Geological Carbon Dioxide Storage Technology Research Association

Practical Guidance for Geological CO_2 Storage

Phase 01

Overview of Geological CO_2 Storage

Chapter 1 Master Planning
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Chapter 1 Master Planning

1.1 Preface

Carbon dioxide capture and storage (CCS) has steadily produced successful results in onshore large-scale CO_2 underground storage projects in Canada and the United States, as well as the offshore natural gas-associated CO_2 underground storage project in Norway. And it is recognized as an effective technology to address global warming. In Japan, a large-scale pilot test totaling 300,000 tonnes has just been completed offshore of Tomakomai, following the pilot test in Nagaoka of the geological sequestering of CO_2 totaling 10,000 tonnes. Figure 1.1-1 shows a conceptual diagram of onshore and offshore CO_2 underground storage projects.

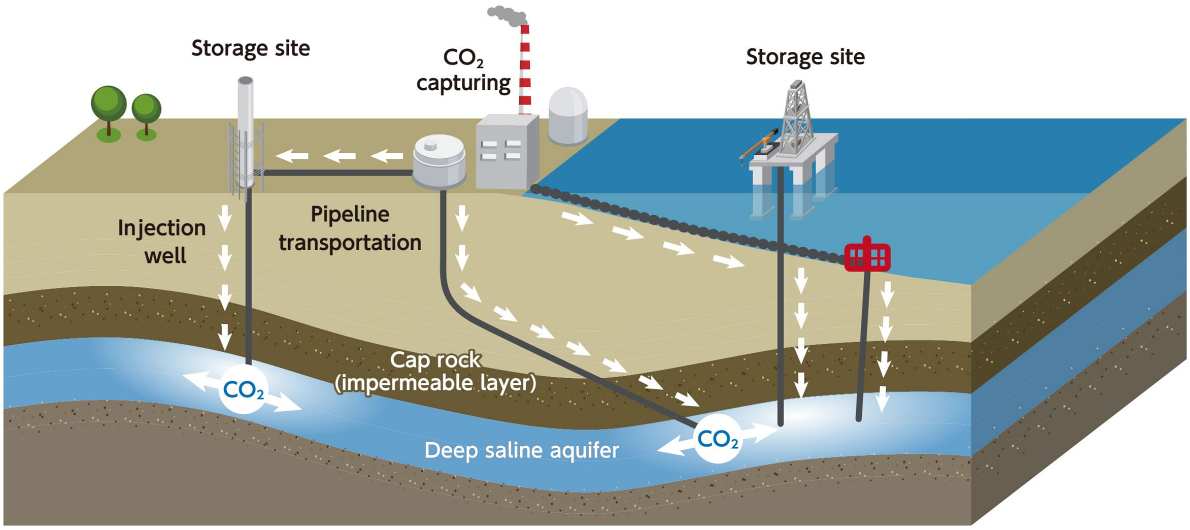


Figure 1.1-1 Concept of CO_2 underground storage

This collection of technical examples introduces domestic and overseas CO_2 underground storage cases, and it is compiled to be a reference manual for future CCS project operators in Japan. A CO_2 underground storage project (excluding separation and capture) can be divided into the following eight phases:

- Master Planning ---------Development of a master plan for a CO_2 underground storage project
- Site selection -------------Extraction of multiple candidate storage sites
- Decision on the site -----Evaluation of the characteristics of candidate sites, selection of the optimal site, and conceptual designs
- Implementation planning------ Development of implementation plans, basic

designs, and economic evaluations

- Design and construction------- Detailed design and construction, such as project equipment and the development of a management plan
- Operation and management-- Operation and management of sequestration and execution of the monitoring plan
- Site closure --------------------- Plugging the injection well
- Post-closure care----------------- Site care until project responsibility is transferred

This collection of technical examples comprises chapters corresponding to each of the above phases, with Chapter 1 Master Planning arranged to provide an overall picture of the project (Figure 1.1-2).

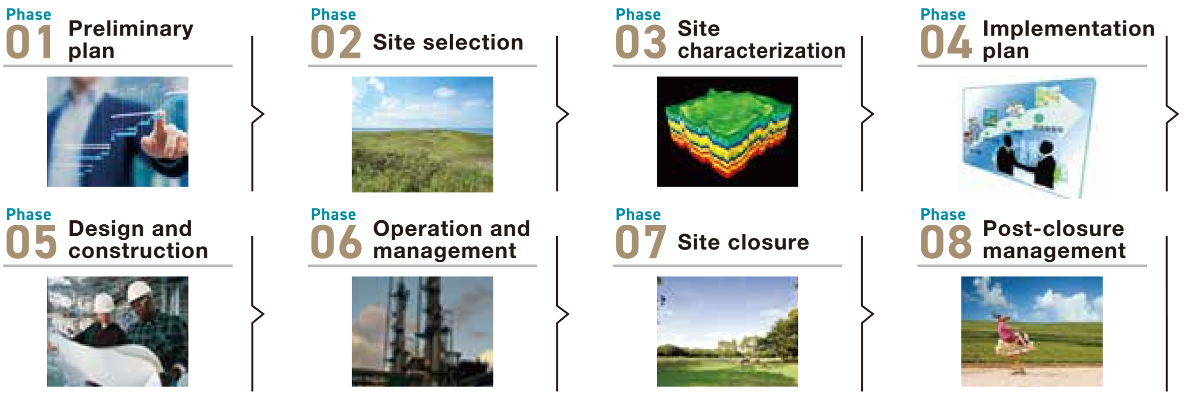


Figure 1.1-2 Technical examples of CCS

The following was referred to in order to prepare for this collection of examples: the research results of a pilot test performed between 2000 and 2007 of the geological sequestration of CO_2 at the Nagaoka site in the development of CO_2 underground storage and sequestration technologies; criteria desirable to comply with from the perspective of safety and environmental concerns, which are contained in research compiled in 2009 by the CCS Study Group formed by the Ministry of Economy, Trade and Industry (METI) in its work on the safe implementation of CCS demonstration projects; the main results of pilot test projects for technologies to reduce carbon dioxide and the large pilot test project in Tomakomai initiated in 2012 by METI and NEDO from 2018. The following manuals and guidelines compiled by overseas organizations and institutes, which are based on analysis of large-scale carbon dioxide underground storage projects, were also used for reference:

- ISO27914: 2017 (EN), Carbon dioxide Capture, Transportation and Geological Storage — Geological Storage
- U.S. NETL (National Energy Technology Laboratory): CCS Best Practice Manual
- WRI (World Resources Institute): Guidelines on CCS projects
- DNV (Det Norske Veritas): Recommended guidelines for the implementation of CCS projects

1.2 Purpose of Master Planning

The purpose of master planning is that a project operator presents an overall picture of the project at the start-up stage in order to gain stakeholders' understanding of the project. Master planning provides an explicit overview of the said CO_2 underground storage project, and it describes the basic concept of implementation details in each phase and schedule after master planning.

A CCS project is composed of the following elements:

- Recover CO_2 from the targeted emission source.
- Transfer captured CO_2 to a storage site (that which follows is for an underground storage project).
- Inject CO_2 deep underground at the site. Perform monitoring of the behavior of the injected CO_2 and monitor for leakage and seepage[1] into shallower strata. Confirm its consistency with predicted CO_2 behavior.
- Close the well after completion of CO_2 injection, and remove whatever facilities that are not required for post-closure care.
- Continue monitoring after the injection, and transfer all responsibilities to a public organization after regulatory authorities determine that safety is confirmed.

The essential basic elements to promote the CO_2 underground storage project are listed below (NETL, 2017):

[1]This collection of examples defines leakage and seepage as follows:
Leakage: CO_2 leaks from the storage system (a geological system that consists of the reservoir and shielding layer that forms traps in which CO_2 can be stored).
Seepage: CO_2 seeps from underground to the ground surface or to the atmosphere or ocean through the seabed.

- The selected storage site has geological conditions that are satisfactory for underground storage, and the project operator has the technical capabilities to implement underground storage there.
- Funds are secured to implement CO_2 underground storage.
- Consent to and support for the said project from stakeholders, including local residents, is received.

Master planning clarifies these elements at the start-up stage, and it presents guidelines for making it possible to achieve the smooth progress of a project. Since an underground storage project has a life cycle of more than several decades, projects must be pursued based on a long-term perspective. This should also be borne in mind when preparing the master plan.

