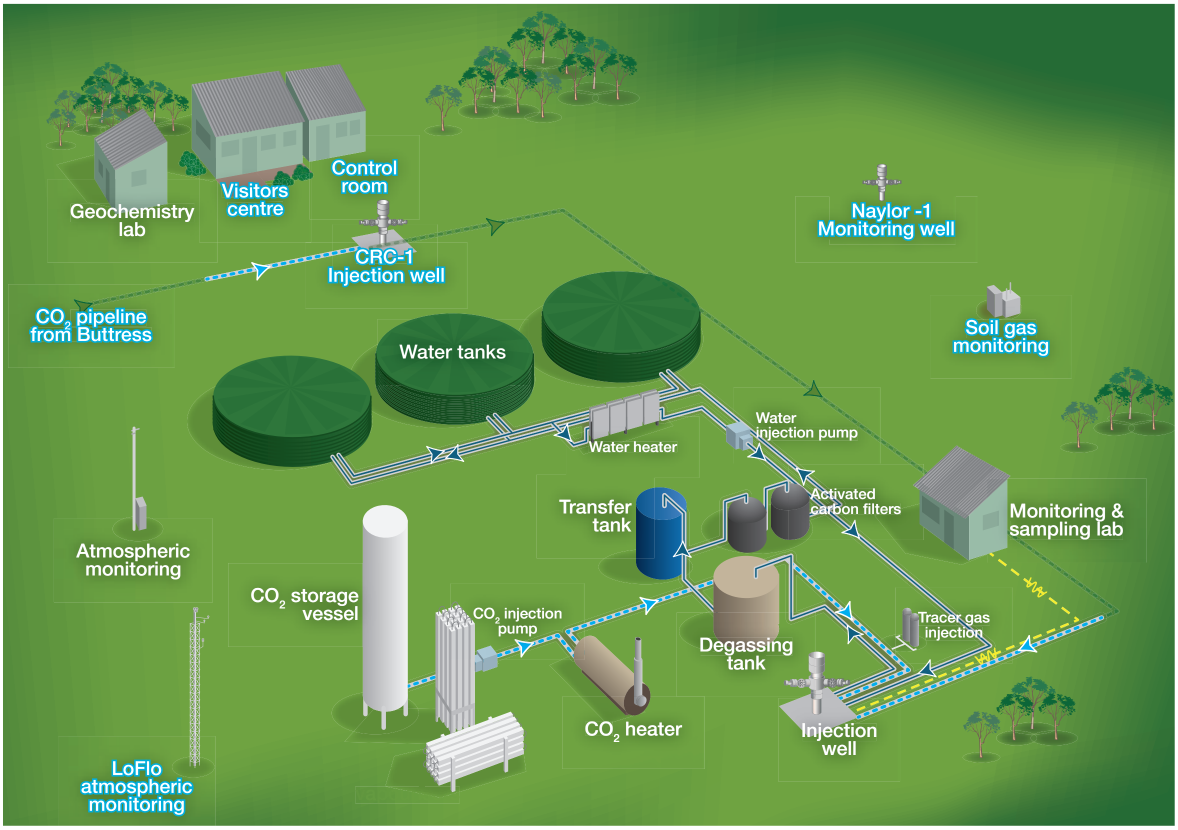

Figure 1.11: Schematic representation of the surface installations at the Otway site (locations labelled in blue indicate surface installations that existed in Otway Stage 1; all other facilities were established for Stage 2).

funding available for a Cooperative Research Centre bid and any bid for major capital costs would have taken the proposal far over the limit, thereby jeopardising the entire bid. Therefore a very conscious decision was taken to seek new funding for any pilot or demonstration bid only when the proposal for a CRC was successful. This successful bid was announced in 2002 and the Centre commenced in mid-2003.

There was now the opportunity for CO2CRC to develop a project proposal of substance. The project in the Otway Basin as initially proposed was fairly simple with the major components consisting of the CO_2 source (Buttress) with some separation of CO_2 from the gas, a pipeline, an injection well (CRC-1) and a single monitoring well (the existing Naylor-1 well). The facilities were greatly expanded for Stage 2 (Figure 1.11).

It was to be accompanied by basic baseline surveys before the commencement of injection of CO_2 and extensive monitoring during and post-injection. While still lacking detail, it did allow CO2CRC for the first time to develop some approximate costings. At this stage (2004), the project cost/budget was estimated at $12.8 million (Table 1.2)

The funding request did not address Otway-related research costs (mostly researcher time) as all such costs had been covered in the original bid for the CRC in 2002. If the budget proposal in 2004–05 had included this, then the original cost would have been of the order of around $20 million. The cost of purchasing the Buttress property ($1 million) was met from existing CO2CRC funds at an early stage in the negotiations. This was a risky move to the extent that there was no certainty that the remainder of the funds would be found, or that the project would go ahead. Nonetheless, access to the Buttress CO_2 was seen as so critical to the success of a future pilot project that it was seen as a risk worth taking. This proved to be the right move.

With $13 million promised by the funders (Federal Government, Victorian State Government and industry) plus the funding already held by CO2CRC, it was now possible to start on developing more detailed plans and costings. Two things happened at this time: first, and somewhat inevitably, real costs proved to be much higher than the original estimates. Second, researchers began to realise that Otway presented some exceptional research opportunities, with the inevitable rise in costs that an expanded science programme entailed. Fortunately the Australian Greenhouse Office agreed to provide some additional funding ($8.8 million) to undertake enhanced monitoring as part of the Project. However, the Project was still some way from having assured budgets and funds that would allow a final investment decision, despite by this time being at an advanced stage of research planning.

Table 1.2: Initial costings for the CO2CRC Otway Project Stage 1 as submitted to potential funders in late 2004–early 2005.

Budget	$ millon
Production and separation of CO_2	6.8
Pipeline	0.7
Injection well	1.5
Monitoring equipment	1.0
Baseline surveys	0.2
Operation of maintenance	0.7
Monitoring	0.6
Planning	0.15
Project management	0.8
Abandonment	0.35
Total	**12.8**
Contributions	
Federal Government	5
Victorian Government	4
Industry	4

This level of financial uncertainty, while not uncommon in a research environment, was new to most of the industry-based CPPL Board, as was the need to operate without a "banker". Research managers are used to "living dangerously" and existing from one research grant to the next. In industry, project managers have access to project funding through their parent organisations and have considerable flexibility to modify specifications, change schedules, and allocate resources to achieve best outcomes for the project. In the case of the Otway Project, much of this flexibility did not exist. It was seen by CPPL as a "real project in an unreal funding environment"! Funds were often tied to specific milestones or goals or available only from grants in specific fiscal periods, or in some instances funds were tied to particular project activities. This restricted CPPL's ability to make changes to get the best operational outcomes, as it was up to CO2CRC to seek out the extra funds required, or make cuts elsewhere in the research programme in order to act (through CMPL) as the project "banker".

