Carbon Sequestration Leadership Forum
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Practical Regulations and Permitting Process for Geological CO_2 Storage

Report Prepared for the Policy Group of the

Carbon Sequestration Leadership Forum (CSLF)

By the CSLF Regulation Task Force

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This report was prepared by participants in the CSLF Regulation Task Force: Ryozo Tanaka (Research Institute of Innovative Technology for the Earth, Japan; Chair), Tim Dixon (IEA Greenhouse Gas R&D Programme), Sallie Greenberg (Illinois State Geological Survey, USA), Ian Havercroft (Global CCS Institute), and Tristan Stanley (International Energy Agency). The Task Force members would like to thank all authors of the case studies: Aaron De Fina (CO2CRC), Chris Gittins (TAQA), Anne Halladay (Shell), Jordan Hamston (CO2CRC), Randy Locke (Illinois State Geological Survey), Britta Paasch (Statoil Research Centre), Lynsey Tinios (Shell), Owain Tucker (Shell), Jonas Nesland Vevatne (Sleipner Asset), and Max Watson (CO2CRC).

EXECUTIVE SUMMARY

This report was aimed at exploring practical regulations for geological CO_2 storage from the viewpoint of smooth planning, development, and operation of carbon capture and storage (CCS) projects. Experiences of seven CCS projects with the regulatory process for geological CO_2 storage in their own country was compiled as case studies here. This report will be useful for regulatory authorities who will develop CCS regulations, regulatory authorities who will review existing CCS regulations and amend them if necessary, and CCS project proponents who will apply for a permit.

CCS is expected to play a great role in long term energy policy to meet ambitious global climate goals. The large-scale deployment of CCS requires appropriate incentives and regulations to be in place in each country. This report fills the gaps of initiatives by other organizations to facilitate the establishment of CCS regulatory frameworks by governments: the initiatives of the International Energy Agency (IEA) in the publication on model regulatory frameworks and knowledge sharing on regulations in major jurisdictions through workshops and a series of publications; and the initiative of the Global CCS Institute (GCCSI) in examining and assessing the completeness of national legal and regulatory frameworks in major jurisdictions.

The seven case studies herein are shared by real CCS projects which are reasonably diversified in terms of region, storage type, scale, and project status. The projects cover different regions (Europe, North America, and Asia Pacific), different storage type (onshore and offshore, saline formation, and depleted gas field), different scale (from pilot through medium scale to large scale) and different project status (operational, post-injection or cancelled). An overview of each case study is summarized in Table-S1.

Table-S1: Overview of the Case Studies

Region	Project	Storage Type		Scale [1)]	Status [2)]
		Outline of Case Study			
Europe	Sleipner CCS Project	Saline Formation	Offshore	Large	Operational
		Sleipner was required to re-apply for a CO_2 storage permit due to the replacement of storage regulations. A number of challenges in the re-permitting and new regulations, such as financial security, were resolved.			
	ROAD and P18-4 CO_2 Storage	Depleted Gas Field	Offshore	Large	Cancelled
		ROAD began its planning before the CO_2 storage regulation was finalized. They resolved a number of challenges such as financial security in permitting through close communication with the regulatory authority. Their application was found to be in compliance with the London Protocol requirements in general.			
	Former Peterhead CCS project	Depleted Gas Field	Offshore	Large	Cancelled
		Peterhead commenced communications with the regulatory authority at a time of its precedent project. The successful outcomes include a reasonably flexible way of determining the length of the closure period. They found a need to actively reach out to different teams within the regulatory authority and noted the benefits of independent external review on their permit application.			
North America	Quest CCS Facility	Saline Formation	Onshore	Large	Operational
		The Quest operator was involved in the establishment of the regulatory framework and also a comprehensive review of the framework afterward. The monitoring plan for the project is being optimized and streamlined as the project progresses thanks to its high adaptability.			
	Illinois Basin – Decatur Project	Saline Formation	Onshore	Medium	Site Closure
		Decatur was planned while the new CO_2 storage regulation was evolving. The developer needed to re-apply for a CO_2 storage permit. This resulted in prolonged permitting process, changes in its monitoring plan, and cost increase for monitoring.			
Asia Pacific	Tomakomai CCS Demonstration Project	Saline Formation	Offshore	Medium	Operational
		Tomakomai had to suspend CO_2 injection in its offshore site due to natural fluctuation in seawater parameters larger than conservative threshold. Injection was resumed after the revision of its monitoring plan to allow for more comprehensive judgement when irregularity is detected.			
	CO2CRC Otway Research Facility	Depleted Gas Field / Saline Formation	Onshore	Small	Operational
		Otway pilot has had three phases and has gone through different CCS regulatory environments. CO_2 storage regulation came into force during the second phase. Since then, the project has worked under exemption as an R&D project, but is currently explore how R&D injection fits into the regulation.			

1) Large: > 1 Mt/yr, Medium: 0.1 - 1 Mt/yr, Small: < 0.1 Mt/yr

2) As of November 2017

This report analyzes the case studies, in particular, their 40 lessons learned in total to draw findings for making CO_2 storage regulations practical. The findings here are categorized into 1) findings for making CO_2 storage regulations practical; 2) findings for effective CO_2 storage permitting process; and 3) findings for making permit application documents and plans pragmatic.

Findings for Making CO_2 Storage Regulations Practical

1. CO_2 storage regulations should be established under the principle of promotion of safe CCS. In the establishment of the regulations, the timely involvement of industry is important.

2. Existing CO_2 storage regulations can be improved through a review by diversified stakeholders.

3. CO_2 storage regulations should be flexible enough for various CCS projects with different characteristics to move forward.

4. New or amended CO_2 storage regulations should be flexible with transitional provisions where necessary for continuation of existing valid projects if any.

5. The definitions of key terms should be made with consideration of technical constraints and should have consistency with those in other related laws and regulations.

Findings for Effective CO_2 Storage Permitting Process

6. CO_2 storage regulations should ideally be in place before a planning of the first CO_2 storage project starts in order to promote the deployment of CCS projects in a country.

7. A permitting process should have adequate time and resources allocated and be appropriate to the scale and the likely impact from the project.

8. For efficient permit award, close communication is essential between a permit applicant and a regulatory authority and should be initiated at an early stage. Such communications can be expedited by diversified members and fixed contact points.

9. A regulatory authority and a permit applicant should identify other regulatory authorities who should be involved in a permitting process and commence communicate with them early.

10. It would be helpful if a regulatory authority can recognize that key permit application documents and plans will mature and should be resubmitted when appropriate.

11. A regulatory authority and a permit applicant in a national jurisdiction that is a contacting party to the 1996 London Protocol should make sure that permit application documents for offshore CO_2 storage are in compliance with the Protocol Requirements.

Findings for Making Permit Application Documents and Plans Pragmatic

12. An independent external review may be useful to make permit application documents better and streamlined.

13. Negotiations between a permit applicant and a regulatory authority to address critical issues in permitting should be initiated as early as possible. These issues may include financial responsibilities of an operator and monitoring plans.

14. Financial responsibilities of an operator should be reasonable and pragmatic. Issues to be addressed may include the length of the closure period[1]; financial contribution from an operator for a regulatory authority's responsibility during the post-closure period[2]; and responsibility to compensate unintended CO_2 leakage by purchasing emission credits.

15. Monitoring plans for CO_2 storage should be risk-based and adaptive; be pragmatic when responding to an irregularity or a potential irregularity; and use monitoring parameters that are well understood and have sufficient baseline data for critical judgements.

The findings should provide useful information in many situations including: regulatory authorities develop regulations for geological CO_2 storage, or review existing regulations for geological CO_2 storage and amend them if necessary; and CCS project proponents apply for, or consider applying for a geological CO_2 storage permit.

And in the future, experiences for the next generation of CCS projects should be examined to look into how the issues to be addressed that have been identified in the findings in this report will have been resolved in various jurisdictions. Many of the issues, including operator's finance responsibilities, may be specific to a first wave of CCS projects which has no or limited precedent experiences in permitting for geological CO_2 storage.

[1] A closure period is a period between the cessation of CO_2 injection and the demonstration of compliance with criteria for storage site closure.

[2] A post-closure period begins with the demonstration of compliance with criteria for storage site closure.

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1 Introduction

1.1 CSLF Purpose

The Carbon Sequestration Leadership Forum (CSLF) is a Ministerial-level international climate change initiative that is focused on the development of improved cost-effective technologies for carbon capture, utilization and storage (CCUS). It also promotes awareness and champions legal, regulatory, financial, and institutional environments conducive to such technologies. The mission of the CSLF is to facilitate the development and deployment of CCUS technologies via collaborative efforts that address key technical, economic, and environmental obstacles.

CSLF comprises 26 members, including 25 countries and the European Commission. The CSLF member countries represent over 3.5 billion people or approximately 60% of the world's population on six continents and comprise 80% of the world's total anthropogenic carbon dioxide (CO_2) emissions.

The CSLF comprises a Policy Group and a Technical Group. The Policy Group governs the overall framework and policies of the CSLF, and focuses mainly on policy, legal, regulatory, financial, economic, and capacity building issues. The Technical Group reports to the Policy Group and focuses on technical issues related to CCUS and CCUS projects in member countries. The two groups carry out activities usually in the form of a task force.

1.2 Regulation Task Force and its Mandate

At the Policy Group meeting held in Abu Dhabi, United Arab Emirates in May 2017, the CSLF Policy Group formally agreed to launch a new task force chaired by Japan to explore practical carbon capture and storage (CCS) regulations from the viewpoint of smooth planning, development, and operation of CCS projects. The Regulation Task Force mandate was to produce a report by compiling case studies of real CCS projects regarding regulations for geological CO_2 storage and identifying findings or recommendations.

1.3 CO_2 Storage Regulations for CCS Deployment

To meet ambitious global climate goals, CCS is expected to play a great role in long term energy policy. The large-scale deployment of CCS requires appropriate incentives and regulations to be in place in each country. A number of governments around the world have already implemented CCS regulations by amending existing resource extraction or environmental impact frameworks or establishing dedicated regulatory frameworks. More and more governments are recognizing the need for appropriate legal and regulatory frameworks if CCS is in their plans.

To facilitate the establishment of CCS regulatory frameworks by governments, the International Energy Agency (IEA) formed the International CCS Regulatory Network in 2008 to bring together international experts in this area to support global knowledge sharing by organizing meetings on an annual basis. Eighth such meeting have been held, the most recent in 2016. The IEA also published the Carbon Capture and Storage Model Regulatory Framework as a guidance document for the development of CCS regulations in 2010. In addition, they published four editions of the Carbon Capture and Storage Legal and Regulatory Review from 2010 to 2014. The publications updated the development of regulatory frameworks in major jurisdictions on a regular basis. The Global CCS Institute (GCCSI) launched the CCS Legal and Regulatory Indicator in 2015 and will release a second edition in 2017. The indicators are aimed at examining and assessing the completeness of national legal and regulatory frameworks in major jurisdictions.

Now that dozens of CCS projects, including anthropogenic CO_2-EOR projects, have gone through regulatory processes in a number of countries, the CSLF Regulation Task Force was formed to produce a report that compiles project experiences with the regulatory process in their own country. The members agreed to put the focus on regulations for geological CO_2 storage since CO_2 capture and CO_2 transportation are generally dealt with by conventional regulations for industry without any major problems. It was not intended to exclude regulations for CO_2-EOR in the scope if they are for permanent geological CO_2 storage, but the projects that agreed to share their experiences as case studies for this report do not include any CO_2-EOR projects. The report compiled seven case studies, which are reasonably diversified in terms of region, storage type, scale, and project status. The case studies, in particular, their lessons learned are analyzed, and findings are drawn for making regulations practical, making a permitting process smooth, and making permit application documents and plans pragmatic.

The information herein will contribute to smooth planning, development and operation of CCS projects. The findings in this report will be useful for regulatory authorities who will develop regulations for, regulatory authorities who will review existing regulations geological CO_2 storage and amend them if necessary, and CCS project proponents who will apply for a permit for geological CO_2 storage.

2 Case Studies

This report compiles seven case studies of project experiences with the regulatory process, listed in the Table 2-1. The projects cover different regions (Europe, North America, and Asia Pacific), different storage type (onshore and offshore, saline formation, and depleted gas field), different scale (from pilot through medium scale to large scale) and different project status (operational, post-injection or cancelled). An outline of each study is also included in the table. Since the seven projects are a pioneer CCS project in their country, almost all of the projects commenced its planning before the CO_2 storage regulations were finalized and enforced or the current regulations replaced the previous regulations which had issued the original permit.