1.3 Contents of Master Planning

The contents to be considered, prepared, and established during master planning cover a broad range of technical, economic, and legal or social aspects, which can be summarized as follows:

- Present an overall picture of the CO_2 underground storage project:
  The location of the CO_2 emission source, the outline of the storage site, and the total target storage volume and injection rate
  A desk study on the injection facilities, CO_2 transportation method, transport route, etc.
- Develop the project schedule.
- Establish a technical evaluation policy and criteria in each phase ranging from site selection to the final investment decision.
- Perform basic economic analysis and evaluations in terms of human resources, materials, and finances.
- Comprehend the legal regulations, obligations, and the approval and permit procedures for the CO_2 underground storage project.
- Confirm the project's uncertainties and risks.
- Identify stakeholders and understand the environmental and social challenges (PO and PA activities*).

*PO = Public Outreach, PA = Public Acceptance

1.3.1 Overview of a CO_2 underground storage project

Figure 1.3.1-1 shows the flow of a CO_2 underground storage project, and it outlines the main project description in each phase below.

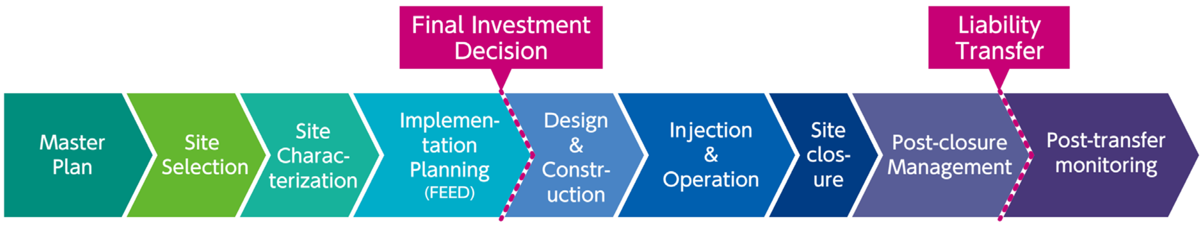


Figure 1.3.1-1 Flow of a CO_2 underground storage project

(1) Development of the master plan

Provide an overall picture of the project, the basic concept (including economic analysis), and the work policy and contents in each phase, schedule, etc. PO activity should be launched early.

(2) Site selection (screening)

Using mainly the geological elements based on the overall plan that are shown in the master plan while also referring to other elements, select multiple candidate sites which satisfy the requirements of a CO_2 storage site by basically using existing geological materials.

(3) Decision on the site (evaluation of site characteristics)

Acquire new geological data for candidate sites, as appropriate, and evaluate the requirements in detail as a CO_2 storage site. Build a geological model, and perform an evaluation of capable storage volumes through CO_2 injection simulations, risk assessments from geological perspectives, and the study of injection specifications. Develop a conceptual design of transport and injection facilities and also evaluate a rough estimate of the costs. From this, make a final decision on the injection site. Also, identify stakeholders at this stage and require PO and PA activities, including the acquisition of new geological data.

(4) Development of the implementation plan

Formulate PO and PA activities in preparation for a concrete project implementation plan and the commencement of operations. In light of the evaluation results, create a working plan for the CO_2 injection and subsequent monitoring, etc. and also develop a basic design for transport and injection facilities (FEED: Front-End Engineering Design). Make a final investment decision (FID) by holistically considering everything, such as the costs, economic analysis based on the aforementioned, and risk assessments, and submit the implementation plan to the regulatory authorities for approval of the project.

(5) Design and construction

After project approval is granted by the regulatory authorities, design the injection and transport facilities, etc. in detail based on the conceptual design and basic design so far. Then, construct the injection and transport facilities and carry out test operations. In addition, before the injection start monitoring the initial state in preparation of the commencement of operations.

(6) Operations and management

Conduct injection operations by the project operator in accordance with the implementation plan. Monitor the distribution of the CO_2 that has been injected underground, any pressure changes in the reservoir, and improve the geological model to increase the accuracy of predictions of long-term CO_2 behavior if any deviation from predicted behavior is found. In addition, conduct monitoring for the purpose of detecting CO_2 leakage and seepage.

(7) Site closure [2]

After completing the CO_2 injection, abandon the injection well and remove the injection facilities and transport equipment, except for that which is necessary for post-closure monitoring. Return the site to the landowner after restoring it to its original state.

(8) Post-closure care

Continue monitoring after site closure in order to check CO_2 behavior and for leakage and seepage. Although the duration of monitoring varies according to legal regulations, management responsibility for the site is transferred to a public organization after regulatory authorities determine that its safety is secured following a specific monitoring period.

The above eight phases are not individually independent but are closely linked to each other and overlap in terms of times with their respective before and after phases. (Figure 1.3.1-2)

[2] In the United States and Canada the end of the care period (post-closure care in this collection of examples) after completion of the injection is defined as “site closure.”

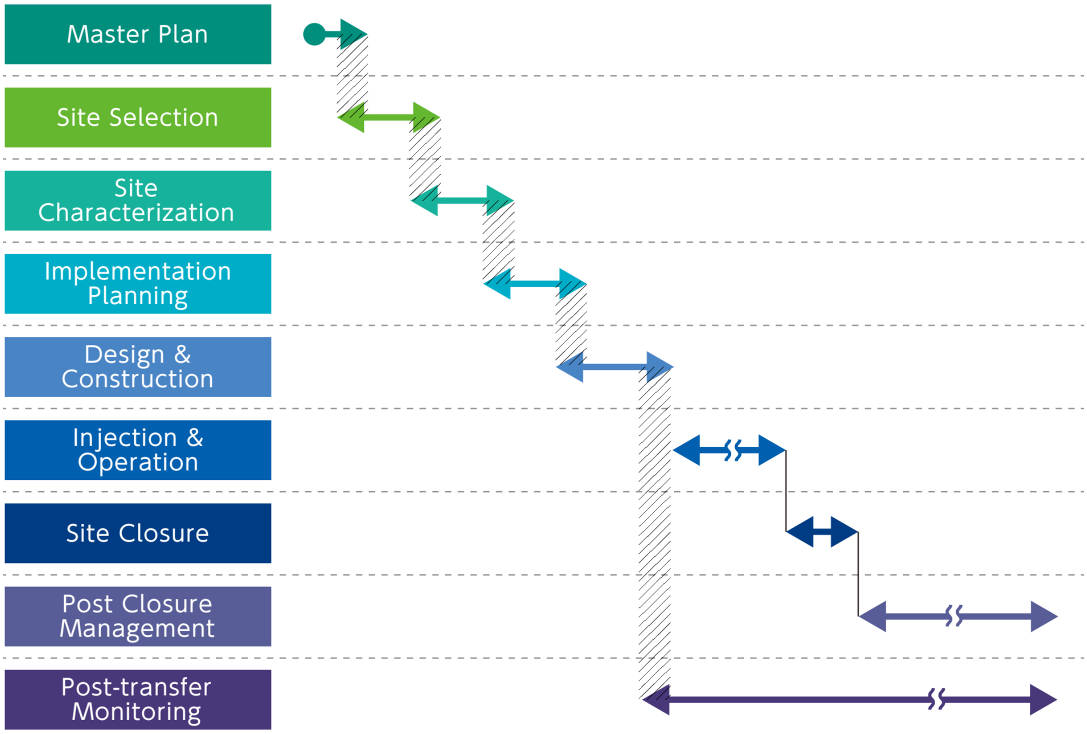


Figure 1.3.1-2 Concept of overlapping phases

Figure 1.3.1-3 shows the promotion flow of a CO_2 underground storage project. After completing preparation of the implementation plan, a final FID is made, and the project operator submits an application for approval of the project. If the investment decision is rejected at the time of FID, the project will be aborted. Furthermore, if elastic wave exploration or drilling of an exploration well is required to acquire new data for evaluation, such exploration costs will increase significantly. But in Japan, utilizing the results of the study project to select suitable sites conducted by METI can also be considered.