One of the major potential costs proved to be for the CO_2 separation plant. Buttress production well tests on the composition and characteristics of the source gas revealed a higher methane content than expected. While the difference was modest, it posed some design, engineering and cost issues to remove the excess methane. In order to execute the operations in a timely and cost effective manner, it was decided to build a simplified surface plant (see Chapter 4). Given that the CO_2-rich gas did not contain any hydrogen sulphide or mercury, it was concluded that the injection of the mixed gas would be possible and would not in any way compromise the research objectives of the Project related to monitoring and verification. This decision resulted in major cost savings.

Early estimates of drilling costs proved overly optimistic. There were several reasons for this: first, the period 2004–07 was a time of massive inflation in costs related to all resource projects. Second, there was a shortage of rigs due to a major increase in drilling activity particularly in Queensland. Third, the repositioning costs proved to be far in excess of what was estimated. Could these budgetary uncertainties have been better handled? Not really, to the extent that the escalation in costs was outside the control of CO2CRC. It was also the period prior to the 2008 Global Financial Crisis, when it was difficult to retain staff (in a booming economy) when they were being offered ever higher salaries by other employers. The programme of research could have been cut, to save funds, but then that would have defeated the whole purpose of the Otway Project. It was therefore decided to seek additional funding.

The industry participants in CPPL agreed to provide an additional $4 million, the US Department of Energy (via NETL and LBNL) was able to fund some of the Otway activities, as was the Korean Geological Survey (KIGAM). The Federal Government, through the CRC Programme, provided some supplementary funds in 2007 for Otway Stage 2 but this also helped with some Stage 1 costs. Finally, CO2CRC undertook a major reassessment of its programme priorities in all areas, in order to reallocate additional funds to Otway. Together, these measures provided sufficient funding to take Stage 1 forward and lay the foundations for Stage 2.

By early 2007, the revised operational budget was on a firm basis, with accurate capex (capital expenditure) and opex (operating expenses) costings of approximately $22 million (Table 1.3). This represented an escalation in

Table 1.3: Stage 1 budget estimates for 2007 and final costings at completion.

Description	Revised Total Budget (Oct 07)	Forecast Final Cost At Completion
Naylor-1 well	800,000	799,919
Monitoring and verification	891,000	892,176
CRC-1 well	4,829,000	4,822,183
Buttress-1 well	571,000	565,133
Pipeline	1,527,000	1,526,871
Process plant	2,793,000	2,928,693
Permits/licenses	252,000	252,043
Process group	1,796,000	1,810,185
Project management	1,905,000	2,005,077
Abandonment	900,000	900,000
Opex total	1,450,000	1,440,000
Ops contingency	201,277	–9,704
Total up	**17,915,277**	**17,942,280**
Scope change	75,000	325,433
Management (legal/bank fees, etc.)	641,000	590,000
Operations (regulatory/landowner permits, etc.)	971,000	729,000
Tenements	2,655,000	2,655,000
Total operations (including scope change)	**22,257,277**	**21,906,576**
CRC Executive OBPP	2,049,000	2,086,000
CRC Geoscience	1,216,000	1,246,000
CRC M&V personnel	1,496,000	1,496,000
CRC M&V research	2,267,000	2,467,000
Monitoring atmosphere	620,000	620,000
Monitoring geochemistry	785,000	877,000
Monitoring geophysics	862,000	970,000
CRC outreach and risk	181,000	327,000
Research and legal contingency	244,000	0
Total science	**7,453,000**	**7,622,000**
Total operations and science	**29,710,277**	**29,528,576**

costs of $9 million or approximately 70%. These figures proved to be close to the final figures (Table 1.3). The research and science management costs were of the order of $7.5 million (Table 1.3) but were more elastic than the operational costs. The in-kind contribution from the research organisations, based on the 50:50 formula applied by the CRC to all its research costs, would have added an additional $7.5 million to these costs. In addition a significant part of the Otway effort was not "booked" by the researchers, either because it was undertaken outside normal hours or because they were too busy! Further, there was significant reallocation of activities such as communications away from more "general" CCS communication to communications specifically targeted at the Otway Project, because the Project provide an unparalleled real-world opportunity for communication. So, rather than the figure of $327,000 shown in Table 1.3 for communication and outreach, that figure is likely to be a million dollars or more over the life of the Project. Finally a great deal of effort was not booked against the Otway Project in the first couple of years when the Project was still at a very preliminary stage. Taking all this into account, a more realistic figure for the cost of Otway Stage 2 science was of the order of $20 million, bringing the total cost of the complete Otway Project Stage 1 to in excess of $40 million.

Was the budgeting for Otway Stage 2 better, i.e. more accurate, than for Stage 1? One of the consequences of a change of government in 2007 was that it introduced a significant element of uncertainty into the CRC Programme, which was not finally resolved until late 2009, when it was agreed to fund a new phase of CO2CRC for the period of 2010–15. This then allowed the Centre to more confidently plan for the next stage of the Otway Project. By this time, the Project team was of course far more aware of the actual costs of drilling a well, moving a rig, or of installing surface plant. In addition better systems were in place for cost control. Further, a realistic amount (20% or more, depending on the item or activity) was set aside for contingencies.

In the case of Stage 2A, even though CRC-2 was shallower than CRC-1, the cost of drilling CRC-2 was significantly higher ($8 million) largely because far more coring was undertaken and the well completion was more complex. Operations expenditure and facilities management cost approximately $1.2 million and the real cost of the science (including approximately $500K of in-kind support) was of the order of $1 million, bringing the total cost of Stage 2A to approximately $10 million (Table 1.4).