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Asia Pacific	CO2CRC Otway Research Facility	Depleted Gas Field / Saline Formation	Onshore	Small	Operational	Otway pilot has had three phases and has gone through different CCS regulatory environments. CO_2 storage regulation came into force during the second phase. Since then, the project has worked under exemption as an R&D project, but is currently explore how R&D injection fits into the regulation.

1) Large: > 1 Mt/yr, Medium: 0.1 - 1 Mt/yr, Small: < 0.1 Mt/yr

2) As of November 2017

2.1 Sleipner CCS Project

Compiled from the Norwegian legal documents by Britta Paasch (Statoil Research Centre) & Jonas Nesland Vevatne (Sleipner Asset)

Overview of the Project

The Sleipner CCS project started in 1996 and played a pivotal role in developing and demonstrating numerous technologies related to CCS, in addition to complying to changing legal requirements during the last 21 years. In 2013, the nearby Gudrun field came online and the gas from this field was also transported to the Sleipner facility for CO_2 removal and storage.

The Sleipner CCS project is an offshore-based, amine-capture facility processing natural gas from the Sleipner field. It is located 250 km offshore southern Norway. The separated CO_2 is injected into the 800-1000 m deep Utsira Formation which is a saline aquifer. So far over 16 Mt CO_2 have been stored at this site. The project continues to give valuable insights into the value of remote geophysical monitoring techniques and their detection capabilities allowing the tracking of the CO_2 plume. Geophysical monitoring data and interpretation contributed to and improved the quantification of CO_2 processes in saline, siliciclastic formations. In addition, the stable performance of the Sleipner CCS project over the last 21 years highlights the value of careful design and engineering.

During the lifetime of the Sleipner CCS project new Norwegian and EU regulations for storage of CO_2 in geological formation were implemented. Statoil applied for re-permitting of CO_2 storage under the new regulations, which was then approved in 2016 by the Norwegian Department of Environment.

Figure 2-1: Sleipner CCS Facility
(photo: Eiken, Statoil)

Changes in the Norwegian regulations regarding storage of CO_2 in geological formations

In the period between 1996 and 2016 Sleipner CO_2 injection was governed by the Norwegian Petroleum Law. In 2015 Statoil re-applied for permission to store CO_2 under the new Norwegian CO_2 storage directive and was subsequently permitted to continue storing CO_2, replacing the previous permit, where storage of CO_2 was permitted as an integrated part of the pollution law related to drilling and production.

In 2014, the EU Directive regarding geological storage of CO_2 was included, with certain modifications, into the Norwegian Petroleum Directive and the Pollution Directive. For CO_2 storage related to petroleum extraction in Norway, it is the petroleum law and pollution regulations that apply.

Background for the application

The gas from Sleipner Vest and Gudrun fields contain 9% and 12% CO_2, respectively. CO_2 from both fields is extracted at the Sleipner T platform. The CO_2 needs to be reduced to <2,5% to meet export gas specifications. This is achieved by a combination of CCS and blending with low-CO_2 gas from other fields. According to the pollution law, injection of CO_2 into a geological formation is classed as pollution and a special permit is required. The aim of the pollution law is to obtain environmentally safe geological storage of CO_2 as a means of mitigating climate change.

Statoil applied for a permit to store an additional 4 Mt CO_2 from the Sleipner and Gudrun field via the Sleipner T platform, including possible new projects. Until now about 16 Mt CO_2 have been stored at the Sleipner storage site. The injection rate has been approximately 0.9 Mt/a. In the future, this rate is expected to decline due to declining production rates of the fields. The Sleipner field is expected to be in production until 2032 and the total capacity of the storage site is estimated to be 25 Mt.

Application Content

The content of the application had to include a description of the storage formation characteristics, a risk assessment, a monitoring plan and a documentation of current financial security for production and activities on the Sleipner field. Statoil's internal requirements for safe storage of CO_2 is in good agreement with official requirements, and much of the content could be based on previous work.

Characterization

The characterization of the storage site mainly comprises data collection prior to injection used for establishing reservoir models for prediction of CO_2 plume behaviour. Statoil has explained to the authorities the existing dataset related to the permit requirements. The regulations require a dynamic model of the injection site, which should be updated through time. This method has not been used at Sleipner, due to challenges specific to modelling the Utsira formation in a predictive manner, and because existing 4-D seismic data is better suited to understanding and predicting the movement of the CO_2 plume. Thanks to flexibility in the regulations, the Norwegian Department of Environment could allow this deviation.

Risk

Any activity related to storage of CO_2 can only be permitted if no significant risk is associated with such activity. Statoil was requested to identify risk elements for both the injection and post injection phase where the post-injection phase was defined as 50 years. The likelihood for leakage to the seabed through faults, weaknesses in the caprock or through plugged exploration wells was found to be very low, with probabilities in the order of 0,0001 to 0,001 for the ongoing and post-injection periods, respectively.

Monitoring plan

The pollution regulation requires the operator to monitor the injection site. This includes the storage site including any area which CO_2 might migrate to. Potential CO_2 emissions include diffuse emissions from the amine process and injection facilities on the platform and emission from to the sea from the storage site. The Sleipner monitoring plan includes monitoring of well-head pressure and temperature, as well as 4-D seismic with a frequency related to the (declining) injection rate. In addition, gravimetry and seabed inspections have been conducted. Other monitoring technologies such as seabed uplift, passive seismic and electromagnetics have also been considered.

The present-day monitoring plan was confirmed to be sufficient to give a good understanding on how the CO_2 plume moves in the subsurface.

Financial solidity, reliability and technical competence

The pollution regulation requires the operator to be financially sustainable throughout the lifetime of the project, in addition to possessing necessary technical competence. Statoil has operated the Sleipner field since 1996 under the Norwegian Petroleum law, which also required both financial and technical capacity. It has been concluded that Statoil as the operator fulfils the necessary requirements with respect the solidity, reliability and technical competence.

Post-injection phase

The field decommissioning plan is covered by the Petroleum Law. The Department of Environment finds it appropriate that the post-injection plan required by the Pollution Regulation is part of the operator's decommissioning plan as required by the Norwegian Petroleum Law. Closure of the CO_2 storage site will therefore be included in the gas field decommissioning plan.

Experience

One important challenge which was identified early, relates to financial security and the long timeframes involved. A requirement to put aside money for an unlikely leakage event would have a significant cost. Also, no company can with 100% certainty guarantee to be present at such time scales. Due to the importance of establishing CCS as a means to reduce greenhouse gas emission, this post-closure financial risk was accepted by the state. The state takes the risk in the post-closure period in case the operator and partners are unable to fulfill the required obligations.

Overall, the transition from the former Petroleum Law to the new regulations governing the geological storage of CO_2 in a geological formation at Sleipner went smoothly. Statoil applied for the permission in June 2015, with some additional information provided during the next months in response to questions from the regulator. The permission was granted in June 2016.

Lessons Learned

- There is the potential that re-permission of geological CO_2 storage is required due to replacement or essential amendment of CO_2 storage regulations, under which the initial permission is obtained. Since already-operational projects may have restrictions to comply with all new regulatory requirements, the requirements should be set out to be flexible to allow the continuation of existing CO_2 storage as far as its validity is demonstrated reasonably.

- It may be reasonable that not the CO_2 storage operator but the government takes post-closure financial risks. This is because (1) reserving money for an unlikely leakage event during a post-injection period may be significantly costly, (2) no company can guarantee to exist on a long time scale such as 50 years and (3) it is essential not to discourage to operate CCS since GHG emission reduction is imperative for the globe.

References

Tillatelse til lagring av CO_2 ved Sleipner-feltet, Miljødirektoratet, 2016

2.2 ROAD Project and P18-4 CO_2 Storage

Compiled by Ryozo Tanaka (Research Institute of Innovative Technology for the Earth (RITE)) and Chris Gittins (TAQA), mainly based on a report entitled "Case study of the ROAD storage permit".

Overview of the Project

Figure 2-2: Offshore Platform P18-A

ROAD was a large-scale integrated CCS demonstration project planned in the Netherlands, led by Uniper (previously E.ON) and Engie (previously GDF SUEZ). ROAD was to capture a portion of the CO_2 from the flue gases of a new and now operational 1,100 MWe coal-fired power plant (Maasvlakte Power Plant 3). The captured CO_2 would be, according to the initial plan, transported by pipeline via an offshore platform P18-A to a depleted gas field P18-4 for storage, located 20 kilometers off the coast at a depth of 3,500 meters under the seabed of the North Sea. The project involved injecting 1.1 million tonnes of CO_2 per year for 5 years. ROAD storage partner TAQA obtained a storage permit for P18-4 in 2013, which is the first permit issued in the framework of the EU Directive on the geological storage of CO_2 (the CCS Directive). However, after failing to fully finance the project, Uniper and Engie withdrew from the project in 2017. The storage permit was extended and currently requires first CO_2 injection before 2021.

What happened during the project in the context of regulations for geological storage?

The Dutch CCS regulation came into force in August 2011 after TAQA submitted a storage permit application in June 2010. The Dutch Ministry of Economic Affairs requested TAQA to resubmit the permit application to conform to the new Dutch CCS regulation. The CCS regulation was embedded primarily in the Dutch Mining Act by transposing the CCS Directive without additional provisions or interpretation of the key elements in the Directive. This means that, in line with the Directive, the Dutch CCS regulation provides general rules for the process of the storage permit application and allows a systematic assessment of each CO_2 storage permit application.

In order to draw up the permit application, ROAD and TAQA formed a team with several members with diversified expertise, including technical, engineering, legal, regulations, communications, and commercial negotiations. This team coordinated communications with stakeholders – for example, a subgroup of the team communicated with the competent authority, which also appointed a specific person for discussions on permitting. This approach worked well, in particular, in the circumstances where the regulations offered room for interpretation and stakeholders wanted to clarify not only procedures but also technical details of the project.

In the permitting process, ROAD faced several challenges to be addressed, including the following major ones:

Timing of submission of required plans

The CCS Directive demands that all the required plans (e.g. monitoring, closure, corrective measures, and financial security) are fully ready when a project submits its application. In reality, fully developing all the studies, collecting all necessary information, and issuing reports will be only completed after a final investment decision (FID) is taken, and in order to take an FID, a valid storage permit is necessary. TAQA and ROAD took an approach of lowering the level of details of all of the required plans for the application and agreed to update these plans a year before commencement of CO_2 injection, which was accepted by the competent authority.

Financial security

The CCS Directive requires a permit applicant to prove that it will be able to finance all regulatory requirements through the project lifetime, which is called financial security. The Directive, however, doesn't specify the obligations to be included for financial security. ROAD and TAQA discussed and agreed with the competent authority which activities should be taken into account if the operator goes bankrupt, and what financial security would be essential for the competent authority to continue or abandon the project: routine monitoring, contingency monitoring, well and platform abandonment, financial contribution and EU emission allowances (EUAs) to be purchased if CO_2 is leaked.

In the estimation of amount of financial security, they faced challenges in particular with regard to future prices of EUAs, which they have to purchase in the year when CO_2 is theoretically leaked. The uncertainty in EUAs prices has the potential to cause another problem because the amount of financial security must be adjusted yearly: future fluctuation of EUA prices will have effect on the amount over time. Several instruments for financial security were discussed including the balance sheet, however the competent authority preferred a bank guarantee. In ROAD's opinion, as long as the balance sheet is healthy, a bank guarantee wouldn't provide any benefit but would increase the costs of the project. The eventual permit lists the alternatives discussed and requires that an acceptable form of security is received by the competent authority before injection begins.

Financial contribution

The CCS Directive requires a permit applicant to make a financial contribution available to the competent authority before the transfer of responsibilities in order to cover at least the anticipated costs of post-transfer monitoring for a period of 30 years. This requirement in the Directive can be interpreted that the competent authority can demand an unlimited financial contribution. If the competent authority would demand an unreasonably high financial contribution, there would actually be no handover of responsibilities from the operator to them. ROAD and TAQA agreed with the competent authority that the financial contribution should be equivalent to costs of routine monitoring for 30 years after the handover and that any other possible costs, including contingency costs in case of leakage, would not be required to be paid after the handover.