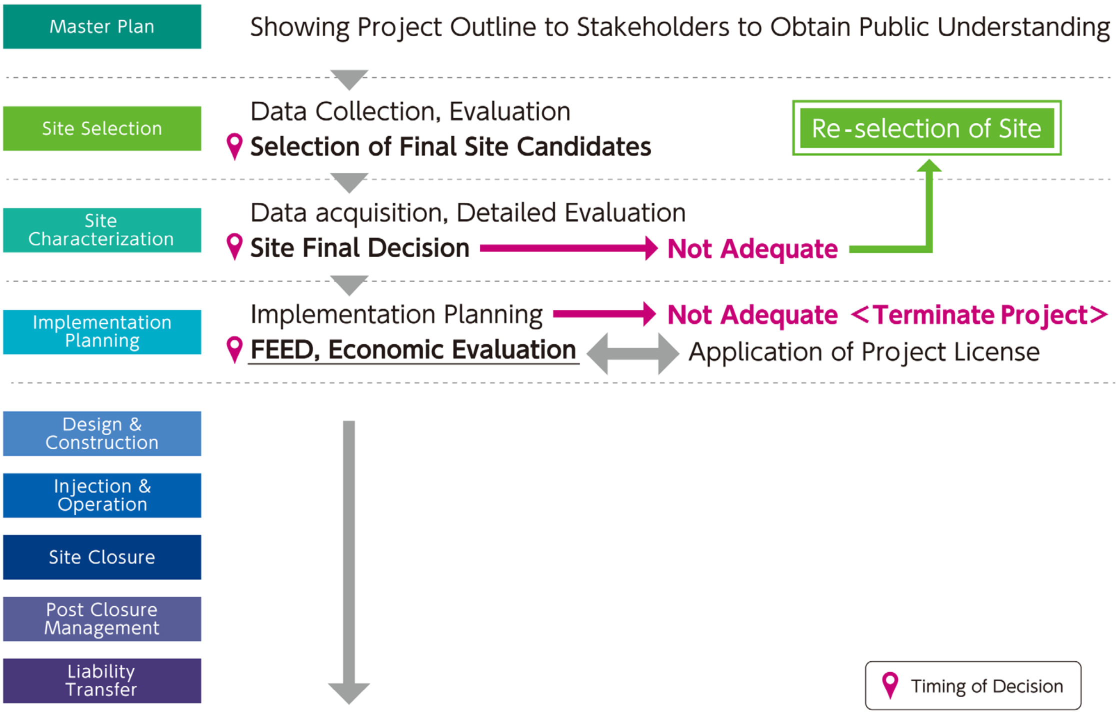


Figure 1.3.1-3 Project promotion flow

1.3.2 Project implementation scheme (implementation structure)

The CO_2 underground storage project includes a long period of time from conception until the termination of project responsibilities, and it also involves many fields. In order for the project to go smoothly, securing human resources with the expertise shown in Table 1.3.2-1 and team formation and cooperation within it are necessary. Since the skills and knowledge cultivated in particular in oil development are applied, human resources highly specialized in relevant fields, such as geoscience and resource engineering, will be required.

Table 1.3.2-1 Example of team composition to promote a CO_2 underground storage project

Field / Team	Main Duties
Project Management	Planning of Each Phase, Integration of the Project, Economic Evaluation and Accounting Control, Data Archive, Legal Processing、Control of licensing procedure
Geologic Evaluation, Injection and Storage Management	Site Selection, Site Characterization、Planning and Operation of Injection and Monitoring, History Matching
Construction and Management of Wells	Planning and Execution of Drilling, Completion and Wells Abandonment
CO_2 Transportation	Planning of CO_2 Transportation, Design, Construction and Operation
Facility Construction	Design, Construction, and Maintenance of Storage Facilities (Injection Facility, Monitoring Facility etc.)
Environmental Assessment	Environmental Assessment of CCS Facilities
Publicity Activities	Provision of Project Information to Stakeholders, Consensus Building
Accounting, Procurement	Accounting Operations, Material Procurement

1.3.3 Project implementation planning

An overall picture of the CO_2 underground storage project (CO_2 emission source, storage site, transport method, total storage volume, injection rate, etc.) is provided, and the implementation policy and plan in each phase below are outlined. Any conditions restricting the positional relationship with emission sources, etc. are indicated in advance.

(1) Outline of the schedule

It is difficult to prepare a detailed schedule in the master planning phase, so an approximate duration is set for each phase as follows:

Site selection ------------------------------ 1 to 2 years
Evaluation of site characteristics --- 2 to 5 years
Implementation planning ------------- 2 to 3 years
Design and construction -------------- 1 to 3 years
Operation and management ----------- 10 to 30 years
Site closure and post-closure care --- 10 to 50 years

Progress of the plan may change significantly depending on difficulties associated with site characteristics, CO_2 transportation methods, time required for approvals and permits, and time constraints on the start of the injection, etc.

(2) Master planning for each phase

1) The process until the final decision is made on project implementation

The process until FID, which is the most important decision in the first half of the project, is shown in Figure 1.3.3-1.

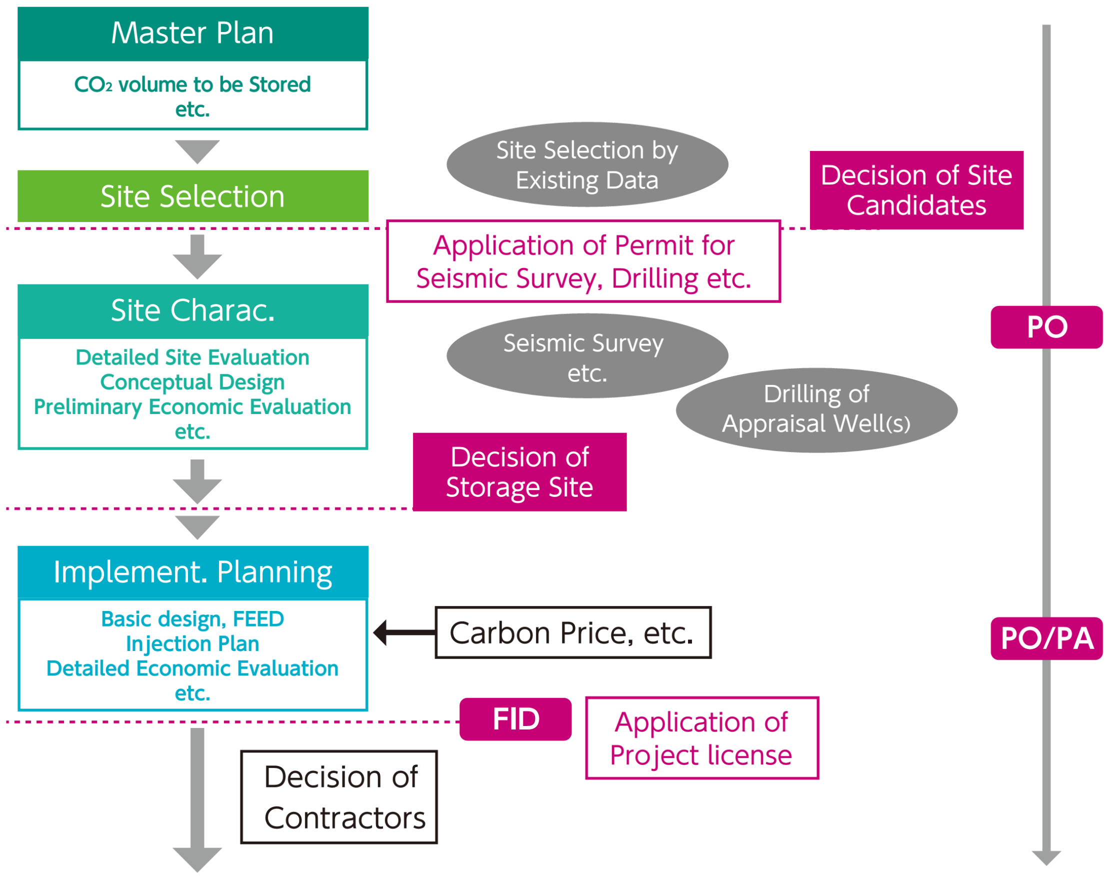


Figure 1.3.3-1 Process until the final decision is made on project implementation

a) Site selection (Chapter 2)

This is mainly a geological study using existing geological materials to select a candidate site which satisfies the requirements of the CO_2 storage site. The important points are to secure storage capacity for the assumed CO_2 storage volume and injection rate and the safety of the site in terms of leakage and seepage, although the volume and quality stated in the existing materials vary by target region. Taking into consideration the risks associated with geological uncertainty, it is desirable to select multiple candidate sites. The following technical requirements are the basic policies for site selection:

- Available storage capacity that can satisfy the required storage volume
- Injection performance that allows injection at the required rate
- Long-term safety

Long-term safety here refers to no leakage of CO_2 to the ground surface or to the seabed, no impact on available underground resources, including groundwater in shallower strata, and no impact on the stability of geological strata from the injection.