Stage 2B did not include any drilling, but did include some complex downhole operations with extensive new surface plant (Figure 1.11) and innovative field experiments (see Chapter 17), which meant moving into relatively unknown territory in terms of budgeting and costs. Consequently once again the final costs were rather different to the preliminary budget. Total operations and related capital expenditure were approximately $15 million. The scientific activities related specifically to 2B cost approximately $3.2 million in cash, but if in-kind contributions are included total science expenditure is approximately $6 million. Therefore the complete cost of Stage 2B operations and science was an estimated $23 million. The estimated costs of all the Otway activities to 2013 is $74 million (Table 1.4). The estimate currently available for the cost of the proposed Stage 2C is $15 million.

There are several observations that should be made about these costs. First, they should be regarded as indicative, with uncertainties arising in the split between categories, particularly costs incurred in the early evolution of Stage 1. Accurately capturing the scientific costs was particularly difficult because some research was relevant not only to Otway but also to non-Otway related CCS research and any split between the two was at times quite arbitrary. There was also at times difficulty in making a precise split between capex and opex, particularly during Stage 2B, when complex surface construction and operations

Table 1.4: Summary project costs for Otway Stage 1, Stage 2A and Stage 2B in A$ millions.

Stage	Capex	Opex	Science	Miscell	Total
Otway 1	13.2	3.4	20	4.2	40.8
Otway 2A	8.0	1.2	1.1	–	10.3
Otway 2B	5.3	9.8	6.4	1.2	22.7
Total	**26.5**	**14.4**	**27.5**	**5.4**	**$73.8**
Otway 2C (early estimate)					$15

tended to be a continuum, rather than discrete activities. A significant part of the science costs were in the form of in-kind contributions from universities and research bodies; CO2CRC was able to capture its own cash costs for that research, but the in-kind costs were not always accurately booked by the contributing organisation. Finally and not surprisingly, there was no hard and fast boundary between the various stages of Otway. Some of the work undertaken during Stage 1 contributed to Stage 2A, which in turn contributed to Stage 2B.

Despite these limitations, the numbers are very useful and, as far as is known, provide some of the first publicly available breakdowns of costs for a successfully completed storage project. They indicate that, in this particular case, capex and science costs were about equal and opex was about half the cost of the capex or the science. Obviously where a project is able to use a pre-existing well, then there are significant savings, although as demonstrated by the problems encountered in using the pre-existing Naylor-1 well, this can also lead to significant compromises. It should of course always be borne in mind that costs will be very site-specific. Drilling costs were relatively high in the Otway Basin compared to many parts of the United States, for example. It was necessary to purchase the petroleum tenements in order to proceed with the Otway Project, at significant cost to the project. Conversely, that provided the Project with access to the large quantity of CO_2 needed for Stage 1; to have purchased that CO_2 from the nearby commercial CO_2 plant would have cost approximately \$13 million. Assuming Stage 2C goes ahead, then there will be further savings of \$6 million on CO_2 costs. Therefore Otway acquired a very significant asset of long-term research significance, through the original purchase of the Buttress Field.

One of the costs for which provision were made by CO2CRC, but which do not show in the figures provided here, was the cost of abandonment and remediation of the site. When Stage 1A was first mooted, provision was made for this, and was initially set at \$900,000. In 2009, at the start of Stage 2A this was increased to \$1.2 million. However, subsequently the scope of the project expanded, more wells were drilled and costs escalated. At the present time, based on more accurate costings, \$3.5 million has been set aside for abandonment and remediation, assuming an abandonment date of 2020. It is possible the site will be abandoned before that date. Equally well, there may be activities beyond that date which could further delay the need to expend any money on abandonment or remediation. The other uncertainty is the extent to which these costs might ultimately be offset in part, or wholly, by the sale of assets, such as the compressor, but also including the petroleum tenements. Conversely the Otway site offers many opportunities for future geosciences research and society could perhaps be better served by keeping the site for that purpose.

It is also important to point out that the Otway Project probably did not make sufficient provision, in terms of cost and time, to fully write up all activities at the end of each stage. Nor was there adequate provision to curate all the data and ensure ongoing accessibility. Most if not all other projects suffer from the same deficiency, which, it has to be said, is a shortcoming of research funding systems in many instances. Finally, as pointed out earlier the funding system that applies to most research projects often leads to a start-stop-start approach to activities, while the next tranche of funding is sought. The Otway Project was better than most in this respect in that the CRC system under which it was funded guaranteed funding for 7 years. A shortcoming was that there was no provision for inflation in that funding, which posed significant difficulties to the Otway Project during the period 2003–10. However, perhaps the greatest difficulties during this time were totally outside the control of CO2CRC, namely the Global Financial Crisis in 2008, and changes in policy associated with the change in government in 2008–09. Indeed the final observation that can be made is that, despite these changes, CO2CRC was able to successfully deliver Australia's first CO_2 storage project, a testament to the robustness of the systems that were in place to manage the operations and the science required to meet the objectives of the CO2CRC Otway Project.

1.6 Designing the Otway Project

Developing a CCS project needs to follow established project development practices, with defined decision points to enable the project to proceed in a staged fashion. An important premise, assuming that an assured source of

CO_2 has been identified, is that, in order to get sufficient investment confidence along the whole chain, it is necessary to have an up front investment in finding and de-risking the storage element. This de-risking requires early screening via desk-top studies and numerical modelling, but these alone are unlikely to give the information required, or to sufficiently de-risk the project to allow a final investment decision. Therefore, acquisition of new field data to address key residual risks and uncertainties is required. This is a critical path activity in seeking a licence to store CO_2.

Development of a storage (and transport) scheme can be divided into two investment periods. The first of these is a preliminary "speculative" exploration or "identify and assess" phase aimed at finding and assessing a site sufficiently to justify investment in later phases (i.e. a stage-gated capital investment project). The second stage focuses on transport and needs to be concurrent with the development of the companion capture project. In the case of the Otway Project a very deliberate decision was made to first obtain the source of CO_2 and examine the feasibility of transport, before examining the storage options. However, it has to be also pointed out that enough information was gleaned at an early (data room) stage to know that there were several feasible storage options in the vicinity.

A generic project development process is shown in Figure 1.12. Each phase is associated with an increasing level of capital exposure and ends with a decision gate which, depending on technical, commercial, economic and regulatory confidence, will yield a STOP, REVIEW or GO decision.