Period until transfer of responsibilities

The CCS Directive states that when a minimum period has elapsed after a storage site had been closed, the responsibility for all legal obligations can be transferred to the competent authority, subject to several other conditions. The competent authority should consider the minimum period as 20 years before such transfer but can reduce on a project-by-project basis. During the period, the operator has to pay for monitoring, financial security and insurances for liabilities but earns no income. From the perspectives of the operator, therefore, the duration of the period should be as short as possible. But the minimum period designated in the Directive has no scientific background and, theoretically speaking, there is a possibility that the competent authority can claim that all available evidence does not indicate the stored CO_2 will be completely and permanently contained, which will result in the postponement of handover indefinitely and costs higher than anticipated. So far, there has been no additional regulation or an agreement to remove this uncertainty, in spite of several reviews and consultations on the CCS Directive.

Definition of CO_2 leakage

CO_2 leakage in the CCS Directive is defined as any release of CO_2 not from the storage site but from the storage complex, which comprises the storage site and surrounding geological domain, including secondary containment formations. CO_2 movement within the storage complex is defined as CO_2 migration and not regarded as CO_2 leakage. CO_2 leakage requires corrective measures to be taken but CO_2 migration does not. However, it is clear that if CO_2 migrates out of the reservoir (out of the storage site) into the complex, the operator would need to scale up a level of its monitoring to demonstrate that there could or would be no leakage out of the complex. Furthermore, there is inconsistency in the definition of CO_2 leakage between the CCS Directive and the EU ETS Directive. The ETS Directive defines that the amount of EUAs to be purchased in case of CO_2 leakage is equivalent to the amount of CO_2 released into the air, which would be in reality difficult to measure.

Compliance with the London Protocol

The permit application was later on assessed by a third party from the viewpoint of the compliance with the guidelines and criteria of the 1996 London Protocol (officially, the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972), which is an international treaty that allows sub-seabed geological CO_2 storage under strict restrictions. Since the Netherlands is a contracting party of the treaty, the P18-4 storage application should fulfill the requirements. The assessment found that the application documents are broadly sufficient to allow the evaluation and indicated that no information was sufficiently absent that would indicate clear non-compliance with the guidelines. This compliance assessment indicated overall technical compliance with the CO_2 Specific Guidelines. This assessment demonstrated that the London Protocol permit conditions can be achieved by projects and by regulators and that transparency of such permitting is possible.

Lessons learned

- It may be ideal that national CCS regulations provide not detailed but general rules for the process of the storage permit application, which allows a systematic assessment for each CCS project applied based on its specific characteristics.

- Delayed establishment of national CCS regulations would give unnecessary uncertainty to early CCS projects.

- Close communication is essential between a project promoter and a regulator for efficient permit award. Forming a team for permit drafting with diversified expertise would be a key element in efficient communication between all parties. Fixed contact points within the promoter team and the competent authority would be another key facilitation measure.

- It helps if the competent authority can recognize that the key documents and plans to be submitted for the permit application will mature and should be resubmitted from time to time up to first injection and then at regular intervals thereafter throughout the project.

- If financial security is required to cover costs for the purchase of emission credits if stored CO_2 theoretically leaks, the CCS project would need to deal with risks of increase in the prices of the credits and hence the project may be unfinancable. This single requirement will obstruct all future projects and pragmatic solutions will need to be agreed between permit applicants and competent authorities.

- The scope of financial contribution from the operator to the competent authority to carry out obligations after responsibility transfer must be discussed pragmatically. Reasonable and practical breadth of the scope is necessary for the project to proceed, but impractical or unreasonable demands should not hamper the investment decision.

- Uncertainty in the length of the period from the site closure to transfer of responsibility to the competent authority poses risks of cost increase for the project. If the competent authority can decide to delay a timing of the transfer, the risks continue until the completion of the transfer. This also affects the ability make a financial investment in the project.

- The definitions of terms should be harmonised, taking technical constraints and also public perception into consideration. Using an inappropriate or misleading term can impact the credibility or understanding of a project immeasurably. There may also need to be efforts made to ensure consistency between CCS regulations and other regional and national laws and regulations.

- If the national jurisdiction is a contacting party to the 1996 London Protocol, which is an international treaty that allows sub-seabed geological CO_2 storage, the competent authority and the permit applicant should make sure to comply with the guidelines and criteria of the Protocol. Ratification of the London Protocol would help this new industry develop.

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2.3 Former Peterhead CCS project

Written by Owain Tucker and Lynsey Tinios, Shell. More information can be found in the GHGT13 paper: Experience in developing the Goldeneye Storage Permit Application.

Overview of the Project

The Peterhead CCS project was slated to be the first full chain gas CCS project in the world. It planned to capture 1 Mtpa of CO_2 from the Peterhead CCGT power station on the north-east coast of Scotland and store it offshore, reusing existing infrastructure from the depleted Goldeneye gas field.

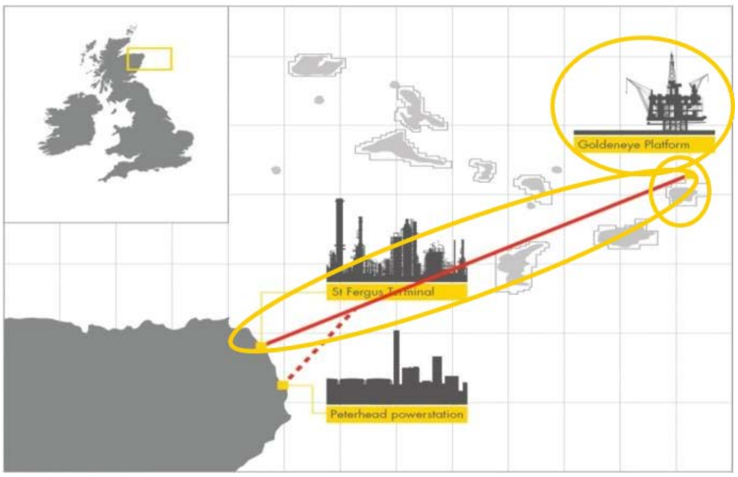


Figure 2-3: Schematic of the project showing the location of the key elements

The project was initiated in response to the UK Government's solicitation for carbon capture and storage projects. Shell UK developed plans to convert the existing Goldeneye gas field into a CO_2 store. The work to assess the suitability started under the UK Government CCS Demonstration competition launched in 2007, when the plan was to store around 20 million tonnes of CO_2 sourced from the Longannet power station in Fife, Scotland.

This project was later halted by the UK Government. Work resumed as part of the subsequent CCS Commercialisation Programme launched in by the UK Government in 2012. The second attempt to develop a CCS project involved transporting CO_2 from the Peterhead Power Station in North East Scotland directly offshore where it would tie into the existing 102 km Goldeneye to St Fergus gas export pipeline to transport the dense phase CO_2 to the normally unmanned Goldeneye platform above the field (see Figure 2-4). This programme was cancelled by the UK Government in November 2015.

Figure 2-4: Photograph of Peterhead power station and the Goldeneye platform

The Goldeneye platform is located ~100 km northeast of the St Fergus gas terminal (which is near Peterhead, Aberdeenshire, Scotland see Figure 2-3) in water of ~120 m depth. From here, the CO_2 was to be injected into the depleted Goldeneye gas field for geological storage, reusing the existing hydrocarbon production wells, at a maximum rate of just over 1 million tonnes per annum.

The project was very advanced when funding was withdrawn by the UK government. When cancelled, it had submitted the Storage Permit Application to the UK regulatory authorities who had sent it on to the European Commission for their review.

What happened during the project in the context of regulations for geological storage?

Member states of the European Union are required to transpose the directive on the geological storage of CO_2 (often called the "CCS Directive"). In the UK, the directive is implemented in The Energy Act of 2008, particularly in Chapter 3: Storage of Carbon Dioxide. In section 18, this act sets out the framework that allows the awarding of licenses for the storage of CO_2 by a licensing authority. In addition to the license, a lease from The Crown Estate, the "land owner", is needed for storage activities for all offshore areas. The details of the licensing regime are outlined in the Carbon Dioxide (Licensing etc.) Regulations 2010. The storage license does not give permission to inject, this permission is conferred by a storage permit which must include all the conditions outlined in the CCS Directive. In many paragraphs, the UK regulations refer back to the CCS Directive directly.

A number of other documents also inform the content of the storage permit application. These are the Guidance Documents[3] that were issued by the EU Commission along with the CCS Directive, and also specific application guidance issued by the UK Oil and Gas Authority – the UK licensing authority for CCS.

The transposition had already taken place before start of the Longannet CCS project, however, some of the supporting regulations were still being drafted.

[3] Implementation of Directive 2009/31/EC on the Geological Storage of Carbon Dioxide Guidance Documents 1-4

Structure of the storage permit application

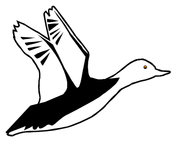
The Goldeneye storage permit application was designed to address all the requirements of both the CCS Directive and the UK regulation.

Because the storage permit application was going to be reviewed by multiple parties, including consultants employed by the EU Commission, the team made the decision to create a self-standing permit application and to extract material from the underlying technical reports. These technical reports had been written over a period of five years by various authors and totalled many thousands of pages. During this time, the Goldeneye gas field had stopped production, the reservoir pressures had evolved, additional analytical laboratory work had been performed, and the development concept had altered from 2Mtpa for ten years to 1Mtpa for fifteen years. Collating all the relevant information into one consistent whole was designed to make the task of any reviewers easier.

One of the tasks of the permitting authorities is to ensure that all requirements laid out in the CCS Directive had been addressed. To make this task easier, the team created a concordance table to cross reference between the UK regulations, the EU Directive and the permit application to show exactly where and in which volume each statutory requirement had been addressed.

The permit application was divided into seven volumes, plus the Offshore Environmental Statement.

Part 0 Introductory Material
Part I Characterisation of the Geological Storage Site and Complex
Part II Containment Risk Assessment
Part III Measurement, Monitoring and Verification Plan
Part IV Corrective Measures Plan
Part V Closure and Post-closure Plan
Part VI Details of Financial Security



The image to the right is the Goldeneye duck after which the gas field was named.

The aim in writing the Goldeneye storage permit application was to lay out all the evidence in support of the containment integrity and the suitability of the store, and then let everything follow from this. At the same time it was necessary to satisfy the requirements of the CCS Directive. This led to the following structure:

I. Detail all the evidence from site characterization and design [~400 pp]
II. Bring the evidence together in a containment risk assessment [~200 pp]
III. Design the MMV plan based on the containment risk assessment [~90pp]
IV. Outline the corrective measures that complement the monitoring plans to create additional safeguards for containment [~90pp]
V. Present the closure and post-closure plans that draw their evidence from the conformance results derived from the monitoring [~25pp]
VI. Outline the financial security that is based on the site selection and characterization, the design decisions, and the risk assessment results [~10pp]

In this manner, although the monitoring and corrective measures provide additional safeguards and do impact the containment risk assessment, it should be possible to read the application from end to end and get a logical flow.

Within the extensive characterization volume, the same stepwise approach was attempted, with the following chapters:

- Definition of Target (Site and Complex)
- Regional Geology and Structure
- Rock and Fluid Properties, which included geochemistry and geomechanics
- Static Models
- Reservoir Engineering and Dynamic Models
- Estimating Storage Capacity
- Effects of Hydraulically Connected Volumes
- Wellbore Containment Assessment
- Secondary Containment
- Transportation and Injection Facilities

All other volumes referred back to the characterization volume.

Process to draft the permit application

The project took the approach of working very closely with the UK regulator. This being a first of a kind application, it was important to ensure that both the project team understood the needs of the regulator, and the regulator had the opportunity to explore the technical details of the project and gain a thorough understanding of the risks. The process of engagement started with the Longannet project and then continued in earnest with the Peterhead project – both planned storage in Goldeneye.

A whole day engagement session was run at the beginning of the process where technical presentations were delivered by the project team. A schedule of meetings and workshops was then established where the project developer and the regulator teams would meet. The permit application was divided into parts and in each meeting the plans for the next part were outlined and discussed prior to writing the formal text. The text was then developed and circulated to the regulator for comment at the next meeting. All feedback was then incorporated.

By the end of the process, there were no surprises in the permit application, and the regulator had a detailed understanding and insight into the risk profile of the proposed project.

The project team also commissioned the British Geological Survey (BGS), a government funded and independent institution of excellent standing in the UK, and an institute with significant expertise over many years in the area of CO_2 storage, to perform an independent external review.

Post closure plan and handover criteria

A key concern amongst potential storage operators is the exposure to commitments of unknown duration and size. It is all but impossible to cost these, and all but impossible to promise that a company will still be operating for twenty or more years after the end of storage. The CCS Directive allows flexibility in the determination of the handover period, but it up to the implementing competent authority to judge if and how to allow for this.