The following storage system[3] is also required to satisfy the aforementioned requirements:

- A reservoir with sufficient potential (stable operations without excessive pressure increases not only for the storage volume but also to maintain the stability of the geological strata)
- A shielding layer above the reservoir that prevents CO_2 leaking outside the reservoir
- The formation of traps that enable long-term underground retention of CO_2

In view of the project's scale (assumed injection volume, etc.) and the diversity of geological conditions, common site selection criteria cannot be always established, but the following are the main items for consideration: the reservoir and shielding layer, geological faults and existing wells, the distance between the CO_2 emission source and the storage site, and whether it is onshore or offshore. From the perspective of oil and gas field developments, the selection criteria in Table 1.3.3-1 are of use as a reference for the reservoir and shielding layer.

[3]It is called a storage system since the functioning of the three elements comprising the reservoir, a shielding layer, and a CO_2 trap is basically indispensable for CO_2 underground storage. A trap is necessary for oil and gas field formations, and an anticlinal trap, which is formed by the combination of the reservoir, shielding layers, and the anticline, is cited as a typical structural trap.

Table 1.3.3-1 Examples of selection criteria

(Assuming domestic/numerical values are used as a guide)

	Reservoir	Seal	Data Source
Lithology	Sandstone／Carbonates	Shale、Evaporite	General Lithostratigraphic Chert, Regional Lithologic Map, Well Information, Seismic facies
Thickness	＞Several 10m	>Several 10m	Geologic Section, Well Correlation Map, Seismic Section, Isopach Map, Wireline Logging
Extent	Several 10km_2	Much More Than ReservoirExtent	Geologic Section, Well Correlation Map, Seismic Section, Isopach Map
Reservoir Quality	Porosity ＞20% Permeability＞ Several 10md	Low Permeability($<\mu$D)	Core Analysis, Wireline Logging

If there is a large fault around the site, the risks of CO_2 leakage and seepage and of induced seismicity must be assessed after establishing in advance the CO_2 distribution range and pressure increase range by conducting a CO_2 injection simulation. Since an existing well has a potential risk of CO_2 leakage and seepage from the reservoir, the history of the well must be investigated.

It is generally desirable that the CO_2 emission source and storage site are located close to each other. The CO_2 transportation method and degree of difficulty of access to materials and equipment, etc. are intimately related to the project's costs, and water depth and the distance offshore are also elements for the selection of offshore sites. Whether a storage site is onshore or offshore causes a pronounced difference in terms of the technology, logistics, regulations, and costs associated with CO_2 underground storage. Offshore storage has the following advantages:

- Available storage capacity is generally large in continental shelves.
- There are no complications associated with land ownership unlike with onshore sites, and it is easier to gain the understanding of local residents.
- There are smaller risks associated with the uses of drinking water and freshwater.
- Long haul transport is feasible with the use of ships.
- It is relatively easy to obtain good quality data in elastic wave exploration.

On the other hand, there are also the following issues compared with onshore sites:

- It is necessary to coordinate with fishing activities and fisheries officials in coastal zones.
- It requires scrupulous attention for the protection of maritime environments.
- The high cost of facility construction (including well-drilling, etc.)
- Injection operations can be affected by weather and hydrographic phenomena.

b) Evaluation of site characteristics (Chapter 3)

The adequacy of a CO_2 storage site is evaluated by obtaining new geological data through elastic wave exploration and exploration well-drilling at the site. CO_2 plume [4] expansion/pressure increases and the ascent range in the reservoir/available storage capacity, etc. are estimated by building a detailed geological/reservoir model and predicting the behavior of injected CO_2 through simulations. The results of the evaluation of the characteristics are also required in order to develop the implementation plan and to apply for approvals and permits for project implementation.

This phase includes the conceptual design of the injection and transport equipment, etc., so approximate cost estimations are also performed. CO_2 pipeline installation is also constrained by land features, etc. on the construction route. On the other hand, changing to transportation by ship has a big impact overall on the injection facility, and the cost estimate also fluctuates greatly. Therefore, the basic design for the CO_2 transportation method and the location of the injection facility should be considered in the master planning phase. Furthermore, PO and PA, environmental protection, and legal issues should also be evaluated. In particular, during the evaluation of the site characteristics of potential storage sites, fully-fledged PO and PA activities will begin. In addition, establishing a good relationship with local stakeholders around the CO_2 transportation route and storage site is essential for the subsequent implementation of the project.

[4] Plume: a three dimensional domain in which injected CO_2 spreads in the ground.

c) Implementation planning (Chapter 4)

A concrete implementation plan is prepared based on the results of the evaluation of candidate sites. Planning for injection operations, such as the injection route, total injection volume, the number of injection wells, and the injection pressure, is conducted on the basis of the results of CO_2 injection simulations using the latest geological model. The implementation plan includes site closures after completing the injection, the post-closure monitoring policy, and PO and PA during and after operation, in addition to monitoring and history matching. The basic design of the storage-related facilities is also done during the implementation planning phase. This is the preliminary stage of the detailed design in the next phase, and it corresponds to FEED (Front-End Engineering Design).

The project operator will make a FID on whether or not to proceed with the project by comprehensively judging it, including risk assessments associated with the CO_2 injection and storage, stakeholder identification and examination of issues from the environmental, legal (regulations, approvals, and permits) and social aspects, as well as an economic analysis based on the basic design. If the project operator decides to implement the project, the operator will submit the implementation plan to the regulatory authorities to seek project approval and permits.

2) Process after the final decision is made on project implementation (Figure 1.3.3-2)

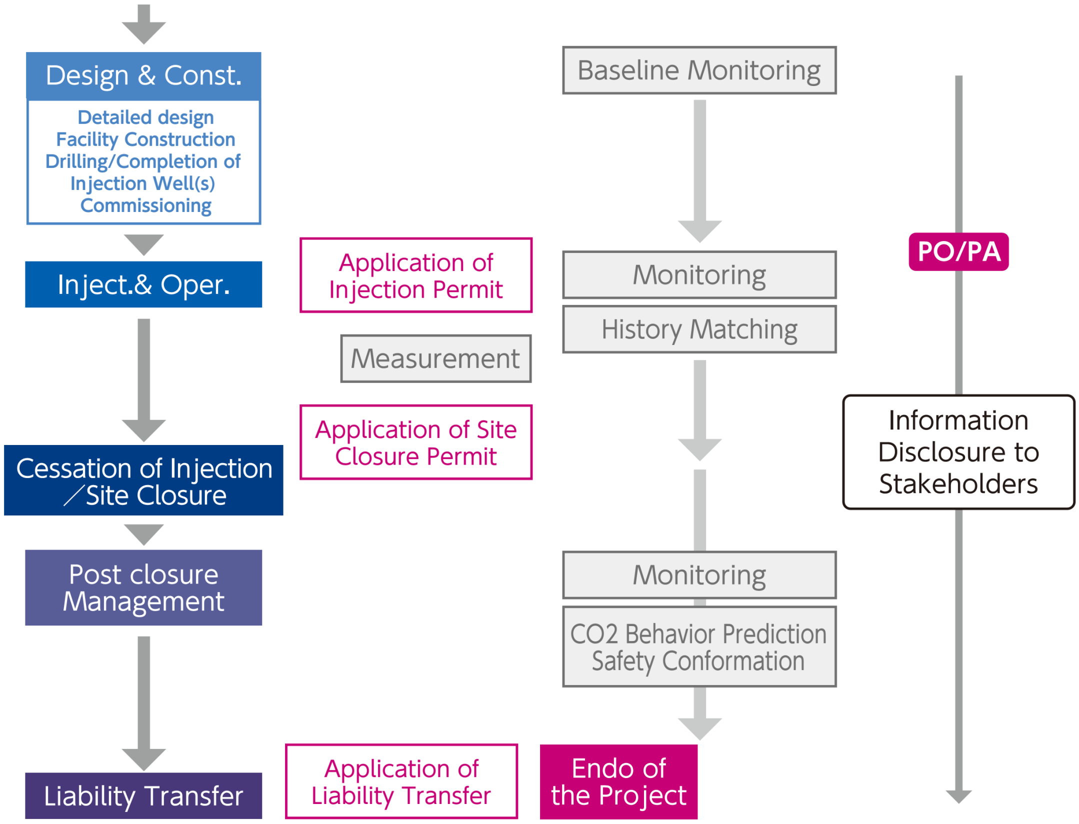


Figure 1.3.3-2 Process after the final decision is made on project implementation

a) Design and construction (Chapter 5)

After project approval is granted, the CO_2 transportation facility, the injection facility, and the CO_2 monitoring-related facilities are designed in detail and constructed with reference to the basic design up to and including the previous phase (Figure 1.3.3-3).