1.6.1 Identifying and assessing the Otway opportunity (2004–05)

The early part of the first phase typically comprised desk-top compilation studies aimed at creating a number of options for further in-depth investigation. For a site to "qualify" for a project, numerous sub-elements of the site (geotechnical, economic, commercial, environmental political) must all work. At Otway, these were all subject to consideration of risk and uncertainty. Prior to 2004, an Australia-wide study of sedimentary basins, conducted by the CO2CRC predecessor APCRC (see Section 1.1), assessed regions (Rigg et al. 2001) for their suitability for the safe, long-term storage of CO_2.

Subsequently, a number of potential sites for a pilot project were considered and the Otway site ranked highly due to the proximity of depleted natural gas fields and high CO_2 fields. The latter could serve as a source and allow for demonstration of storage in the depleted fields (Section 1.1).

In the absence of legislation governing CCS and the long-term liability associated with storage, cooperation from the Victorian State Government was sought regarding defining the legislative framework for the project. To address asset ownership, including ownership of the petroleum leases containing the Buttress-1 and Naylor-1 wells, and on-site operational liabilities and to undertake all operational aspects of the Otway Project, the special purpose company, CO2CRC Pilot Project Limited (CPPL), was established in November 2005 (Section 1.2).

Hand in hand with defining the property rights, a number of other processes were initiated which were critical for developing the project:

- an "asset team" was formed, led by a Programme Manager and staffed by people with the appropriate geotechnical skill set
- a contracting strategy was designed to allow specific project tasks to be contracted
- early public discussions and community consultations started referring to the project

Figure 1.12: The generic project development process used for the Otway Project.

as a "potential" one should all the approvals including the support of the shire and community be obtained

- project governance and approval processes were defined
- a draft budget was prepared and funding gaps defined to allow additional capital raising efforts.

1.6.2 Select concept: feasibility through to FEED (2005)

In contrast to the previous more speculative phase, which could have resulted in null findings (hence the need for more than one option), the "select concept" phase was expected to result in a higher level of confidence and therefore justified higher levels of investment.

The project was also breaking new ground in terms of testing the existing regulatory frameworks and finding solutions to the long-term liability associated with the storage of CO_2. In consultation with the Victorian Department of Primary Industries (DPI) and the Victorian Environment Protection Agency (EPA), a process to permit the Project was proposed using the Research Development and Demonstration (RD&D) approval provision under the Victorian *Environment Protection Act*, while recognising that more comprehensive legislative cover would be necessary in the future for any commercial geosequestration projects. This provision covered projects (such as the Otway Project) that were limited in scale, duration and environmental impact. Therefore it provided a simple mechanism to develop and test new technologies with legal certainty through the issuing of an RD&D approval. This is discussed in some detail in Chapter 3. It was agreed that conditions of approval would be established between the EPA and CO2CRC, underpinned by a set of key performance indicators (KPIs). Once the monitoring results demonstrated that the agreed KPIs had been met, then the organisation would be considered to have met all of its obligations under that approval (Table 1.5).

The Project work scope was divided into four project phases (Table 1.6), which reflected the focus of the Project on storage and related monitoring activities. This matrix provided a legislative pathway and gave certainty to permitting the Project for activities ranging from working-over and drilling wells, to constructing surface facilities and laying pipelines. It also provided access mechanisms to enable the CRC to conduct monitoring activities and negotiate with relevant landowners.

Table 1.5: The key performance indicators (KPIs) required by the Victorian Environmental Protection Agency.

Phase	Key Performance Indicator (KPI)
1	1. Establish injection and migration models and uncertainties
1A	2. Environmental impacts within SEPP bounds 3. Injection/migration within model prediction bounds
2	4. Verified stable plume within model prediction bounds a. Measurements show no evidence of CO_2 beyond secondary containment in Naylor-1 b. Air samples collected over deep water wells show no evidence of injected CO_2 c. Air samples collected over Naylor-1 (over a few days) show no evidence of injected CO_2 5. Appropriate decommissioning certificate from authorities a. Wells decommissioned as per regulation b. Sites restored as per regulation
3	6. No evidence of injected CO_2 over 2 years a. Air samples collected over deep water wells show no evidence of injected CO_2 b. Air samples collected over Naylor-1, (over a few days) show no evidence of injected CO_2
4	7. No evidence of injected CO_2 over 2 years a. Air samples collected over deep water wells show no evidence of injected CO_2

Table 1.6: Otway Stage 1 showing the various phases from pre-injection to post-closure.

	Phase 1A Pre-injection 2005–07	**Phase 1B** Injection 2007–08 approx.	**Phase 2** Post-injection Post-2008 approx.	**Phase 3** Post-closure 2009+	**Phase 4** Longer term
Surface activities	Plant, gathering line, baseline monitoring	Atmospheric, seismic, geochemical monitoring	Atmospheric, seismic, geochemical monitoring, closure	Surface monitoring	Surface monitoring
Legislation	Petroleum	Petroleum (production) EPA (injection)	Petroleum, EPA	EPA	EPA
Risk management	Insurance	Insurance	Insurance	TBA	TBA
Subsurface activities	Well operations, new well drilling and completions, logging	Injection, well operations, M&V	Logging and sampling, well operations, M&V	None	None
Legislation	Petroleum, EPA	Petroleum (production) EPA (injection)	Petroleum (closure) EPA (M&V KPIs)	EPA	EPA
Risk management	Operational: insurance Reservoir: operational control	Operational: insurance Reservoir: operational control	Operational: insurance Reservoir: operational control	Operational: TBA Reservoir: TBA	Operational: TBA Reservoir: TBA

A conceptual plant design was constructed based on an estimated 90% CO_2 content of Buttress. This involved distillation and refrigeration columns to purify the CO_2 to 97% and use of available methane for co-generation (see Chapter 4).

Multiple reservoir geo-models were constructed in PETREL™ and provided the basis on which reservoir simulations were undertaken (Chapter 5). Formation properties were estimated from the basic wire-line log interpretations of the Waarre C in Naylor-1 and Naylor South-1. History matching was performed using the available production wellhead pressure data from Naylor-1 and a reasonable match was achieved (Sharma et al. 2007). These models allowed further development of the permitting conditions with the EPA, including agreement on the KPIs.