In article 18 on transfer of responsibility, the CCS Directive states that where a storage site has been closed pursuant to certain criteria then responsibility shall be transferred to the competent authority, if the following conditions are met:

(a) all available evidence indicates that the stored CO_2 will be completely and permanently contained;
(b) a minimum period, to be determined by the competent authority has elapsed.

This minimum period shall be no shorter than 20 years, unless the competent authority is convinced that the criterion referred to in point (a) is complied with before the end of that period;

The aim of conformance monitoring throughout the project and in the period between the end of injection and handover is to satisfy point (a) above, i.e. show that all available evidence indicates that the stored CO_2 will be completely and permanently contained. Once this has been shown, the site can be transferred to the Competent Authority. It is important to have a set of performance criteria against which to measure the monitoring results. In the Goldeneye structural store in a depleted gas field, this translated into the following performance criteria:

- CO_2 is behaving as predicted and is unlikely to deviate from prediction
  - 3D dynamic simulation forecasts of the movement of continuous phase CO_2 indicate that the continuous phase CO_2 is approaching a gravity stable equilibrium within the site.
- No leaks or unexpected migration paths are observed: Two separate seismic surveys – with an expected separation of five years, show that continuous phase CO_2 is not migrating laterally or vertically from the licensed storage site.
  - In the Goldeneye specific case, a post closure survey is a combination of a time-lapse 3D seismic survey for subsurface profiling and site surveys of well locations to look for surface indications of CO_2 leakage.

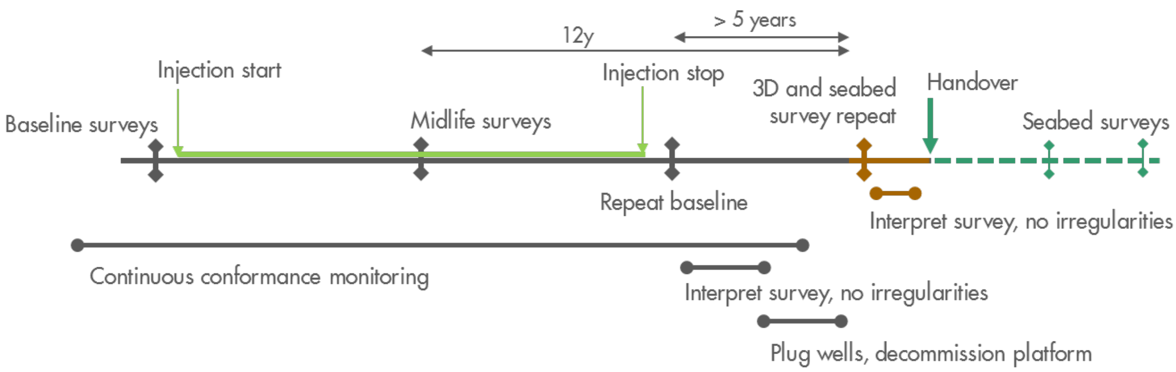


Figure 2-5: Logic behind post closure monitoring

While the CCS Directive in point (b) above indicates that the minimum period could be 20 years, it also gives the latitude to the competent authority to determine the duration based on the risk. In the Goldeneye case this translated in to a performance based plan, not a time based plan. This is illustrated in Figure 2-5. The logic is step wise and the approach measured. All monitoring is aimed at identifying losses of containment and at giving data to improve the conformance modelling. At the end of injection, a seismic survey was planned to show, in combination with previous surveys, that no migration was taking place behind the casing. If migration were taking place behind casing, the abandonment would involve milling the casing and setting two new long cement plugs; if not then the abandonment would be less intrusive and would involve setting a two long cement plugs inside the casing. A second survey would then be taken with a separation of at least five years to give time for any migration to create a CO_2 accumulation that would be detectable below 8000ft of solid rock. If interpretation of this second survey in combination with the results of all prior monitoring showed that the site was now secure, then handover could be progressed.

EU Commission review and opinion

Formal feedback on the permit application was received from the EU Commission: on the 21st of January 2016, after the announcement of the end of the commercialization process funding by the UK Government, the EU Commission published its opinion on the Goldeneye storage permit[4].

In accordance with Article 10 of the CCS Directive and based on its review of the draft permit, the Commission concludes that the draft storage permit fulfils the requirements of the CCS Directive save as outlined below. Moreover, the prospective operator appears technically and financially competent and capable of carrying out the planned CO_2 storage operation at the proposed storage site.

The Commission considers that, to prevent any negative impacts on the environment, an assessment of the effects of substances other than CO_2 that may be present in leaking CO_2 streams must be included in the Environment Statement before consent to the project is granted. Moreover, the Commission considers that financial security must be based on a postclosure monitoring period of 20 years in accordance with Article 18(1)(b) and Article (19)(1) of the CCS Directive.

Done at Brussels, 20.1.2016
For the Commission Miguel ARIAS CAÑETE Member of the Commission

[4] E. Commission, COMMISSION OPINION of 20.1.2016 on a draft permit for the permanent storage of carbon dioxide in the depleted Goldeneye gas condensate field located in blocks 14/28b, 14/29a, 14/29e, 20/3b, 20/4b and 20/4c on the United Kingdom Continental Shelf, in accor.

Lessons learned

- *Developing a first of kind permit application:* We recommend the collaborative process as used by the project team and the UK regulator for any region trying to develop a storage permit for the first time. There are key differences between CO_2 storage and hydrocarbon production and these have to be recognised by both parties and designed into the permit application.

- *Independent external review:* The project team found the external review very constructive, and despite initial concerns about cost increase, the review identified redundancy in the MMV plan and simplification in areas such as handover criteria. It led to a better, more streamlined storage permit application.

  The review also led to external confirmation that the store was suitable: *"Our conclusion is that the proposed Goldeneye storage site is suitable for the purpose of storing up to 20 million tonnes of CO_2 injected according to the specified plan. BGS have signed a statement to this effect."*

- *Interfaces between regulatory teams:* Interfaces between regulatory teams were sometimes less streamlined than originally expected. The project team found that different regulatory teams were responsible for the seabed monitoring and risk assessment and the deep monitoring and risk assessment. Because the CO_2 is injected at over 8000ft below layers of impervious rock, because of the extremely thorough risk assessment, and because the wellbores which cut across the containment layers are intensively monitored, then the risk to benthic populations is negligible, and any CO_2 migration would be expected to be detected at depth before it reaches the surface. This means that marine environmental monitoring does not perform a detection role, rather it is used to establish the undisturbed situation should any significant irregularity take place.

  While the storage regulatory team appreciated this fact, the project team did not interact with the environmental monitoring team till late in the process and had to go over much of the ground that had been covered with the storage team over the previous year.

  A similar experience was had when the team moved onto determining the financial security provision. This also required the engagement of a new team within the regulatory division who had to be on-boarded.

  The learning here is not to underestimate the novelty of CO_2 storage and to ensure that all regulatory stakeholders are effectively engaged early on, even if this is not normally the case for standard hydrocarbon developments.

- *The form of the actual Storage Permit:* The actual wording of the Storage Permit was only determined after the development of the Storage Permit Application. This led to some reformatting of the permit application and even some additional dynamic simulation runs to determine pressure bounds as it was found to be useful to apply maxima to the injection pressures. The team had not focused on point this because the injection volumes were only half the store capacity therefore there was no possibility of exceeding any geomechanical pressure limit therefore the pressure limits had not been critical in the design of the injection facilities.

  This was a first of a kind issue, but it could be good learning for other first of a kind projects.

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2.4 Quest CCS Facility

Written by Anne Halladay, Subsurface Advisor for Quest

Overview of the Project

The Quest CCS facility is a commercial-scale CCS project attached to an industrial facility northwest of Edmonton, Alberta, Canada. The purpose of Quest is to deploy technology to capture CO_2 produced at the Scotford Upgrader and to compress, transport, and inject the CO_2 for permanent storage in a deep saline formation. More than 1.2 Mt/a of CO_2 is currently being captured, representing greater than 35% of the CO_2 produced from the Scotford Upgrader. Shell Canada Energy operates Quest as agent for and on behalf of the AOSP Joint Venture and its participants (Canadian Natural Resources Limited, Chevron Canada Limited and Shell Canada Limited).

Quest began operations in August 2015 and achieved commercial operation status in September 2015. The CO_2 is captured using Shell's-patented amine capture technology from three hydrogen manufacturing units (HMUs) (Figure 2-6). The CO_2 is then compressed by an electrical drive compressor and transported in dense phase through a 12-inch diameter pipeline to a storage site. The CO_2 is injected through two vertical injection wells into a saline aquifer overlying the basement–the Basal Cambrian Sandstone (BCS). After two years of injection, in August 2017, more than two million tonnes of CO_2 have been safely stored in the BCS.

Figure 2-6: Quest CCS Facility at the Scotford Upgrader

What happened during the project in the context of regulations for geological storage?

It is well recognized that Alberta is showing leadership in implementing climate policies, including carbon pricing mechanisms and CCS-enabling regulations. Carbon capture and storage in Alberta, Canada is regulated by the Government of Alberta's (GOA) Alberta Energy Ministry, including the Alberta Energy Regulator (AER). In addition to the existing oil and gas regulations and directives applicable to CCS projects, the GOA enacted the Carbon Capture and Storage Funding Act, Carbon Capture and Storage Statues Amendment Act 2010 and established the Carbon Sequestration Tenure Regulation[0]. The CCS Statutes Amendment Act defines the assumption by the government of the long-term liability for sites in post-closure and requires operators to contribute to the Post-Closure Stewardship Fund. The Tenure Regulation defines the process (outlined in the CCS Statues Amendment Act) to evaluate and acquire pore space leases for carbon sequestration, including monitoring, measurement and verification plans (MMV), and contributions to the Post-Closure Stewardship Fund.

To help create the regulatory environment for CCS, Shell worked with the regulator closely. After the establishment of the regulatory framework, the GOA launched a process called the Regulatory Framework Assessment (RFA) to make sure that the right regulations are in place before full-scale CCS projects become operational. To ensure that the regulatory review was complete and balanced, many Canadian and international experts from industry, universities, research organizations, environmental groups and provincial and national governments participated. The process resulted in 71 recommendations to close regulatory gaps or enhance current requirements. Shell was involved in the RFA as well.

With the established framework outlined above, the Quest storage facility operates under an AER Approval that specifies the operating and reporting conditions for CO_2 injection and storage. A key requirement of the AER Approval and the Carbon Sequestration Lease Approval is the submission of an MMV Plan. The Quest MMV plan outlines activities related to monitoring the injection stream composition, and activities related to addressing the containment and conformance of the CO_2 in the storage reservoir, the BCS. As a first-of-its-kind MMV Plan, it is designed based on the following principles: Regulatory-Compliance; Risk-Based; Site-Specific; and Adaptive. The assessment of storage risks includes both containment and conformance risks, and relies on an evidence-based evaluation of threats and consequences, and the effectiveness of safeguards in place. The MMV Plan contains the monitoring tasks, safeguards, control measures, performance targets, and operating procedures designed to manage and minimize the storage risks.

The MMV Plan is adapted in response to new information gained from well data, site-specific technical feasibility assessments, and monitoring during the injection and closure periods. The 2017 MMV plan contains updates based on learnings from the initial phase of injection which provide a basis to optimize and streamline MMV activities, as per the design principles of the MMV plan (Figure 2-7). The learnings from the first year of injection operations demonstrate that the original monitoring plan has been working according to the MMV aims of containment and conformance, and provide a basis to optimize and streamline MMV activities as per the design principles.