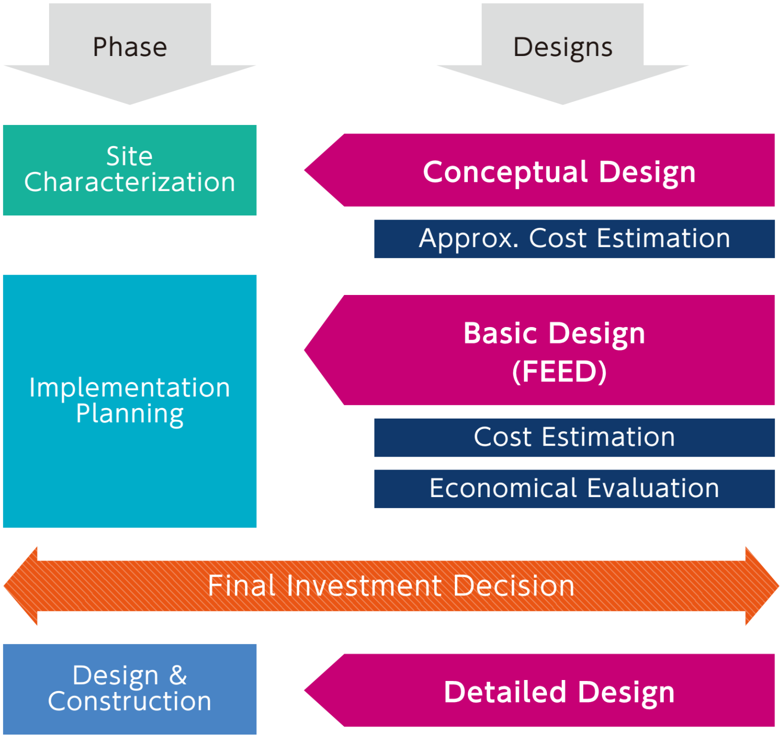


Figure 1.3.3-3 Design components in each phase

In the detailed design, all specifications and drawings for field erection work are established, as with general construction work. PO and PA also includes important information such as pipeline installation routes and the CO_2 emission system in case of an emergency equipment stop. Detailed design work is rarely done alone, and as a general international rule, a project operator often places a package order for a set of work comprising the facility's detailed design, procurement, and construction work through an EPC (Engineering, Procurement, and Construction) contract. There are different styles of orders, such as placing an order for the entire work with one company or an order dividing the work area according to the project operator's policy.

After moving to the construction phase and the start of on-site construction work, such as engineering, it is necessary to have even closer cooperation with stakeholders in order to smoothly implement on-site work. There are cases in which disclosure of the project's progress is required because of a funding agreement with the government and municipality, like the Quest project in Canada. A series of acceptance inspections, called commissioning (performance validation), are conducted at the end of construction work to confirm that the CO_2 reaches the injection well in a safe manner with the pressure, temperature, rate, and composition described in the design specifications.

b) Operations and management (Chapter 6)

CO_2 injection operations commence in accordance with the implementation plan. CO_2 is generally injected into a reservoir deep underground through the injection well by a pump installed at the injection site. When preparing the master plan, instructions issued by the regulatory authorities, such as the record of injection (including the injection rate), and monitoring and security-related records, must be understood.

There are two main purposes of monitoring: to check the behavior of injected CO_2 through elastic wave exploration or the reservoir's pressure change and the implementation of history matching with the results of CO_2 behavior simulations based on the monitoring results. Then, the geological model that was built during the phase in which characteristics were evaluated is modified, as appropriate, and predictions of long-term CO_2 behavior are revised. This is fundamental work to confirm the safety of the CO_2 underground storage site, and it is also important from the perspectives of fostering relationships of trust with stakeholders and the legal obligations, such as reporting to the regulatory authorities. Moreover, highly accurate predictions of long-term behavior are also involved in the management plan, including monitoring after completion of the injection, the transfer of responsibilities after the site's closure, and ultimately the economics of the entire project. Another purpose is to monitor for CO_2 leakage and seepage caused by defects in the shielding layer and well.

An incident response protocol and a contingency plan should also be specified in the master plan in case of an abnormal or emergency situation, such as anomaly detection during monitoring, an unexpected pressure increase in the reservoir, or the occurrence of a natural disaster, including earthquakes. With respect to concerns for induced seismicity, as stated in the site selection criteria (faults), avoiding faults which can be the main source of earthquakes is an obvious prerequisite. Moreover, the stability of faults is monitored through observations of micro earthquakes, etc.

c) Site closure (Chapter 7)

In accordance with the initial plan, facilities on the injection site are removed after completing the CO_2 injection. The injection well is basically plugged, and the majority of the facilities, except for those necessary for post-closure monitoring, are removed. The site is returned to the landowner after restoring it to its original state. Upon closure of the site, there is a law that stipulates the project operator must assume the financial obligations for post-closure care, and that must be recognized in the master planning phase.

d) Post-closure site care (Chapter 8)

The monitoring is similar to that undertaken during injection operations, and the incident response protocol in the case of an abnormal situation continues even after site closure. In response to reduced uncertainties and risks upon completion of the injection (described later in Figure 1.3.7-2), some ingenious attempts to reduce the monitoring frequency, etc. are necessary, even from the viewpoint of cost reductions. On the other hand, it is crucial to verify long-term safety by continuing history matching based on the monitoring results and continuing to revise predictions of long-term CO_2 behavior. The duration of post-closure care varies depending on the country, and in some cases is 20 to 50 years. After it is judged that future safety is ensured, responsibility will be transferred to a public organization, such as the government (Figure 1.3.3-4).

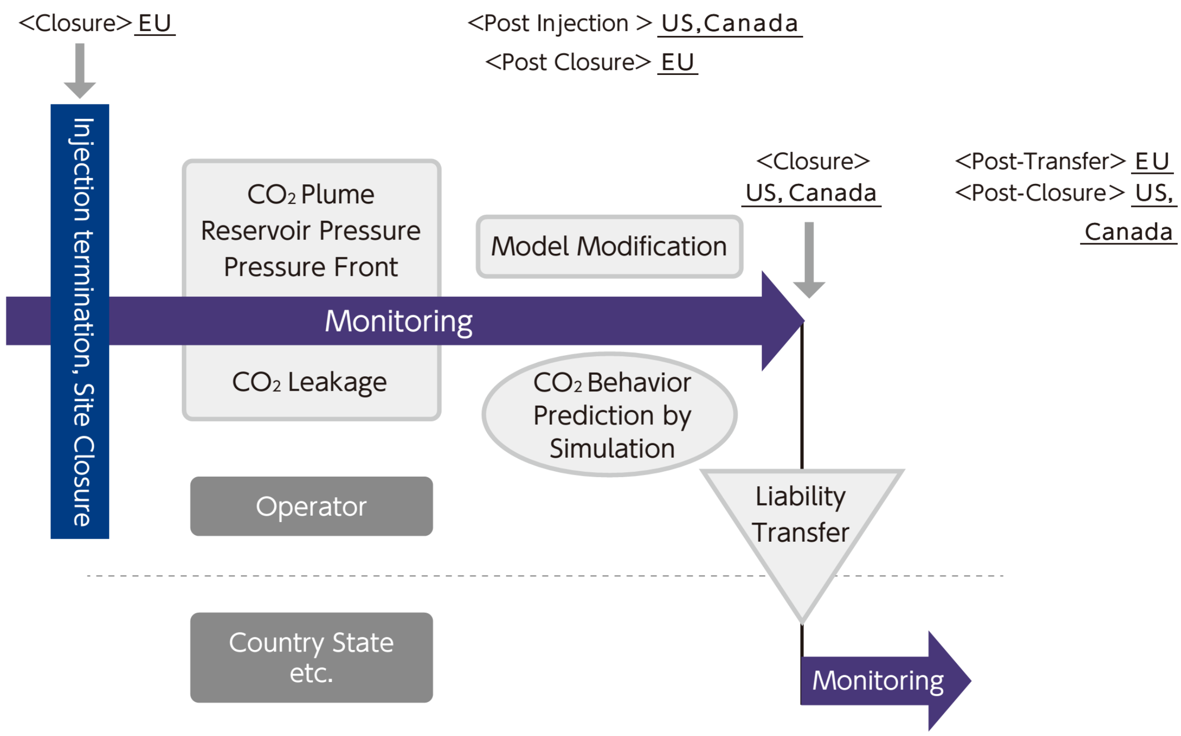


Figure 1.3.3-4 General post-closure flow of a CO_2 underground storage project

It is believed that many countries, including Japan, will enact legislation for post-closure care. The longer the duration, the greater will be the impact of post-closure care costs on the economics of the project. Therefore, during master planning, a project operator's care obligations, financial obligations, and site care period after completing the injection must be understood, and at the same time, it is desirable to consider the course of action for cost reductions, such as a request to the relevant regulatory authorities to shorten the care period.