Risk assessment of the Otway Project was carried out at all stages, considering both the engineered and natural systems. The engineered systems consisted of the wells, the processing plant, and the gathering line while the natural system included the geology, the reservoir, the overlying and underlying sealing formations and the groundwater flow regimes (see Chapter 8). Overall, it was considered that risks associated with the capture, transport and injection components of the project were well understood by the oil and gas industry, with robust engineering design methodologies, established procedures and continuous improvement management practices. Conversely, risks associated with the long-term storage of CO_2 were considered to be an active area of research. A quantitative risk assessment was performed using the RISQUE method and it was concluded that the Otway site was capable of achieving a proposed benchmark of 99% containment of the injected CO_2 for 1000 years (Bowden and Rigg 2004) in the target reservoir. The site was therefore considered acceptable on that basis (see Chapter 8).

A comprehensive monitoring and verification concept plan was developed to support the primary project objectives to safely transport, inject and store CO_2, and in addition to safely decommission facilities and restore all disturbed surface sites. The main drivers for the monitoring and verification plan were based on site characterisation, risk assessment and meeting the requirements of the key performance indicators agreed with regulatory authorities as part of the project approval (see Chapter 9).

The geotechnical and engineering works helped identify the key uncertainties so that a new data acquisition programme could be planned. Key uncertainties in Buttress were around the gas composition and pressures, which needed to be resolved before a target injection well location could be finalised.

Concurrently, a range of project planning tasks continued during this phase including:

- the contracting strategy was approved and a lead contractor selected on the basis of qualification conditions
- public discussions and community consultations continued and always included members of the Victorian Government
- a project risk register was constructed
- budget and schedules were refined, allowing for a new data acquisition and uncertainty reduction plan.

1.6.3 Define: detailed engineering design to FID (2005–06)

The aim of this phase was to reduce uncertainty and finalise the project design before entering into the expensive execution and construction phase.

A well test was performed at Buttress and the fluid composition and reservoir pressures were determined. Given the results of the pressure tests, confidence increased in the field being able to supply the 100,000 t of CO_2 needed for the Project. The fluid composition analysis determined that the CO_2 content was lower than anticipated (79%); this had major implications on the plant design and an iteration of the initial design concept was undertaken. The options are considered in detail in Chapter 4, but can be summarised as:

- base case plant design (distillation/refrigeration to inject 97% purity CO_2)
- alternative plant design: dehydration and compression option (while not much water production was expected during the project operations phase, it was recognised it could be an issue over time)
- common aspects to both of the above, relating to wax drop out and potential blockage of tubulars etc. (considerations from a process perspective were likely to add to the cost, i.e. injecting a pore point depressant (ppd), setting up a pipeline for pigging, heat tracing and jacketing on pipe)
- injection of gas (as produced from Buttress) straight into Naylor (given the pressure differentials; it was expected that injection would be possible for the first few months, with subsequent support through a compressor or multiphase pump).

Following a detailed evaluation (see Chapter 4) and budgetary considerations, it was decided to inject the Buttress gas directly into Naylor. As the gas was not dehydrated, the 2″ pipeline was constructed from stainless steel. The process envelope for the systems at early time, mid time and late time was constructed to ensure that the compressor specifications were selected to ensure dense phase transport. Detailed engineering commenced around this option and the compressor was sited as close as possible to the Buttress well.

Reservoir saturation and well seismic surveys were recorded in Naylor-1 to determine the reservoir pressures and fluid contacts. The offset seismic data were used to try and map the gas-water contact spatially as well as vertically. During this process it emerged that the original history match was not as predicted, as the reservoir pressure was higher than anticipated. This led to a broader study and a dual aquifer simulation model being developed. A good history match was obtained and this became the basis for selecting the new (CRC-1) injection well target location, at a distance of around 300 m along the line of maximum dip (south-east) and with an anticipated CO_2 breakthrough time of between 4 and 9 months at Naylor.

The M&V plan was updated and baseline data acquisition of water wells and soil gas commenced. The well completion for Naylor-1 (to allow it to function as a monitoring well) was designed and the injection well design was finalised. All technical work was peer reviewed by the industry support advisory group under the CPPL governance system.

Concurrently, a range of project planning tasks continued during this phase:

- landowner lease agreements were finalised; there were difficulties with one particular landowner, requiring the Victorian Government to carry out a compulsory acquisition (see Chapter 3)

- a health, safety and environmental management system (HSEMS) was developed for the Project and mapped across the system used by the lead contractor to ensure all elements were covered
- project approvals were obtained from the relevant Victorian State Government authorities
- public discussions and community consultations continued and always included members of the Victorian Government (see Chapter 3)
- the project risk register was updated
- budget and schedules were refined and adequate contingency built in for field activities.

The end of this phase was the Final Investment Decision (FID) which was contingent on technical success and economic and regulatory confidence in delivery. This received Board approval in late 2006.

1.6.4 Execute, construct and commission (2006–08)

This phase was broken into individual sub-projects relating to the drilling of the injection well, completing Naylor-1 as a monitoring well and constructing and commissioning the compression station and the injection pipeline.

Each of these sub-projects had their own unique challenges. The injection well CRC-1 had to be pre-terminated in the Eumerella Formation (but well below the target reservoir interval in the Waarre Formation) as there were concerns regarding hole stability. Fortunately this contingency had been anticipated and the project objectives were not adversely impacted. Good quality log and core data were obtained, allowing the picking of the injection target and the refining of the reservoir model. The Naylor-1 completion was extremely challenging as a lot of instrumentation was deployed into a small borehole in a live gas well. In addition to the custom design of the completion itself, an enormous amount of effort was required to define adequate safety procedures for conveyance of the instrumentation into the well (see Chapter 12).

Wet weather impacted on the pipeline construction and boring machines had to be deployed to complete certain sections. There were delays in getting power to the site; this in turn impacted on the plant schedule. Commissioning took longer than initially expected as additional vibration tests and process-related changes, such as providing thermal cladding to exposed pipes, had to be performed. The delays totalled around 3 months, with the site ready for injection at the end of March 2008.

Additional project planning tasks continued during this phase, including:

- refining the monitoring plan based on the updated reservoir model; this included finalising the selection and the quantities of tracers to be injected
- developing a Journey Management Plan to the site to manage the increased traffic
- developing an operations and Emergency Response Plan for the site
- designing a visitors' centre and making provision for future educational needs
- obtaining project approvals from the relevant Victorian State Government authorities
- public discussions and community consultations continued
- updating the project risk register
- refining of budget and schedules at the end of the construction phase in preparation for the operations phase.