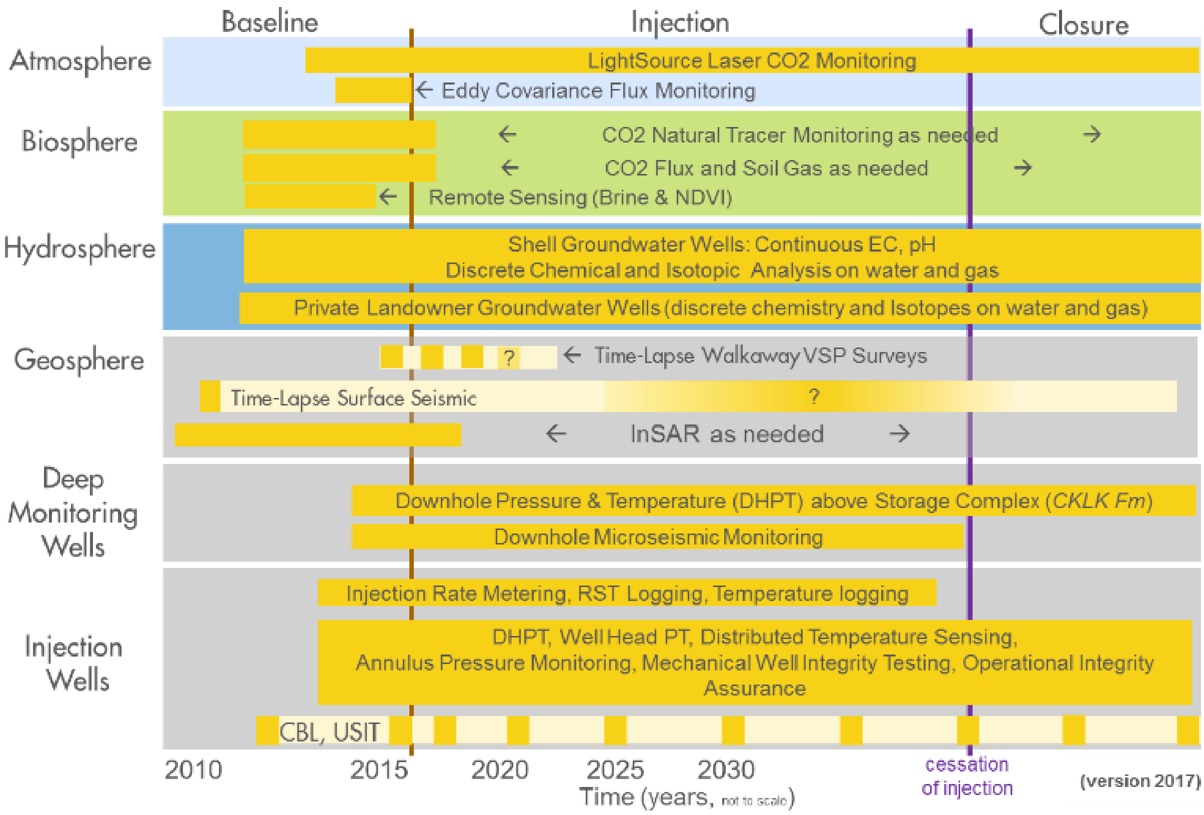

Figure 2-7: 2017 Quest MMV Plan overview

Some of the changes include:

- A cessation of the assessment of DAS (distributed acoustic sensing) for novel potential applications related to well integrity monitoring, as the well integrity monitoring program has demonstrated performance.
- Following a report on the efficacy of InSAR (a satellite remote sensing method designed to monitor surface heave), InSAR is now considered to be a secondary technology within the MMV plan that will only be used in a contingency role (if another technology indicates a potential issue).

- DTS (distributed temperature sensing) data have been collected in the injection wells since the baseline monitoring period, with the aim of aiding well integrity assessments in a continuous, quantitative application. At present, DTS can only be used for a qualitative assessment primarily by observing rates of change in temperature over time and the integration of temporal data on CO_2 flow into the injection wells.

- The timeline for the deployment of time-lapse seismic surveys was modified to reflect observed and predicted CO_2 plume growth rather than preset dates.

The MMV operations have had no trigger events indicating any storage complex containment or conformance issues. This is in a large part due to the site selection process, where a significant portion of the risks associated with CCS activities were mitigated by the choice of the storage complex itself.

Lessons learned

- To promote the development of commercial-scale CCS and the safe and effective use of CCS technologies, the creation of a good regulatory environment for CCS is essential. This may include a carbon credit system to provide incentives for sequestration, defining the pore space tenure, the clarification of long-term liability, closure planning, and determining the requirements for Monitoring, Measurement and Verification (MMV), and building a quantification protocol to generate carbon credits..[0]

- The involvement of industry is critically important to create effective regulatory framework. A comprehensive review of the established framework by diversified stakeholders may be also effective to close regulatory gaps or enhance current requirements.

- The MMV plan should be adaptable in response to new information gained from well data, site-specific technical feasibility assessments, and monitoring during the injection and closure periods. The process enables the MMV plan to be optimized and streamlined.

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2.5 Illinois Basin - Decatur Project

Authored by: Sallie Greenberg and Randy Locke at the Illinois State Geological Survey

Overview of the Project

Figure 2-8: Injection Well for the Illinois Basin - Decatur Project

The Illinois Basin – Decatur Project (IBDP), located in Decatur, Illinois USA, is a one million tonne bio-energy carbon capture and storage (BECCS) deep saline geologic CO_2 storage project. It is led by the Midwest Geologic Sequestration Consortium (MGSC) and funded by the United States Department of Energy (US DOE) – National Energy Technology Laboratory through the Regional Carbon Sequestration Partnership Program. IBDP is a fully integrated large-scale demonstration project in an onshore sedimentary basin, the Illinois Basin. The source CO_2 was derived from biofuel production at the Archer Daniels Midland (ADM) hosted test site.

IBDP field activities began in 2007 with a 4-year pre-injection characterization and design period, followed by 3 years of injection (2011-2014) and will conduct more than 5 years of post-injection monitoring (ending in 2020). In November 2014, the injection phase was safely and successfully completed with 999,215 tonnes of CO_2 injected at rate of 1,000 tonnes/day into the lower Mt. Simon Sandstone at a depth of 2.1 km. The project infrastructure includes three deep wells (injection (CCS1), monitoring (VW1), geophysical (GM1)), 17 shallow groundwater monitoring wells, passive microseismic monitoring, an extensive monitoring, verification, and accounting (MVA) system, a compression/ dehydration facility, and a 2-km pipeline.

IBDP is currently in the post-injection monitoring phase, and in this phase, is linked to the Illinois Industrial Sources CCS (IL ICCS) Project through scientific and permitting-related activities. These two projects hold the first-ever United States Environmental Protection Agency (US EPA) Underground Injection Control (UIC) permits for Class VI injection, specifically developed for the subsurface storage of CO_2.

Permitting and regulatory context for storage of CO_2 at the IBDP

At the beginning of the IBDP, the carbon storage regulatory framework in the United States was not yet established and regulatory requirements were guided by the existing UIC framework. To address uncertainty in this evolving regulatory environment, IBDP designed a comprehensive, risk-based, monitoring strategy that was anticipated to be over and above new regulatory requirements. Throughout the project (2007-present), two lengthy permitting processes have been undertaken that proved to be a primary rate-limiting factor for the project. The permitting process increased the length of time before CO_2 injection began, resulted in additional monitoring and modeling requirements, and required additional funding resources and project time for the required post-injection site care and monitoring.

In January 2008, the IBDP submitted a UIC Class I injection permit application to the Illinois Environmental Protection Agency (Illinois EPA). In January 2009, the IBDP site operator, ADM, received a draft Class I - Non-hazardous UIC permit issued by the Illinois EPA. The draft permit only provided authorization to drill the injection well (CCS1). Between 2009 and 2011, additional site characterization was performed, site infrastructure constructed and baseline monitoring networks established. IBDP was required to apply for a Class VI well permit from the US EPA authority under the new regulatory framework as a condition of the Class I permit.

Coincident with the IBDP Class I permitting process, the US EPA promulgated final regulations in December 2010 for a new class of injection well (Class VI) specific to the injection of CO_2 into the subsurface. The rules were effective in September 2011 and were published in the Code of Federal Regulations (CFR) in 40 CFR 146 Subpart H. In October 2011, the final UIC Class I permit was issued to the site operator (ADM) and authorization to inject one million tonnes of CO_2 was received. The conversion of the IBDP Class I permit was not automatic and the IBDP was required to go through the full Class VI application process. For IBDP, the final Class VI permit was issued in 2014 as the injection was nearing completion and went into effect in February 2015.

From the date of submission to the Illinois EPA, the Class I permitting process took approximately one year for a draft permit to be issued and more than 3.5 years for a final permit to be issued. While some benefit to the extended permitting time was realized due to additional time for project planning and baseline data gathering, the lengthy permitting process added very significant delays to the start of CO_2 injection. Similarly, the IBDP Class VI permitting process took over four years from submission to final effective permit. During the process, the US EPA required IBDP wells and infrastructure to be used in the monitoring of the adjacent Illinois Industrial CCS (IL ICCS) project. The IBDP deep wells (CCS1 and VW1) then became part of the monitoring program for IL ICCS, which started injection in April 2017. Thus, the IBDP post-injection regulatory monitoring requirement went from 3 years (planned) to more than 5 years, requiring additional field support, analyses, and funding.

Under the Class VI permit, a significant number of changes occurred to the IBDP monitoring program. For example, groundwater monitoring under the Class I permit focused on 11 parameters selected for their sensitivity to detect fluid quality changes resulting from interactions with CO_2 or brine: pH, temperature, specific conductance, dissolved oxygen, dissolved CO_2 as total inorganic carbon, alkalinity, bromide, chloride, calcium, sodium, and groundwater elevation at four sampling locations in Pennsylvanian-age bedrock (lower most USDW under the Class I permit). The Class VI permit added groundwater sampling locations from three deeper depths (St. Peter Sandstone, Ironton-Galesville Formation and Mt. Simon Sandstone) and retained the four sampling locations in Pennsylvanian-age bedrock. The permit also increased the number of water quality parameters to be monitored from 11 to 30 that included additional major and minor elements and isotopes. The conditions of the IBDP Class VI final permit required additional fluid sampling from deeper formations resulting in greater logistical efforts for sampling at depths from 900 to 2,100 m than were needed previously for shallow (43 m) fluid sampling for the IBDP Class I permit. Those modifications resulted in additional personnel time and equipment costs to the IBDP.

An approximate 4-fold increase in compliance-related analytical costs were realized by the IBDP when site monitoring (4 shallow and VW1) was aligned with the final Class VI permit. An approximate 5-fold increase occurred when also considering wells associated with the IL-ICCS project (VW2 and GM2). Costs were associated with the increase in permit compliance sampling locations (number of samples) and increase in water quality parameters to be measured.

The most significant remaining sources of regulatory uncertainty for the IBDP are related to monitoring program requirements during the post-injection site care (PISC) period. They include the length of PISC period monitoring and the process by which a non-endangerment determination will be sought from the US EPA and how the project should proceed to closure. At present, IBDP has a PISC monitoring requirement through April 2020 and the IL ICCS project has a 10-year PISC requirement (adjusted from the default 50-year requirement). The adjusted PISC timeframe is linked to the completion of IL ICCS injection and would not likely begin before 2022.

Lessons Learned

- Regulatory uncertainty can impact projects by requiring significant time and resources.
- Regulatory permitting can be a major rate limiting step in conducting a project.
- Future projects in the United States will likely continue to experience significant regulatory uncertainty.
- Operators and regulators can benefit by reducing the length of time for Class VI permitting.
- CCS monitoring programs should be risk-based and adaptive.

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2.6 Tomakomai CCS Demonstration Project

Written by Ryozo Tanaka, Research Institute of Innovative Technology for the Earth (RITE)

Overview of the Project

The Tomakomai CCS Demonstration Project, located on Hokkaido in the northern part of Japan, is aimed at demonstrating the technical viability of the complete CCS value from capture to storage in an offshore saline reservoir at full scale. The project is funded and owned by the Ministry of Economy, Trade and Industry (METI) and Japan CCS Company (JCCS) is the project developer and operator. The CO_2 source is a hydrogen production unit for an oil refinery, where CO_2 is captured with an amine base technology at a rate of 100,000 tonnes per year or more. The captured CO_2 is injected through two directional wells from onshore wellheads which are adjacent to the capture unit into offshore saline reservoirs under the seabed. The two reservoirs have different geological characteristics and are located at different depths. The Tomakomai project obtained a storage permit in late March 2016 and initiated the three-year CO_2 injection in early April 2016.

Figure 2-9: Tomakomai CCS Facility (Courtesy of JCCS)

What happened during the project in the context of regulations for geological storage?

Sub-seabed geological CO_2 storage in Japan is regulated by the Act on the Prevention of Marine Pollution and Maritime Disasters (the Act). The ministry responsible for the Act, the Ministry of the Environment (MOE), states that they designed the Act to regulate CCS for the protection of the marine environment not as a mechanism to promote CCS. The Act requires those who want to store CO_2 in a geological formation under the seabed to assess the potential impacts of CO_2 storage on the marine environment. This assessment must be done in advance and then used to obtain a CO_2 storage permit from the environment minister. Permit applications are required to include a plan for monitoring the status of marine pollution, which should consist of three monitoring phases: 1) the routine phase, 2) the precautionary phase and, 3) the contingency phase. If a project were to enter the precautionary phase, CO_2 injection should be suspended.