1.3.4 Relevant legislation

(1) Current situation of relevant legislation

Master planning must investigate and cover the relevant legislation for the project. Careful study is required, since the relevant legislation ranges widely from that directly related to project implementation to geological surveys, facility construction, and environmental regulations. Applications for approvals and permits related to such legislation are filed with accompanying relevant documents, such as the implementation plan and the environmental assessment report, at the time the site characteristics are evaluated and after preparation of the implementation plan. Numerous procedures to use land and ocean areas are required in accordance with laws even for surveys and construction of facilities on roads, farm land, in the neighborhoods of public facilities, ports and harbors, etc. Such compliance with the relevant legislation is required to the end of the project, which is a long period of time. Therefore, it is crucial to organize information such as the format and timing of the documents for submission when developing the master plan, so that legal procedures, including preparation of documents to submit, can be smoothly undertaken and approvals and permits can be acquired in a quick and efficient manner.

Legislation related to a CCS project and practical guides and international standards (ISO) for CCS projects in various countries are shown in Table 1.3.4-1. In 2010, the U.S. Environmental Protection Agency (EPA) added well class (class VI) for CCS projects to the Underground Injection Control (UIC) program, which regulates liquid injections in order to prevent contamination of a potable groundwater source under the Safe Drinking Water Act. In addition, the European Union (EU) adopted the CCS Directive (DIRECTIVE 2009/31/EC) in 2009, which is the basis of the regulatory framework for CCS implementation in the EU's member countries.

There is also an international convention, the London Convention, which regulates dumping at sea, etc. with the aim of preventing marine pollution. The 1996 protocol permitted dumping of some materials, and the 2006 amendments allowed CO_2 storage in geological formations below the seabed, which became effective in 2007. In response to this, the Ministry of the Environment in Japan amended the Prevention of Marine Pollution and Maritime Disaster law (hereinafter referred to as the "Marine Pollution Prevention Law") to prepare for the storage of CO_2 beneath the seabed, and a guideline for project application procedures has been issued. Attention must be paid to the fact that the legal framework for the transfer of responsibility after a site closure has not yet been established in the Marine Pollution Prevention Law.

In addition, establishing international standards by ISO for CCS projects has also been discussed. ISO 27914:2017 for CO_2 storage in deep underground saline aquifers covers the life cycle of underground storage, except for the post-site closure care period. ISO 27916:2019 for CO_2 storage associated with CO_2-EOR (enhanced oil recovery) operations is also being discussed, but it is not included in the table below. Standards are listed herein only for those phases of actual operations (including equipment, facility designs, and construction), with a focus on CO_2 storage, except for petroleum exploration and development elements.

Table 1.3.4-1 CCS project legislation, international standardization, and practical guides

Country、Area	Regulation、Standard		Guideline etc.
International	ISO	ISO 27914:2017	International standards have been issued for safe and effective implementation of all phases of the CO_2 geological storage from ISO / TC265
US (Environment Protection Agency, EPA)	Underground Injection Control Program Class VI well		・Area of Review Evaluation and Corrective Action Guidance ・Financial Responsibility Requirements and Guidance ・Plugging, Post-Injection Site Care, and Site Closure Guidance ・Project Plan Development Guidance ・Site Characterization Guidance ・Testing and Monitoring Guidance ・Construction Guidance etc.
EU	DIRECTIVE 2009/31/EC		・GD(Guidance Document)1：CO_2 Storage Life Cycle Risk Management Framework ・GD2：Characterisation of the Storage Complex, CO_2 Stream Composition, Monitoring and Corrective Measures ・GD3：Criteria for Transfer of Responsibility to the Competent Authority ・GD4：Article 19 Financial Security and Article 20 Financial Mechanism
Japan (Ministry of the Environment)	Law Relating to the Prevention of Marine Pollution and Maritime Disaster and Related Laws and Ordinances		Guideline for Application of CO_2 offshore Storage Permit

(2) Approval/permit timing

In response to relevant legislation, various approvals, permits, and notifications are required in each phase (Figure 1.3.4-1). In the case of Japan, applications for approvals, permits, and notifications are required for elastic wave explorations or drilling exploration wells when evaluating site characteristics, in accordance with the Mining Act and the Mining Safety Act for the use of roads, farm land, etc., ports and harbors. After FID, the most important project application will be filed with the Ministry of the Environment in accordance with the Marine Pollution Prevention Law. Subsequently, applications for the construction of pipelines and injection facilities and for safety screening at the commencement and termination of operations will be required. Since there are no rules for the transfer of responsibility as previously mentioned for post-closures, attention should be paid to legislative amendments, etc. in the future.

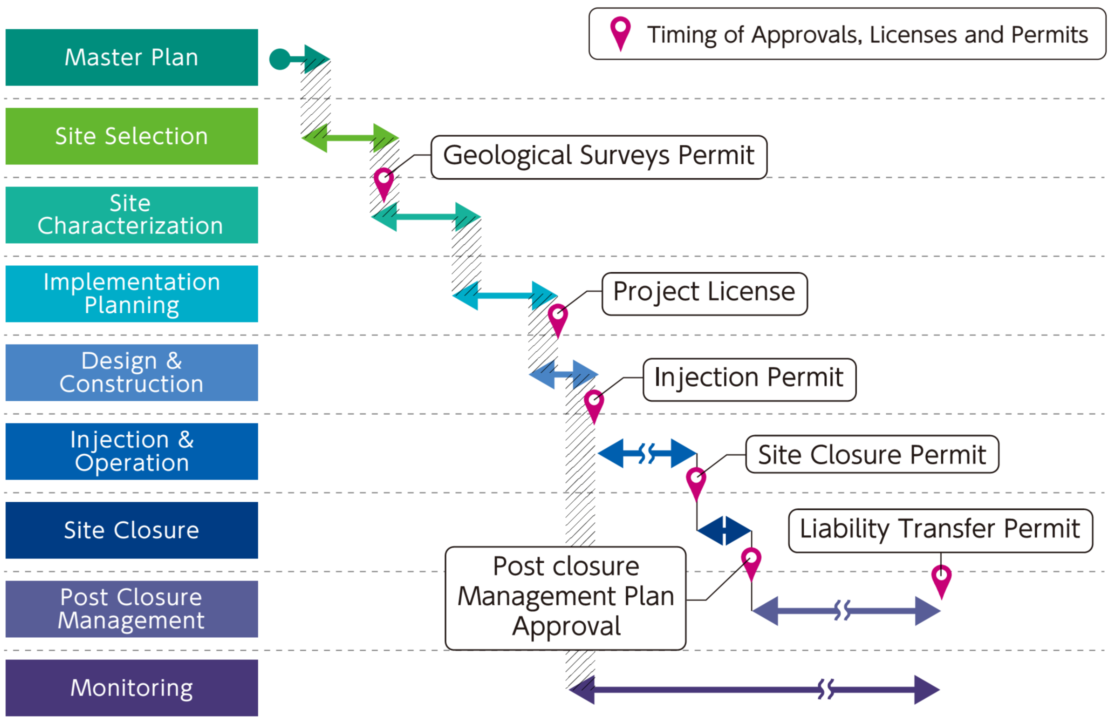


Figure 1.3.4-1 Flow of CO_2 underground storage projects and the timing of important approvals and permits

(3) Long-term legal responsibilities

Even after completing the CO_2 injection, post-closure care of the storage site must continue as part of the project. This is mainly for monitoring the behavior of the injected CO_2. In the United States and the EU, the implementation of history matching with monitoring data is also required. There are some countries, including Japan, in which the duration and subsequent transfer of responsibilities are not defined (Table 1.3.4-2).

During master planning, the project operator confirms the legal responsibilities associated with the transfer of responsibilities and the conditions, in addition to the care period and compulsory tasks, including monitoring, and the project operator must also clarify its own policy. A policy for the response plan and compensation for CO_2 leakage and seepage, including the injection operation period, also has to be considered. The project operator's own resources, insurance, funds established by multiple project operators, government support, etc. are considered as sources of funds for compensation.