1.6.5 Operate (2008–09)

Commencing in March 2008, CO_2-rich gas was injected into the Waaree C Formation through the injection well CRC-1, and a full range of monitoring and verification activities were carried out (see Chapter 10). The operations phase was planned to last for 2 years with a target volume of 100,000 t of CO_2 injected. However, after 18 months of injection, it was considered that the project objectives had been met, with around 66,000 t of gas (approximately 60,000 t of CO_2) injected.

Under the initial approvals the CRC tenure would have expired in July 2010. Consequently the monitoring and verification programme was structured to ensure that the Project objectives were satisfied within that time frame. The site would then have been decommissioned following the cessation of injection. However, funding for CO2CRC was extended to 2015 and a second stage (Stage 2) of the Otway project was launched, retaining the current assets for ongoing use. Decommissioning was thus deferred and its budget was carried forward on the CRC balance sheet (see Section 1.5).

1.6.6 Operations relating to Stage 2

As pointed out in Section 1.5, there were significant delays in the period 2008–09, due to a change in government and related funding uncertainties for CO2CRC. Consequently it was not until very early in 2010 that the new operational stage could be commenced and a new well (CRC-2) drilled. However, it is important to note that monitoring activities related to the Stage 1 injection continued after the Stage 1 injection had been completed. Indeed at the time of writing (January 2014) monitoring activities related to Stage 1 are still underway. In other words the ongoing nature of the research has meant that there was no sharp and well-defined end to Stage 1 activities.

Otway Stage 2 was based on the idea of injection into the Parattee Formation, with the objective of understanding trapping mechanisms in a saline aquifer. The research programme was developed by CO2CRC and its Members and refined through assurance reviews by the sponsoring companies. Stage 2 was structured to ensure that Stage 1 was not in anyway compromised. Managing the Project expenses in-line with the available grant funding required that Stage 2 was divided into separate phases. This was not ideal from an operational perspective but did allow the work to progress in a staged manner that was logical, though not necessarily the most cost-effective way to proceed, Therefore Stage 2 was constructed as a series of building blocks with clearly defined research objectives, with the potential to be enhanced beyond 2010. Programmatically, the Stage 2 effort was broken into discrete stages aimed at fulfilling specific objectives of the overall research programme.

The stages were as follows:

Scope objective

2A Characterisation of Parattee:

- detailed site characterisation with support from experimental data with laboratory determination of relative permeability and geophysical properties from cores obtained from new well (CRC-2).

2B Residual saturation tests:

- investigating residual saturation processes using a Huff-n-Puff (inject/soak/back-produce) type of CO_2 injection testing methodology.

2C Limited volume injection:

- demonstrate that injection in an unconfined aquifer is safe and can be monitored reliably, that the CO_2 is residually trapped and ultimately dissolves.

Initially Stage 2B and 2C were considered as part of a single test design, using a notional 10,000 t of CO_2. However, as the theoretical work advanced it became evident that the investigation of residual processes could be undertaken with smaller quantities of CO_2 than 10,000 t (Zhang et al. 2011). While this simplified the 2B process, the volumes injected for 2B would not be sufficient for 2C from a surface detectability perspective using seismic techniques. As a result, Stage 2C was defined as a separate stage to enable planning to progress, based on a larger scale "seismic-detectable" injection of CO_2.

Stage 2A was a relatively straight-forward activity (Figure 1.13(a)) focused on drilling and completing the new well (CRC-2). Consequently the pathway followed for Stage 1 and the drilling of CRC-1 was followed quite closely and the CRC-2 well was successfully drilled and cored in January–February 2010 under a water licence, with approvals from Southern Rural Water and the EPA (Singh and Steeper 2011). At the same time approval in principle was also given for Stage 2B and Stage 2C.

Stage 2B involved major new surface installations (Figure 1.11), sophisticated downhole engineering (Figure 1.13(b)) and complex science that was unlike anything previously undertaken at the Otway site, or indeed anywhere else (Chapter 17). Throughout 2010 and into 2011, major new

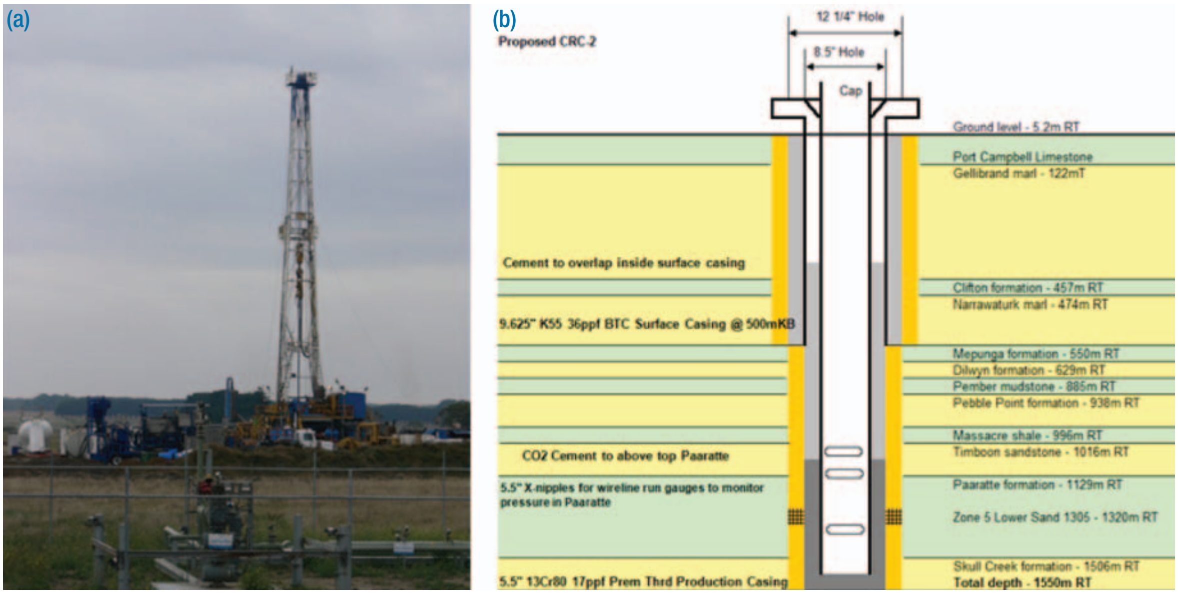

Figure 1.13: (a) Drilling of the CRC-2 well by Hunt Energy using Moduspec Rig, February 2010. (b) The configuration of the CRC-2 well.