The Tomakomai project is the first project to apply for a sub-seabed CO_2 storage permit and therefore MOE started preparation for handling this permit application well in advance. MOE deemed that the seawater sampling was as essential as seismic surveys and the measurement of downhole temperature and pressure in order to detect CO_2 leakage even though there had been limited demonstrated experience and expertise in the detection of CO_2 leakage through seawater sampling. For that reason, they obtained various baseline data with a focus on chemical parameters in seawater offshore Tomakomai by themselves for several years and then examined appropriate requirements for monitoring to be performed by the operator.

Independently from, but in consultation with MOE, METI and JCCS collected the required seawater baseline data in a limited fashion. Samples were collected once in each of the four seasons starting in the Summer of 2013. This length of the baseline survey period was determined to fulfill a guidance presented by MOE, which was defined as one year or more. In December 2015, after evaluating various potential seawater parameters and their thresholds for transition of the monitoring phases, MOE instructed METI and JCCS to adopt a conservative threshold line. The threshold was established as the upper bound of 95% prediction interval of CO_2 partial pressure (pCO_2) calculated by the correlation with dissolved Oxygen saturation (DO). The number of baseline data sets available for creating the MOE-required thresholds was limited to the 4 seasonal samples taken per year. 32 samples in total were used to create the threshold, which in retrospect might not be enough to reliably define the threshold. The approved threshold line is shown as the red line and the baseline data used are shown in the open circles in Figure 2-10.

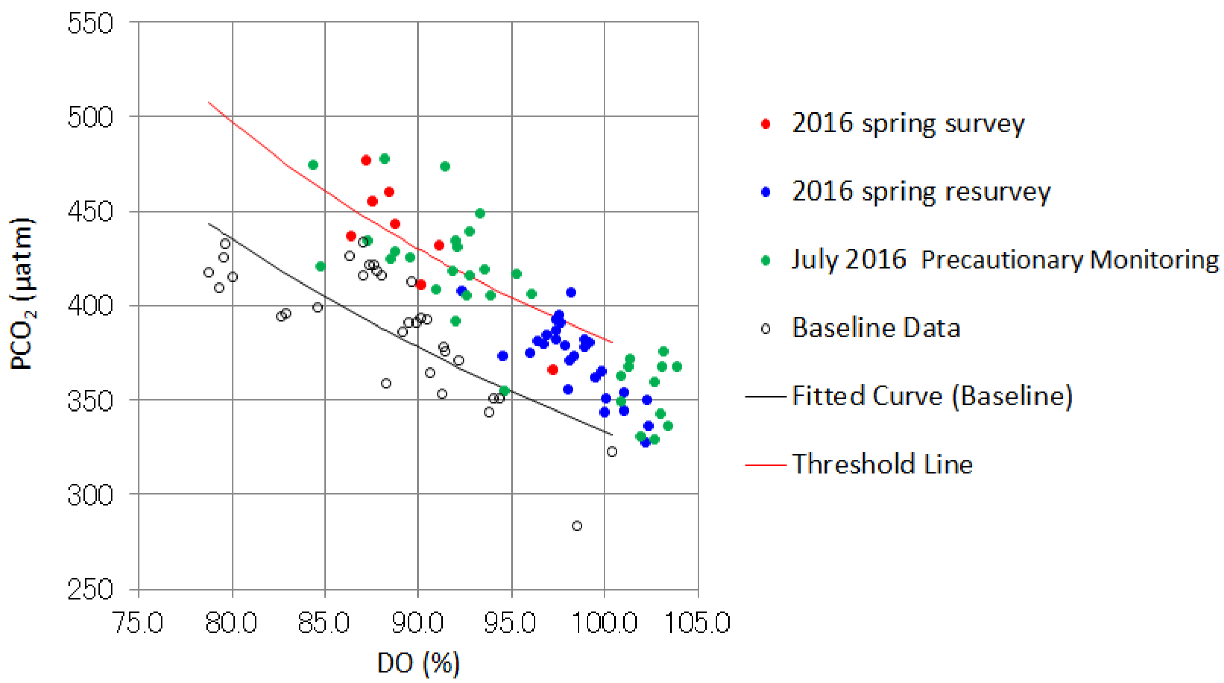

Figure 2-10: pCO_2 and DO Acquired in Offshore Tomakomai
(Source: Kawabata, 2017)

JCCS obtained a storage permit with the MOE-required thresholds in late March 2016 and initiated CO_2 injection in April 2016. During a scheduled injection interruption in early June, the operator performed the first routine marine monitoring, which resulted in several data points that exceeded the threshold line (shown with the red circles in Figure 2-10). Following the protocol in the monitoring plan, a follow-up survey was conducted to evaluate more seawater samples in late June, but the results again included data points above the threshold (shown by the blue circles in Figure 2-10). Both surveys produced data points with irregular data that were spatially and temporally discontinuous. As a result, JCCS concluded that the irregularities were due to natural seawater fluctuations and that the MOE threshold, which was based on a limited number of baseline data collected for the limited period, was insufficient to accommodate such fluctuations. There is also growing uncertainty on whether it is possible to collect enough baseline data to quantify natural variation in a way that will be meaningful for leakage attribution. Alternative approaches should be developed, and some are in development

The June marine monitoring results had impact on Tomakomai because the monitoring phase was transferred to the precautionary phase in accordance with the monitoring protocol. This resulted in the postponement of injection restart scheduled in early August. The precautionary monitoring in late July delivered a number of data beyond the limit again (shown by the green circles in Figure 2-10). Later the precautionary phase was escalated to the contingency phase. The contingency survey was conducted in late August and resulted in no data exceeding the threshold.

After assessment of the outcomes from these surveys, MOE announced their view on the monitoring plan for Tomakomai in mid-October 2016. Their announcement and its consequences implied that they deemed exceeding the threshold was not caused by CO_2 leakage. In the published documents, they determined that the monitoring plan, as written, might result in the long-term suspension of CO_2 injection even in a case where there is no CO_2 leak. MOE also stated this process would be good from the viewpoint of the marine environmental protection but expressed concerns that this could deteriorate public trust and public acceptance for the project. Finally, the regulator concluded that the monitoring protocol in a case where seawater sampling data exceeded the threshold should be revised in such a way that multiple methods such as pH sensor towing and side-scan sonar for detecting CO_2 leakage are used so that informed decisions about whether or not to transit to the precautionary phase can be made. This comprehensive approach to determining whether CO_2 injection should be suspended will allow for the results of additional water sampling to be evaluated in the context with the results of other surveys designed to detect CO_2 leakage directly. However, there is insufficient expertise in CO_2 leakage detection by pH sensor towing or side-scan sonar. The optimal operation method has yet to be established and has been explored by, for example, the Research Institute of Innovative Technology for the Earth (RITE) funded by METI.

Based on this ruling, METI and JCCS revised the Tomakomai monitoring plan to include the additional surveys instructed by MOE without revising the disputed threshold line and obtained a permit for the revision from the environment minister. They resumed CO_2 injection in early February 2017 after a six-month regulatory suspension.

Lessons learned

- CCS regulations should be established for the purpose of promotion of safe CCS. Regulations without such a purpose may increase the cost of CCS projects by creating unnecessary interruptions in operations or by adding additional monitoring and/or research to satisfy a conservative regulatory approach.

- An unnecessary suspension of project operation caused by an immature plan or protocol can deteriorate public trust on a CCS project and as a result can hinder the project and future projects.

- Plans and protocols need to be reasonable and practical in how they respond to irregularities or potential irregularities. Close communications and co-operation between the operator and the regulator are necessary to ensure that plans and protocols fit project and monitoring objectives to protect the environment.

- Once a potential problem is identified in, for example, conditions or regulatory requirements specified in permit documents, the problem should be rectified as quickly as possible through close communication between the operator and the regulator. However, it should be noted that it can be difficult to change conditions or regulatory requirements radically once they have been approved. This suggests the importance of communication with the regulators before a permit is issued.

- Monitoring parameters that are being used for critical pathways in permit compliance (*e.g.* additional costly surveys, suspension of CO_2 injection) should be selected from established technologies and monitor environments whose variations are well understood. Those parameters should have a sufficient number of baseline data to account for natural fluctuations if any. When parameters do not meet these conditions, the determination to change permit status should incorporate multiple parameters and data sources.

- For offshore CO_2 storage, chemical parameters in seawater can be an indicator for CO_2 leakage, but there is lack of expertise in using these parameters as a single identifier for CO_2 leaks.

- There is growing uncertainty on whether it is possible to collect enough baseline data to quantify natural variation in a way that will be meaningful for leakage attribution. Alternative approaches should be developed, and some are in development.

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2.7 CO2CRC Otway Research Facility

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Project Introduction

The CO2CRC Otway Research Facility in the State of Victoria's south-western region is Australia's first end-to-end demonstration of carbon capture and storage (CCS). The project provides technical information on CCS processes, technologies and monitoring and verification regimes that will help inform public policy and industry decision-makers while also providing assurance to the community.

1The facility has one of world's most comprehensive characterisation, CO_2 injection, monitoring and verification programs with more than $100 million invested in research over a decade that has both met and helped guide future CCS legislation within Australia.

The project currently utilises two petroleum production licences (PPL-11 and PPL-13) acquired through commercial negotiation specifically for this demonstration (with overarching Research Demonstration and Development licenses issued under the ***Environment Protection Act 1970***). These petroleum authorities contain a non-commercial CO_2 field (Buttress), which is the source of CO_2 (and some associated hydrocarbons) for the facility's operations, and a 2 km deep depleted gas field (Naylor) located around 2 km south of Buttress, which was the first storage formation used by the Project.

Over the life of the facility, the Otway Research Facility has progressed through 3 unique research programmes each bringing with them a new set of challenges, due to the activities taking place and the specific regulatory environment at the time of execution.

Figure 2-11: CO2CRC Otway Research Facility

Otway Stage 1 (2004-2009)

Establishment of a Pilot Project, to extract ~65,000 t of naturally occurring CO_2 from the Buttress-1 well, compress at the Buttress facility, and then transport the gas into a deeper depleted natural gas field (Naylor) via the CRC-1 well. This stage occurred during an era of no formal Carbon Storage Legislation.

Otway Stage 2 (2009-2019)

Enhancement of the understanding of saline formation storage, and improved methodologies for characterisation, monitoring, and long-term predictions of plume migration and stabilisation. This project injected approximately 15,000 t of CO_2 into a saline formation, leveraging an extensive seismic monitoring regime. This expanded on our previous regulatory needs while occurring in a time of the creation and implementation of new carbon storage legislation. This involved managing the Otway sites through the transitioning of multi-jurisdictional legislative approvals to the new carbon storage legislation passed by the Victorian State Government.

Otway Stage 3 (2016-2023)

Designed to holistically assess the effectiveness of characterisation, injection and storage management techniques and methodologies currently under development. This project has the aims of both significantly reducing the cost of geological CO_2 storage and monitoring, while meeting and guiding future regulatory imperatives. Stage 3 is purposefully designed to produce knowledge and technology that will be needed for the work of regulation of CCS projects in the future.

Regulation over project life

Projects at the Otway Research Facility are designed for purely research and demonstration purposes and as such are not designed for commercial scale CO_2 storage. However, the lessons learnt from establishing a CO_2 storage project within a region with an absence of any legislation, operating a storage project within a changing regulatory environment and then designing future research solutions for evolving regulatory environments, could be invaluable to upcoming projects within Australia and abroad.

Note that in the State of Victoria, the regulation for the production of CO_2 gas with some associated hydrocarbon is through the ***Petroleum Act 1998***. The Otway Research Facility will therefore always be required to hold the appropriate petroleum licences for the operation of the Buttress facility.

Please also note that although not explicitly noted, we also comply with all relevant Victorian legislation surrounding any site operations i.e. Worksafe, Country Fire Authority etc.

Stage 1 – Pilot Project in absence of legislation

As CO2CRC were undertaking an Australia's first geological storage research and demonstration project, it was inevitably going to face a unique legislative environment that would require extensive negotiations and flexibility from all parties involved to reach an acceptable outcome. The aims of this project were to show that the technology was viable and readily available in Australia as well as providing an example/driver for CCS legislatively within Victoria.

The closest industry regarding operational activities, to reference for legislative requirements was the Petroleum Industry. The onshore Petroleum industry in Victoria is tightly regulated under the ***Petroleum Act 1998,*** which is controlled by the Earth Resources Regulation (ERR) Branch (then within the Department of Primary Industries). Given the nature of the Otway Research Facility, specifically discharging material into the environment, it was also regulated by the ***Environmental Protection Act 1970***, which is the responsibility of the Environmental Protection Agency (EPA).