Table 1.3.4-2 Rules in countries for the post-site closure care period and the transfer of responsibility

Country, Area	Name of act, regulation	Regulatory agent	year	Duration of post injection site care, liability transfer
US	Underground Injection Control(UIC) Program Class VI well	EPA	2010	Site management including Monitoring, for, in principle, 50 years after injection termination. No regulation on Liability Transfer
EU	DIRECTIVE 2009/31/EC	European Commission	2009	After Years which Each Member country decided, Liability transfer to The county (in principle, at least 20 years after injection termination)
Australia	Offshore Petroleum and Greenhouse Gas Storage Act (OPGGS)	Department of Industry, Science, Energy and Resources	2008	At least, 15 years after issue of Site Closing Certificate, liability transferred to the government
Japan	Law Relating to the Prevention of Marine Pollution and Maritime Disaster	Ministry of the Environment	2007	Under discussion

1.3.5 Emission sources

(1) Location of emission sources and CO_2 transportation

From the perspective of CO_2 transportation costs, it is desirable that the CO_2 emission source and the storage site are located close to each other. Storage underground around the emission source is ideal. In reality, it is often the case that a place far from the emission source is selected as a storage site due to geological requirements, etc. In the case of storage offshore or in a coastal zone, long-haul CO_2 transport is limited to transportation by pipelines or ships. In general, the greater the distance, the more advantageous shipping is (see 1.3.6-4, the current cost situation). In the case of inland sites when the storage size is not large, transportation by short-distance pipelines or tanker trucks is also considered.

(2) Composition of gas to be stored

Many countries have legal restrictions which do not allow underground storage if the CO_2 gas contains more than a certain amount of NOx, SOx, etc. During master planning, the composition of captured CO_2 must be checked. According to the Japanese Marine Pollution Prevention Law, the following is specified for CO_2 that can be injected:

- CO_2 captured by the amine absorption process
- CO_2 concentrations of 99 %v/v and above (98 %v/v and above if it is used to produce hydrogen for refining oil)
- No oil, etc. other than CO_2 is added

(3) Assumed total injection volume and injection rate

Injection-related assumed values (injection rate, injection period, and total injection volume) are the starting point of the project, including master planning. The project's economics are also roughly analyzed on the basis of these assumed values during master planning.

1.3.6 Economics

(1) CCS project's economic analysis

Figure 1.3.6-1 schematically shows the CCS project model (ZEP, 2014), and we can see that the overall project has a long life cycle and long expenditure period. Additional costs may also be incurred from an abnormal or emergency situation occurring during the period up to the transfer of responsibility after commencement of injection operations. A CCS project operator must perform economic evaluations and judge whether to carry out the project based on a long-term perspective of several decades.

In the economic analysis of a CO_2 storage project, there will be large fluctuations in costs associated with injection equipment (onshore and offshore) and transportation (pipelines and ships). It is difficult to perform highly accurate, specific economic analysis in the master planning phase, but it is desirable to perform economic analysis on the basis of a rough estimate and to determine the appropriate budgetary ceiling (e.g., offshore equipment is not allowed, there are limits on pipelines, etc.). Ultimately, the evaluation will be performed at the stage in which all the latest data, including costs, are available in the implementation planning phase.

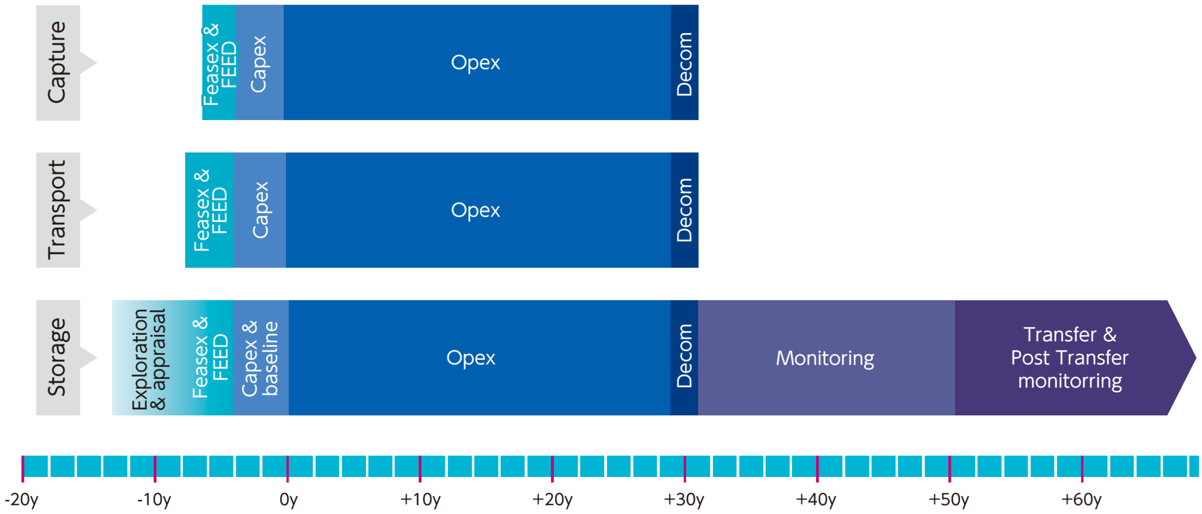


Figure 1.3.6-1 Expenditure period of a CCS project (partially revised ZEP, 2014)

(2) CCS project costs

CCS project costs can be broadly divided into costs associated with CO_2 capture at the emission source, CO_2 transportation to the injection site, underground storage in the injection site, initial capital investment, operations, and removal of equipment after the project ends. For underground storage, costs associated with surveys and evaluations for the initial capital investment and site care costs after the removal of equipment, etc. are added. It will be necessary to show in the master plan the outline of costs in each phase and to clarify factors causing increases. For example, the following items are cited as costs associated with CO_2 transportation and underground storage:

- CO_2 transportation costs using pipelines
  - Route selection
  - Conceptual design, basic design, and detailed design
  - PO and PA-related

- Purchase of materials and equipment, such as pipes
- Construction
- Operations
- Closure
- Approval and permit application-related procedures

● Storage costs

- Geological surveys (elastic wave exploration, drilling of an exploration well, various lab tests, geological evaluations, etc.)
- Conceptual design, basic design, detailed design for injection equipment
- Initial investment (drilling of an injection well, construction of injection/monitoring facilities, etc.)
- PO and PA related
- Baseline monitoring before injection
- Operations (including monitoring)
- Site closure
- Post-site closure monitoring
- Financial obligations associated with the transfer of site responsibility (monitoring costs, etc. after transfer)
- Expenditure for risks and the burden of liability and insurance
- Approval and permit application-related procedures

Among the above, transportation costs can change significantly depending on whether it is by pipeline or ship. For storage, costs will be added if an elastic wave exploration or drilling of an exploration well is required during site evaluation. Reservoir capacity and injection capacity per well is reflected in the total number of injection wells. If equipment is installed offshore, equipment and operating costs will be higher than if onshore. The current cost situation is described below.

● CO_2 capture costs

If the emission source is identified, costs associated with separation and capture can be estimated according to the technology level at that point. IPCC (2005) has consolidated study cases (2000–2005) on CO_2 capture costs with the chemical absorption method as follows:

- For new coal-fired power generation: US$29 for 51/t-$CO_2$

・For existing coal-fired power generation: US$45 for 73/t-$CO_2$

・For new natural gas-fired power generation: US$37 for 74/t-$CO_2$

RITE (2005) estimates domestically assumed CO_2 capture costs* as follows:

・For new coal-fired power generation: JPY4,256/t-CO_2

・For existing coal-fired power generation: JPY7,752/t-CO_2

*CO_2 capture costs here include equipment and operations. Net costs exclude CO_2 emitted from the separation and capture equipment for energy consumption (CO_2 avoided cost).

● Transportation costs

Since transportation costs fluctuate substantially according to the distance and means of transport, the respective fluctuation factors that determine costs and acceptable limits of cost fluctuations, etc. are indicated at the time of the master planning. With respect to a CO_2 tanker, which is one of the fluctuation factors, the technology is being studied; although there is no experience of using a large ship. Comparing transportation by submarine pipelines and ships, and on the assumption that storage is in the British North Sea by Element Energy Limited (2018), when transporting 500,000 tonnes per year of CO_2 to an injection site 200 km or 500 km away, transportation by ship is superior in both cases.

● Storage costs

Storage costs fluctuate substantially according to the conditions at the location and the underground geological conditions, but if infrastructure for past oil and gas development and production can be converted for use, it will lead to cost reductions. During master planning, when considering the geological conditions of a target site, costs are estimated on the basis of standards at that point (the prices of materials and equipment, drilling costs, etc.) for time-fluctuation factors due to the economic climate. At the same time, it is desirable to investigate the latest database applicable to the CCS project for comparison and reference.