Table 1.7: The approvals required for Stage 2 activities.

Activity	Approval/Permits	Regulator	Application Process
Production of CO_2	Production plan	DPI	- *Petroleum Act 2000* (DPI)
Compression and transport of CO_2 1. Plant (compressor) 2. Gathering line 3. Other facilities (centre, etc.)	Planning approval, gathering line approval	DSE, DPI, Moyne Shire, DOI	- *Petroleum Act 2000* (DPI) - Ministerial Amendment request of the *Planning and Environment Act 1987* (Moyne Shire/DSE) - *Exemption of Pipeline Act 2005* (DPI) - *Cultural Heritage Act* (DPI) - Compensation agreement: consent to land access - Project of Significance and Compulsory Aquisition (DOI) - Exemption of Rural Fire Service (CFA)
Drilling of new well	Drilling licence	SRW	- Submit EMP, SPM and drilling plan. Well being drilled underwater well licence.
Injection of CO_2 (CRC-2)	Disposal approval	SRW, EPA	- *Water Act 1989* Sections 76 and 67: Application for approval to dispose of matter by means of a bore - Compensation agreement: consent to land access
Storage of CO_2	Storage approvals	EPA	- *Environmental Protection Act 1970*: Research development and demonstration (RDD) approval (EPA)
Monitoring and verification 1. Atmospheric 2. Water wells 3. Downhole (Naylor-1) Monitoring	Planning approvals, compensation agreement, DSE access rights	EPA, DSE, Moyne Shire	- Ministerial amendment request of the *Planning and Environment Act 1987* (Moyne Shire/DSE) - Consent to use (SOBN) bores (DSE) - Compensation agreement: consent to land access

surface facilities were established at the site, with the actual field experiments undertaken between June and September 2011. Because of the novelty of the experiments there was a need for particularly close collaboration between the researchers, the operators and all levels of management, as well as with the regulators (Table 1.7). Nonetheless much the same project development and approvals template was followed as in Stage 1 (Figure 1.12).

1.7 Project liability and risk

1.7.1 Categories of risks and liabilities

The issue of risk associated with as storage project is considered in some detail in Chapter 8. There is general agreement that at well characterised CO_2 storage sites, there is a low level of risk. Nonetheless the issue of how to handle (and equitably share) risk and liability was a major concern to the Board; it had a major impact on the final structure of CO2CRC and related entities and also resulted in a significant delay in reaching agreement amongst the stakeholders.

It was important that all aspects of risk and liability were considered in formulating the Otway operations. The nature of the risks associated with the Otway Project was considered to result in potential liability in two broad categories:

- liability associated with long-term storage of sequestered CO_2
- operational risks and liabilities associated with engineering activities including design, construction, and operation of the project and management of the petroleum tenements.

The former category was novel in the case of Otway, because no statutory regulations existed to define the boundaries of compliance and the initial issue confronting the Project was to understand how this category of risk and potential liability should be managed. On the other hand potential for liability arising from operational activity was a risk that was very familiar to petroleum and mining operators; there were well established methods of dealing with this risk.

1.7.2 Liability associated with sequestered CO_2

Companies routinely take on liability arising from projects, but sequestered CO_2 is assumed to be stored indefinitely so that the company carrying out the sequestration process is unlikely to still be in existence over comparable time frames. Indeed, CPPL was formed as a special purpose vehicle only for the duration of the Project. The simple solution to the issue, as far as the Project was concerned, would have been for government(s) to assume this liability in the public interest. However, difficulties arise in this approach, partly because of the time frames involved. The legal position in terms of sequestered CO_2 was complex as indicated by the comprehensive legal advice obtained by CPPL at the time, but in practical terms a successful project had to be based around credibility and reputation.

The proposition then put forward was that if the company gave the government certain undertakings in respect to the performance of the Project and was able to deliver those outcomes, then the government should treat the tenements and regulatory matters in much the same way as a normal petroleum tenement, allowing relinquishment at project completion. This was accepted as the way forward.

Table 1.8: The Hazardous Operations/Hazards Identification (HAZOP/HAZID) compilation for Otway Stage 1.

No.	HAZOP/HAZID/SIL/Risk Assessment	Date
1	HAZOP of commissioning procedures	1/08/07
2	HAZOP of tracer chemical injection report	8/08/07
3	Naylor-1 workcover and CRC-1 completion HAZID and risk	8/08/07
4	CO2CRC Project—detailed HAZOP follow-up report	9/08/07
5	Buttress well test CO_2 dispersion assessment	30/05/06
6	Buttress-1 well test HAZOP	9/06/06
7	HAZARD risk register	14/11/06
8	Wellhead ESD SIL assessment	2/03/07
9	CO2CRC Project—operational phase HAZID and risk assessment	5/12/06
10	Gathering line construction HAZID worksheets Close out report	4/04/07
11	Compressor station construction—HAZID workshop	3/04/07
12	CO2CRC Project—operational phase HAZOP	5/12/07
13	CO2CRC Project—detailed HAZOP report	5/04/07
14	CO2CRC Project—plant SIL assessment	17/04/07
15	Buttress and Naylor well work—HAZID and risk assessment	19/05/07
16	CO2CRC HAZOP shop drawings	29/11/06

1.7.3 Operational risks and liabilities

Operational liability was a much more familiar issue for companies and governments to deal with compared to the sequestration issue. The risks were those associated with conventional engineering design, construction and operations. A review of the Project showed that none of the activities was novel in the context of petroleum or mining activities. Consequently conventional mitigation measures were utilised in the Project. In summary these included establishment of typical industry based systems and processes including a HSE system (Table 1.9) and reporting protocol, conventional HAZOP/HAZID analysis (Table 1.8), peer review of all major technical and engineering assumptions, and a system of financial budgets, controls and reporting requirements.

From its inception the Otway Project was developed in a stage-gated fashion (Figure 1.12), assessing the risks and developing mitigation plans in accordance with the ALARP (as low as reasonably possible) principle. The process followed was to use the widely accepted qualitative risk matrix approach (Chapter 8). Project risks were considered across the range and included those associated with producing, transporting and storing CO_2 safely. The plant

Table 1.9: Comparison of systems to ensure HSE conformity between CPPL and the main contractor.