After acquiring the two PPLs, the application to the EPA for approval for Stage 1 was submitted in November 2006 and subsequently approved within a complex permitting regime in July 2007. Storage of injected CO_2 at the Otway Research Facility is being regulated by the Research Demonstration and Development (RDD) provision of the Victorian ***Environment Protection Act 1970***. The drilling of CRC-1, conversion of Naylor-1 to a monitoring well, and subsequent extraction and transportation of CO_2 from Buttress 1 to CRC-1 was covered under approvals from ***the Petroleum Act 1998***.

Ultimately, following exceptional collaboration between all regulating bodies, the approval process for the project was defined using a combination of legislations. The Departments involved were the Victorian Department of Primary Industries, The Department of Sustainability and Environment, The Department of Environment and Heritage, The Environmental Protection Agency (EPA), Southern Rural Water (SRW), The Moyne Shire and Local Government, The Department of Infrastructure, Aboriginal Affairs Victoria and the Central Fire Authority.

It took over two years to obtain all the regulatory approvals for the project, which included a local change to the planning regulations to allow for planning permission to be granted. Long-term liability issues associated with the stored CO_2 were the subject of a long debate, with the Victorian Government not prepared to indemnify the proponents against common law liabilities. Ultimately, it was accepted that if CO2CRC met all the EPA KPIs, they would have fulfilled their responsibilities and could hand the tenements back to the government (Sharma et al. 2008).

Table 2-2: Regulations Applied to the Otway's Stage 1 Activities

Stage 1 Activities	Stage 1 Approvals	Related Regulatory Bodies
CO_2 Production and transport (including all wells)	Petroleum Act 1998	ERR
CO2 Injection and Storage	Environment Protection Act 1970	EPA
Monitoring and Verification	Environment Protection Act 1970 Petroleum Act 1998	EPA ERR

Stage 2 – Expansion during a changing regulatory regime

The application for EPA approval for Stage 2 was submitted in May 2009 and the EPA approval was granted (for a period of 6 years) in October 2009.

The Otway Research Facility initially commenced in the absence of legislation specific to carbon storage. However, by the time that Stage 2 was being planned and developed, the ***Victorian Greenhouse Gas Geological Sequestration Act 2008*** (VGGGSA) had been finalised and was about to come into operation. The VGGGSA requirements are primarily based on the State's well-established and effective petroleum legislation

In October 2008, the Victorian Parliament passed the VGGGSA, and it came into operation on 1^{st} December 2009. This Act established an exclusive jurisdiction specifically prohibiting any storage activities except those specially permitted under the Act.

The thinking behind key features in the Victorian legislation originated from the Otway Research Facility which included;

- Maintaining the involvement of the EPA and Water Authority by formally identifying them as referral authority (with involvement) in the appropriate processes;
- The importance of acting in public interest and public consultation,
- Defined requirements for special access authorities, and greenhouse gas infrastructure lines; and
- The criteria for surrender of injection authorities.

Unfortunately, the VGGGSA did not sufficiently provide for the non-commercial research and development activities at the Otway Research Facility and some gaps were identified, where it could be seen that the ongoing activities may be in breach of this newly introduced Act. After much consultation, specific regulations were passed exempting the Project from the VGGGSA so long as it maintained the approvals obtained under the previous regulatory regime.

Discussions over the Stage 2 approvals were held with the regulators after initial review by CO2CRC, and these approvals were obtained by extending the existing RD&D approvals from the EPA, and obtaining new approvals from Southern Rural Water (SRW) the local authority for the **Water Act 1989**. The new well CRC-2 was drilled under the **Water Act 1989,** as it did not meet the definitions of a petroleum activity as per the ***Petroleum Act 1998***.

Table 2-3: Regulations Applied to the Otway's Stage 2 Activities

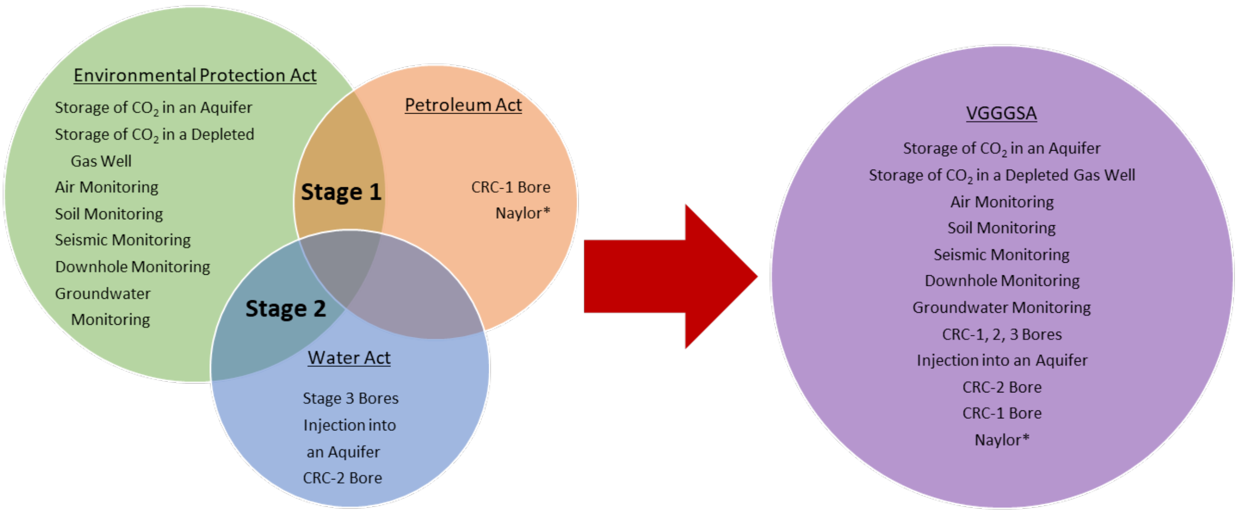
Additional Stage 2 Activities	Additional Stage 2 Approvals	Regulatory Bodies
Injection Bores	Water Act 1989	SRW
CO_2 Injection and Storage	Environment Protection Act 1970 Water Act 1989	EPA SRW

Stage 3 – Opportunities for refinement

As part of the planned Stage 3 operations, CO2CRC and the Regulators recognised that operating under an exemption to the VGGGSA is not the most appropriate way to have the storage research facility regulated in an ongoing operational basis. CO2CRC are currently working closely with the Victorian Government to seek a formal solution.

Currently the legislation has not changed so that the Stage 3 project is remaining under the same regime as Stage 2, with new bores to be drilled under the ***Water Act 1989***, and the storage operations approved via the ***Environment Protection Act 1970***, Research, Demonstration and Development processes.

If the legislation changes, the storage activities, including the drilling of the new monitoring wells, will all be regulated by the ***Victorian Greenhouse Gas Geological Sequestration Act 2008*** (example shown below)***,*** with the EPA and SRW being formally requested by ERR to comment upon the proposed activities via the identified referral process within the ***Victorian Greenhouse Gas Geological Sequestration Act 2008***. The production of the CO_2 at Buttress will remain a petroleum activity with associated approvals via the ***Petroleum Act 1998***.



*Naylor was decommissioned in 2017 under the Petroleum Act 1998
Modified from Ranasinghe (2013)

Figure 2-12: Effect of the Proposed Changes to the VGGGSA on the Otway's Storage Activities

Lessons Learnt

The activities in the Otway Research Facility revealed that it would be best to use a less prescriptive and more outcomes based overarching approach to developing regulations (in line with accepted regulatory best practice for other industries). This allows for the operator to have flexibility to utilise best practice techniques without compromising the outcomes, whilst giving the regulatory authority the appropriate assessment and enforcement mechanisms to manage the operations. It also showed the importance of ensuring the need to conduct research is recognised in the legislation. From a governmental regulatory perspective, the lessons from this project were summarised by Cook et al. 2014 below:

- Adequate time and resources should be allocated for the project approval processes, particularly for pilot project where the potential regulatory framework for the project is unclear
- Project operator and regulators need to collaborate at the concept phase of the project to clarify the process for approve the project
- The project approvals process needs to be appropriate to the scale and the likely impact from the project
- Although a CCS project may be approved by environmental regulators, the petroleum regulators have a valuable contribution to make in carbon storage, based on their experience with the petroleum sector
- The petroleum industry regulation model has a lot to offer for the regulation of the carbon storage industry and the expertise required for resulting the petroleum industry is transferable to the carbon storage sector
- Water authority's inputs/approvals are an integral part of regulating carbon storage projects, particularly where there are beneficial aquifers in the vicinity of the project
- Adequate time and resources need to be allocated for any potential land access issue even if a project is small-scale, non-commercial research project
- In developing new legislation alongside projects in operation, the transitional provisions need to provide for projects already in existence
- Although, liability is a challenging topic to resolve, discussion must take place early in the project planning, to clarify the distributions of liability over time especially for the long term and at project closure.
- Stakeholder engagement is a critical part of any pilot project and needs to be planning and managed carefully including a proactive approach to managing media matters

The activities within the Otway Research Facility presented a number of challenges from a government perspective but both the government team and CO2CRC teams involved were able to work through each of these challenges and together they delivered an iconic project for Victoria.

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3 Analysis and Findings

This chapter analyzes the case studies, in particular, their 40 lessons learned in total to draw findings for making CO_2 storage regulations practical. The findings here are categorized into 1) findings for making CO_2 storage regulations practical; 2) findings for effective CO_2 storage permitting process; and 3) findings for making permit application documents and plans pragmatic. Those findings will be useful for regulatory authorities to develop regulations for geological CO_2 storage, or to review existing regulations for geological CO_2 storage and amend them if necessary, and for CCS project proponents to apply for a CO_2 storage permit.

3.1 Findings for Making CO_2 Storage Regulations Practical

It is apparent that, to facilitate the deployment of CCS projects, CO_2 storage regulations should be practical and reasonable scientifically, technically and financially. Impractical regulations discourage CCS projects to take place, for example, by increasing costs significantly.

Principle of and Industry Role in the Establishment of Regulations

Finding 1: CO_2 storage regulations should be established under the principle of promotion of safe CCS. In the establishment of the regulations, the timely involvement of industry is important.

The creation of practical CO_2 regulations is essential to promote the development and deployment of CCS projects since it can provide a measure of certainty to potential CCS investors and project developers. Tomakomai insists that CO_2 storage regulations should be established under the principle of promotion of safe CCS and that regulations without such a principle may increase the cost of CCS projects by creating unnecessary interruptions in operations or by adding unnecessary monitoring and/or research to satisfy a conservative regulatory approach. Quest experience indicates that to create such regulations, the timely involvement of industry is critically important.

Review of Existing Regulations

Finding 2: Existing CO_2 storage regulations can be improved through a review by diversified stakeholders.

After CO_2 storage regulations come into force, it may be effective to review the regulations by diversified stakeholders in a comprehensive manner and amend them if necessary to make them more practical. The Quest proponent was involved in not only the establishment of regulations but also a comprehensive review of the regulations after established. This would be an ideal approach to refine practical regulations.

Flexibility in Regulations

Finding 3: CO_2 storage regulations should be flexible enough for various CCS projects with different characteristics to move forward.

ROAD found that not detailed but general rules provided in their regulatory frameworks worked well, which allows a systematic assessment for each CCS project applied based on its specific characteristics. In this case, however, close communications between a permit applicant and a regulatory authority is essential and adequate time and resources should be allocated for the discussions and negotiations. Otway pointed out that the project approvals process should be able to account the scale and the likely impact from the project.

Transitional Provisions in New or Amended Regulations

Finding 4: New or amended CO_2 storage regulations should be flexible with transitional provisions where necessary for continuation of existing valid projects if any.

Projects already in existence can be affected significantly by new legislation, replacement or amendment of existing regulations. Sleipner and Otway have gone through a replacement of regulatory frameworks in their project lifetime and concluded that the new frameworks should be flexible, for example, with transitional provisions where necessary for ongoing valid projects approved in the previous frameworks.

Validity of and Consistency in the Definitions of Key Terms

Finding 5: The definitions of key terms should be made with consideration of technical constraints and should have consistency with those in other related laws and regulations.

The definitions of key terms should be harmonized, taking technical constraints and also public perception into consideration. ROAD experienced confusion in definitions of terminologies in their CO_2 storage regulations and other applicable regulations. If CO_2 goes out of a reservoir, the operator would need to scale up a level of its monitoring. In their regulations, however, the movement of CO_2 is regarded as not leakage but migration and does not require the operator to take corrective measures. In addition, the definition of CO_2 leakage in their CO_2 storage regulations is different from that of the EU ETS Directive. Using an inappropriate or misleading key term can impact the credibility or understanding of a project immeasurably.

3.2 Findings for Effective CO_2 Storage Permitting Process

The CO_2 storage permitting process can be a major retardation factor in a planning and development phase of CCS projects. The reduction of the length of time for permitting can benefit both a permit applicant and a regulatory authority.

Regulations to be in Place

Finding 6: CO_2 storage regulations should ideally be in place before a planning of the first CO_2 storage project starts in order to promote the deployment of CCS projects in a country.

The majority of the CCS projects in this report initiated project planning before their regulatory frameworks came into force and needed to proceed in regulatory uncertainties. ROAD and Decatur found that delayed establishment of national CO_2 storage regulations would give unnecessary uncertainty to early CCS projects. As a matter of fact, Decatur was required re-permitting, resulting in prolonged permitting process, changes in its monitoring plan, and cost increase for monitoring. Experiences in Otway imply that regulations for other sectors such as the petroleum sector may help to develop CO_2 storage regulations. On the other hand, Peterhead points out that it should be recognized that there are significant differences between CO_2 storage and petroleum activities.

Practical Permitting Process

Finding 7: A permitting process should have adequate time and resources allocated and be appropriate to the scale and the likely impact from the project.

Especially when a regulatory authority has no precedent experience, or regulatory frameworks have uncertainties, adequate time and resources should be allocated for a permitting process. Otherwise, the process would take a longer time than necessary. Decatur was required re-permitting and experienced prolonged permitting process. The project insists that the reduction of the length of time for permitting can benefit both a permit applicant and a regulatory authority. Otway, which is pilot storage for the purpose of R&D, wanted the regulatory authority to have applied a simpler process to it with consideration for its characteristics such as pilot scale and likely limited impacts.

Communications between a Permit Applicant and a Regulatory Authority

Finding 8: For efficient permit award, close communication is essential between a permit applicant and a regulatory authority and should be initiated at an early stage. Such communications can be expedited by diversified members and fixed contact points.

Close communication is essential between a permit applicant and a regulatory authority for efficient permit award, in particular, when a regulatory authority has no precedent experience or regulations have uncertainties. Regulatory authority's sentiment supportive to the project was also essential for a permit applicant to resolve the challenges reasonably and programmatically. The majority of the case studies in this report referred to the importance of communications between a permit applicant and a regulatory authority. Tomakomai pointed out its importance from a different perspective based on their experience of difficulty to change conditions or regulatory requirements radically once they have been approved. ROAD found that fixed contact points within a permit applicant and a regulatory authority would be a key facilitation measure for such communications.

Communications with other Regulatory Authorities

Finding 9: A regulatory authority and a permit applicant should identify other regulatory authorities who should be involved in a permitting process and commence communicate with them early.

Peterhead found a need to actively reach out to different teams within the regulatory authority. This issue can emerge when the regulatory authority has no precedent experience and may result in a prolonged permitting process. Otway recommends earlier commencement of the communications with regulatory authorities in other sectors such as drinking water, petroleum and land access. Communications with water authority may be essential when there are beneficial aquifers in the vicinity of the project. The petroleum regulatory authority may have a valuable contribution to make in carbon storage, based on their experience with the petroleum sector. Potential land access can be an issue to be addressed.

Re-appraisal of Permit Application Documents

Finding 10: It would be helpful if a regulatory authority can recognize that key permit application documents and plans will mature and should be resubmitted when appropriate.

ROAD found that it would be helpful if a regulatory authority recognizes that key documents and plans will mature and should be resubmitted when appropriate. Fully developing all the studies, collecting all necessary information, and issuing reports will be only completed after a final investment decision (FID) is taken, and in order to take an FID, a valid storage permit is necessary. Peterhead had a similar but different experience – the permit applicant altered their engineering judgements and found that the actual wording of the storage permit was only determined after the development of application documents.

Compliance with the 1996 London Protocol

Finding 11: A regulatory authority and a permit applicant in a national jurisdiction that is a contacting party to the 1996 London Protocol should make sure that permit application documents for offshore CO_2 storage are in compliance with the Protocol Requirements.

The ROAD application documents were found to be generally in compliance with the requirements of the 1996 London Protocol (officially, the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972), which is an international treaty that allows sub-seabed geological CO_2 storage under strict restrictions. Regulatory requirements for sub-seabed CO_2 storage in a jurisdiction that is a contacting party to the Protocol should be compliant with the Protocol requirements but possibly implicitly. In such as case, a regulatory authority and a permit applicant should make sure that the project fulfills the guidelines and criteria of the Protocol.

More and more Parties are required to ratify 2009 Amendment on CO_2 Export for Storage to remove a barrier to future projects where London Protocol countries want to export CO_2 to another country for sub-seabed CO_2 storage. The current London Protocol prohibits export of CO_2 for offshore storage by a Party to another country. An amendment to allow this activity was proposed by Norway in 2009 and adopted by the London Protocol, however to come into force it needs to be ratified by 2/3 of the London Protocol Parties, currently 47 Parties. Since 2009, only three Parties have ratified it (UK, Norway and Netherlands) so there is very slow progress to ratification.

3.3 Findings for Making Permit Application Documents and Plans Pragmatic

Financial security related documents and monitoring plans are usually one of the major documents in permit application for CO_2 storage. These documents and plans should be able to reasonable and pragmatic since otherwise final investment decision on a CCS project cannot be taken or a project can be stopped in due course. An unnecessary suspension of project operation can deteriorate public trust on the project and consequently hinder the project and also future projects.

Independent External Review

Finding 12: An independent external review may be useful to make permit application documents better and streamlined.

Peterhead found that an independent external review on their permit application documents was effective to make them better. The commission of such a review will increase costs but has the potential to reduce costs if documents such as monitoring plans and criteria for storage site closure are streamlined. It may be also beneficial for the project to have a third party confirmation for the validity of the application and suitability of the CO_2 storage site from the viewpoint of public confidence for the project.

Earlier Commencement of Critical Negotiation

Finding 13: Negotiations between a permit applicant and a regulatory authority to address critical issues in permitting should be initiated as early as possible. These issues may include financial responsibilities of an operator and monitoring plans.

ROAD, Sleipner and Otway recommend that negotiations on arguable issues such as financial responsibilities and liability should be commenced between a permit applicant and a regulatory authority as early as possible. This recommendation can be applied to monitoring plans as well. Tomakomai experienced unnecessary suspension of CO_2 injection due to an inappropriate protocol to response monitoring irregularities that the applicant had made based on short-notice instructions from the regulatory authority.

Potential Arguable Financial Responsibilities

Finding 14: Financial responsibilities of an operator should be reasonable and pragmatic. Issues to be addressed may include the length of the closure period[5]; financial contribution from an operator for a regulatory authority's responsibility during the post-closure period[6]; and responsibility to compensate unintended CO_2 leakage by purchasing emission credits.

It is apparent that financial responsibility of operators should be reasonable and pragmatic since no projects take place if costs for financial responsibility are deemed too onerous. ROAD and Sleipner, both of which were permitted in the framework of the EU CCS Directive, re-emphasize the criticality of this issue. As such challenges, ROAD refers to the length of a closure period for CO_2 storage site; operator's financial contribution for a post closure period; and unforeseeable prices of emission credits which is to compensate unintended CO_2 leakage. It may be worthwhile to consider an approach that Peterhead took to determine the length of closure period based not on time criteria but on performance criteria. Sleipner also points out post-closure financial risks and insists that it is reasonable for a regulatory authority to take the risks. If financial security is required to cover costs for the purchase of emission credits if stored CO_2 theoretically leaks, the CCS project would need to deal with risks of increase in the prices of the credits and hence the project may be unfinanecable.

Principles in Monitoring Plans

Finding 15: Monitoring plans for CO_2 storage should be risk-based and adaptive; be pragmatic when responding to an irregularity or a potential irregularity; and use monitoring parameters that are well understood and have sufficient baseline data for critical judgements.

Monitoring plans are one of the major documents in permit application. Decatur deems that monitoring plans should be risk-based and adaptive. Quest supports the importance of adaptability, because it enables monitoring plans to be optimized and streamlined. Tomakomai concluded that monitoring plans should be reasonable and practical in how they respond to an irregularity or a potential irregularity. It should be noted that inappropriate response can affect public trust on the CCS project and future projects adversely. Tomakomai also emphasizes the importance of selection of parameters for critical decisions such as CO_2 injection suspension. The project deems that chemical parameters in seawater can be an indicator for CO_2 leakage from offshore reservoirs, but that there is currently lack of expertise in using these parameters as a single identifier for CO_2 leaks. Alternative approaches are, however, in development, for example, in the UK.

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[5] A closure period is a period between the cessation of CO_2 injection and the demonstration of compliance with criteria for storage site closure.

[6] A post-closure period begins with the demonstration of compliance with criteria for storage site closure.

4 Conclusions

Based on the 40 lessons learned from the seven case studies of project experiences with regulations for geological CO_2 storage, this report drew 15 findings presented in the previous chapter.

The findings should provide useful information in many situations including: regulatory authorities develop regulations for geological CO_2 storage, or review existing regulations for geological CO_2 storage and amend them if necessary; and CCS project proponents apply for, or consider applying for a geological CO_2 storage permit (See APPENDIX: Check List for Regulatory Authority & Project Proponent).

And in the future, experiences for the next generation of CCS projects should be examined to look into how the issues to be addressed that have been identified in the findings in this report will have been resolved in various jurisdictions. Many of the issues, including operator's finance responsibilities, may be specific to a first wave of CCS projects which has no or limited precedent experiences in permitting for geological CO_2 storage.

APPENDIX: Check List for Regulatory Authority & Project Proponent

This is a check list of the findings from the case studies for regulatory authorities who will develop regulations for CO_2 storage or review existing regulations for CO_2 storage and amend them if necessary, and CCS project proponents who will or may apply for a CO_2 storage permit.

Findings for Making CO_2 Storage Regulations Practical	Regulatory Authority	Project Proponent
Finding 1: CO_2 storage regulations should be established under the principle of promotion of safe CCS. In the establishment of the regulations, the timely involvement of industry is important.		
Finding 2: Existing CO_2 storage regulations can be improved through a review by diversified stakeholders.		
Finding 3: CO_2 storage regulations should be flexible enough for various CCS projects with different characteristics to move forward.		
Finding 4: New or amended CO_2 storage regulations should be flexible with transitional provisions where necessary for continuation of existing valid projects if any.		
Finding 5: The definitions of key terms should be made with consideration of technical constraints and should have consistency with those in other related laws and regulations.		

Findings for Effective CO_2 Storage Permitting Process	Regulatory Authority	Project Proponent
Finding 6: CO_2 storage regulations should ideally be in place before a planning of the first CO_2 storage project starts in order to promote the deployment of CCS projects in a country.		
Finding 7: A permitting process should have adequate time and resources allocated and be appropriate to the scale and the likely impact from the project.		
Finding 8: For efficient permit award, close communication is essential between a permit applicant and a regulatory authority and should be initiated at an early stage. Such communications can be expedited by diversified members and fixed contact points.		
Finding 9: A regulatory authority and a permit applicant should identify other regulatory authorities who should be involved in a permitting process and commence communicate with them early.		
Finding 10: It would be helpful if a regulatory authority can recognize that key permit application documents and plans will mature and should be resubmitted when appropriate.		
Finding 11: A regulatory authority and a permit applicant in a national jurisdiction that is a contacting party to the 1996 London Protocol should make sure that permit application documents for offshore CO_2 storage are in compliance with the Protocol Requirements.		

Findings for Making Permit Documents and Plans Pragmatic	Regulatory Authority	Project Proponent
Finding 12: An independent external review may be useful to make permit application documents better and streamlined.		
Finding 13: Negotiations between a permit applicant and a regulatory authority to address critical issues in permitting should be initiated as early as possible. These issues may include financial responsibilities of an operator and monitoring plans.		
Finding 14: Financial responsibilities of an operator should be reasonable and pragmatic. Issues to be addressed may include the length of the closure period; financial contribution from an operator for a regulatory authority's responsibility during the post-closure period; and responsibility to compensate unintended CO_2 leakage by purchasing emission credits.		
Finding 15: Monitoring plans for CO_2 storage should be risk-based and adaptive; be pragmatic when responding to an irregularity or a potential irregularity; and use monitoring parameters that are well understood and have sufficient baseline data for critical judgements.		