		CCPL												
		Risk management	Standard for HSE planning	Training and competency	Contractor management	Document management	Communication and consultation	Conduct of work, management and performance standards	Environmental standards	Management of change	Disaster planning	Incident reporting	HSE audits	Management review and evaluation
Main Contractor	Management system policy, objectives and planning		■											
	Organisation and responsibilty								■					
	Information management and document control					■								
	Control of service provision				■									
	Risk assessment and risk management	■												
	Communication and consultation						■							
	Resources management			■	■									
	Contractor and support services				■									
	Procurement					■								
	Design, construction and commissioning							■						
	Control of operations							■						
	Maintenance, inspection and testing							■						
	Change management									■				
	Emergency response										■			
	Incident/hazard/non-conformances reporting and investigating											■		
	Managing materials, waste and discharges								■					
	Decommissioning and abandonment							■						
	Audit, management review												■	■

and pipeline construction, injection well construction and CO_2 production and injection procedures were developed in-line with the established processes from the oil and gas and chemical industries.

Standards were established for HSE and a bridging document (Table 1.9) was prepared with the principal contractor to ensure that their HSE management systems were in compliance with those developed by CPPL and required to deliver the project.

The subsurface storage risk assessment process used at Otway was a less well defined process and an ongoing area of research (Chapter 8). The Otway Project built on a process developed by the APCRC, using a technique based on developing risk categories through expert solicitation and subjecting the assessed probabilities and consequences through a probabilistic Monte-Carlo process (Bowden et al. 2001; Bowden and Rigg 2004). This allowed the ranking of the Otway site compared to others in Australia and also estimated the project risk against a target of being able to retain 99% of the injected CO_2 in the target reservoir for 1000 years. The quantified risk assessment (QRA) exercise confirmed that the selected site in the Waarre reservoir was adequate to meet these metrics (Chapter 8).

Once the risks were identified and control actions defined, mitigation was managed through a few principle mechanisms:

- operational control by CPPL: this ensured that a rigorous process was in place from planning through to operation to minimise risks. Peer reviews and audits were instituted to ensure robust plans and operational readiness was thoroughly tested through a pre-start audit prior to injection. HSE was allocated the highest priority and, as such, site-specific journey management plans and emergency response plans were created and tested
- insurance for all key operational elements to ensure that well control, property loss and third party liability-related risks were adequately covered
- financial control processes to ensure that, in a limited budget, project flags were raised early enough if cost escalation were to occur.

The project processes and systems worked as planned and the Project was delivered safely without a single lost time incident.

Considerable attention was also paid to reputational issues especially in dealings with governments, landowners, and the local community. While all of these matters were pursued in some detail, a high level risk assessment conforming to the Australian Standard was also developed at Board level to highlight and manage the key risks for the Project. The objective was to identify any matters that might be "showstoppers" and focus attention on managing those risks so that project integrity was not threatened.

1.7.4 The process prior to injection

While the management of operational risks was an ongoing matter, the risk associated with injection received special attention because of its novel nature and the requirement to have a unanimous Board decision.

Prior to the formal CPPL Board decision to carry out injection of the gas at Otway, a pre-start-up review was held in December 2007. This was conducted at a time when almost all construction activities were complete and pre-commissioning activities were in progress. The primary outcome of this meeting was to agree a commissioning plan that would enable the hard target of the official opening on 2 April 2008. Along with this was the need to assess the readiness of the CO2CRC plant for the injection of Buttress gas and check that systems, processes and procedures were in place to ensure that plant integrity could be maintained at all times and that the scientific objectives could be met. This required that there was confirmation of the following:

- facilities were constructed as per the design requirements
- design integrity had been maintained during the construction phase
- flow assurance controls (design, procedures, competencies) were in place
- pre-commissioning checks demonstrated system integrity

- operations staff were sufficiently competent to commence normal running of the facility
- HSE management systems were in place including an HSE case and emergency response capability
- information management systems were in place, including "as built" drawings and vendor information
- operations philosophy had been complied with
- any imperatives had been complied with.

Overall, the audit confirmed that all of these were met although it did identify the need for immediate attention be given to (1) HAZOP close out, (2) operations recruitment and training, (3) high pressure sampling at the Naylor monitoring well and (4) development of a schedule for start up.

As a separate but related exercise, a comprehensive assurance checklist was compiled to ensure that all key risk areas had been addressed. This was summarised with document links to archived files that validated each of the principal check items. This list defined the items, requirements, status, and links to documents that validated these.

The categories covered on this list included:

- regulator/government approvals/licenses
- long-term liability (legal advice and review)
- EPA approvals
- subsurface assurance
- quantitative risk assessment
- risk mitigation
- Otway site closure plan mapping out CPPL's approach to risk minimisation
- decommissioning and rehabilitation
- operations
- HSE requirements
- Project obligations
- Project due diligence
- heritage survey
- Project schedule update/key decision points
- key performance indicators
- cost estimate and budget
- community consultation.

Supporting this in some detail were documents defining the project phases, key performance indicators as required by the EPA as part of the approvals process, the Board responsibilities, any safety incidents, the HAZID/HAZOP register and a legal obligations register. In addition, a QRA register was continually updated throughout the life of the Project. Together these processes enabled Otway 1, Otway 2A and Otway 2B to be safely and successfully undertaken.

1.8 Conclusions

The idea of undertaking a small-scale Australian injection project was developed in 2002–03 and proceeded along a non-linear path for several years as various challenges were met and overcome, before injection finally commenced in 2008. The Project that was successfully delivered in 2008–09 was in fact close to the original concept in terms of the science. But the manner in which it was achieved underwent many changes. Notable amongst these was the need to:

- establish a special purpose operating company
- work very closely with a range of state government bodies because of the lack of a specific regulatory regime for CO_2 storage
- develop innovative arrangements for dealing with long-term liability
- establish clear protocols for scientists, contract staff and visitors to ensure a safe working environment
- recognise the necessity to press ahead with planning, despite the many financial uncertainties that arise in a research environment
- ensure risk and uncertainty were understood, documented and managed as an integral part of the project
- plan to maximise the long-term research opportunities offered by the Otway site

- accept that in a research environment it is often necessary to start planning for the next stage of research before the current stage had been completed
- compromise where necessary to ensure scientific activities can be undertaken despite budgetary limitation, provided this does not impact on science quality and credibility or on key scientific objectives.

Chapter 1 documents how many of these issues were successfully handled over the life of Otway Stage 1 and into Stage 2. The remainder of this volume provides the detail of what science was done, how it was done and what was learned.

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