RITE (2013) estimated costs associated with an injection based on the conceptual design for three candidate storage sites in an offshore deep saline aquifer, (including construction costs association with the injection, operating costs, well abandonment costs, monitoring after well abandonment, etc. but excluding CO_2 capture and transportation costs). As a result, the entire storage costs of 1.5 million tonnes per year of CO_2 and 30 million tonnes in total were 22 billion yen and 31 billion yen, respectively.

ZEP (2011) indicates the range of storage costs for six cases, including a depleted oil and gas field whose old infrastructure can be used (Figure 1.3.6-2) and also shows the breakdown of average cases (Figure 1.3.6-3).

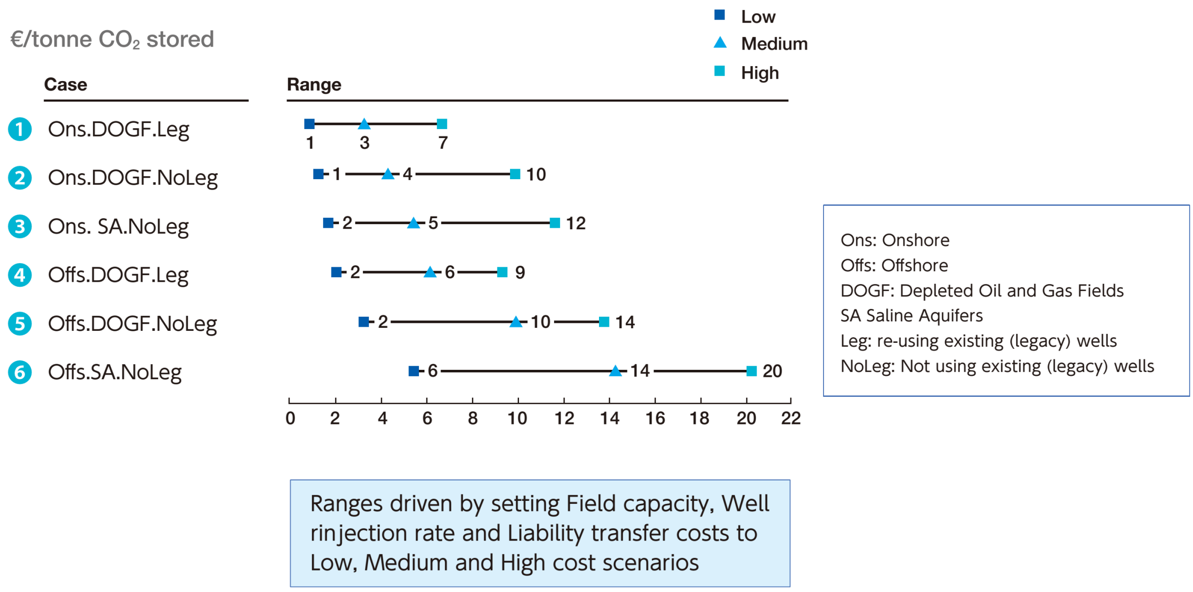


Figure 1.3.6-2 Underground storage cost range for six cases (ZEP, 2011)

Underground storage costs fluctuate substantially according to site location, type (onshore or offshore, oil or gas fields, and reuse of infrastructure), or reservoir performance (storage capacity and injection rate). In general, onshore and depleted oil and gas fields (using existing wells) are low-cost, and offshore storage is high-cost.

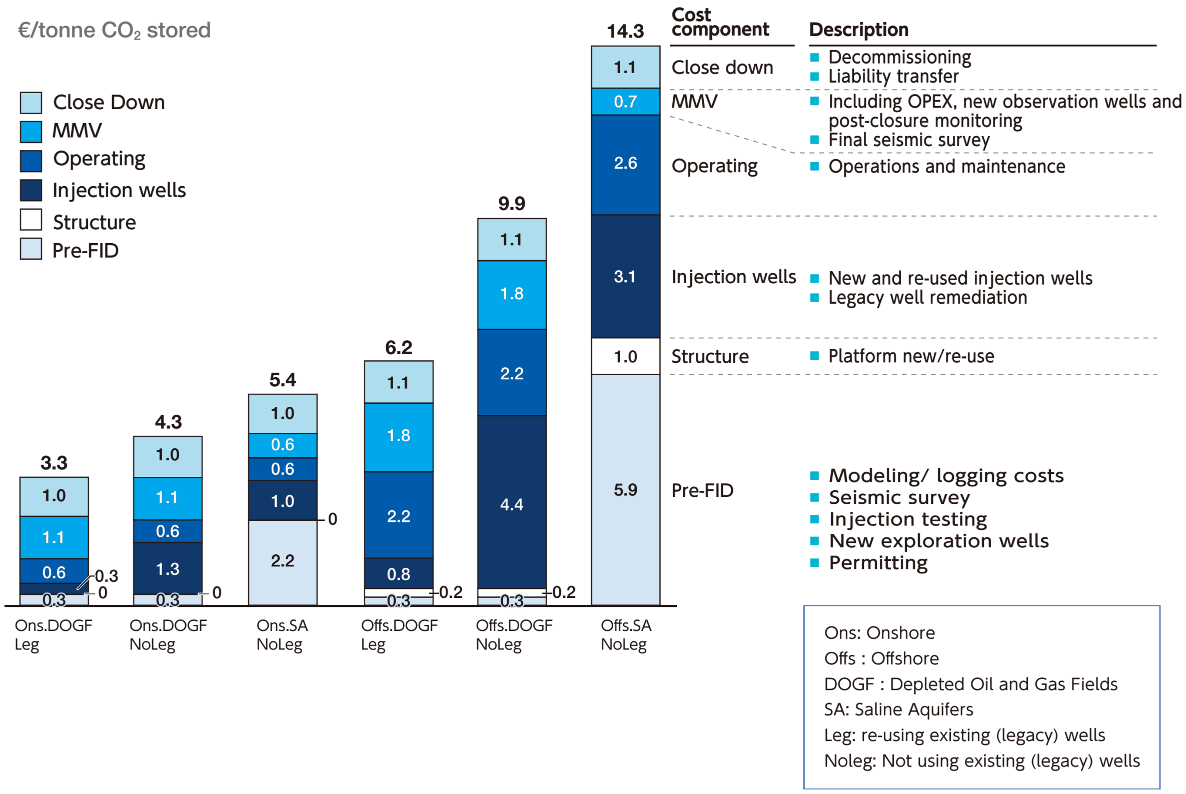


Figure 1.3.6-3 Cost breakdowns for average cases (ZEP, 2011)

(3) Financial responsibility, financing, and tax credits

Financial responsibility covers the entire project life cycle, so a sufficient financial foundation is required to cover the costs up to site closure, including injection well plugging and post-closure care. Some countries and regions impose on a project operator a financial guarantee, etc. for the execution of a CO_2 underground storage project and the monitoring after the transfer of responsibility, etc., so it is necessary to understand the current situation in the master planning phase and to clarify the basic financial policy.

The business model for CCS projects has not yet been established. There is a possibility that we can expect public grants or funding from the government, financial support in the future from the Green Investment Bank, which was established for the purpose of promoting the shift to a low carbon economy, and funds from international financial institutions, such as the World Bank and the Asian Development Bank. In addition, a business model in which part of the project costs are covered by a carbon tax, emissions trading, credit transactions, etc. is being considered. During master planning, financial support from various quarters needs to be aggressively investigated while conducting the project's economic evaluation.

There are tax credit movements for CCS in some countries. In the United States, tax credits for promoting a CCS project along with CCUS (CO_2-EOR) have been offered. Project funding for a CO_2 underground storage project is covered, as with other projects, with equity finance through stock issuance by the project operator, which carries no repayment obligation, plus debt finance and a grant. Figure 1.3.6-4 (Zapantis et al., 2019) shows examples of financing for CCS projects currently in operation, as shown in Table 1.3.6-1.

Table 1.3.6-1 CCS projects currently in operation

Air Product SMR	CO_2 associated with steam methane reformer (SMR) for production of H_2 and CO is transported to oil fields for CO_2EOR.
Illinois Industrial	CO_2 emitted by bio-ethanol production is stored 1mill.ton/y in deep saline aquifer under plant site.
Boundary Dam	CO_2 emitted from power plant transported via 100km pipeline to EOR oil fields and geological storage site.
Quest	CO_2 emitted by production of hydrogen for up-grading of bitumen from oil sand is transported via 84km pipeline to injection site for geologic storage
Petra Nova	CO_2 emitted from coal-fired power plant transported via 130km pipeline to oil field for EOR.

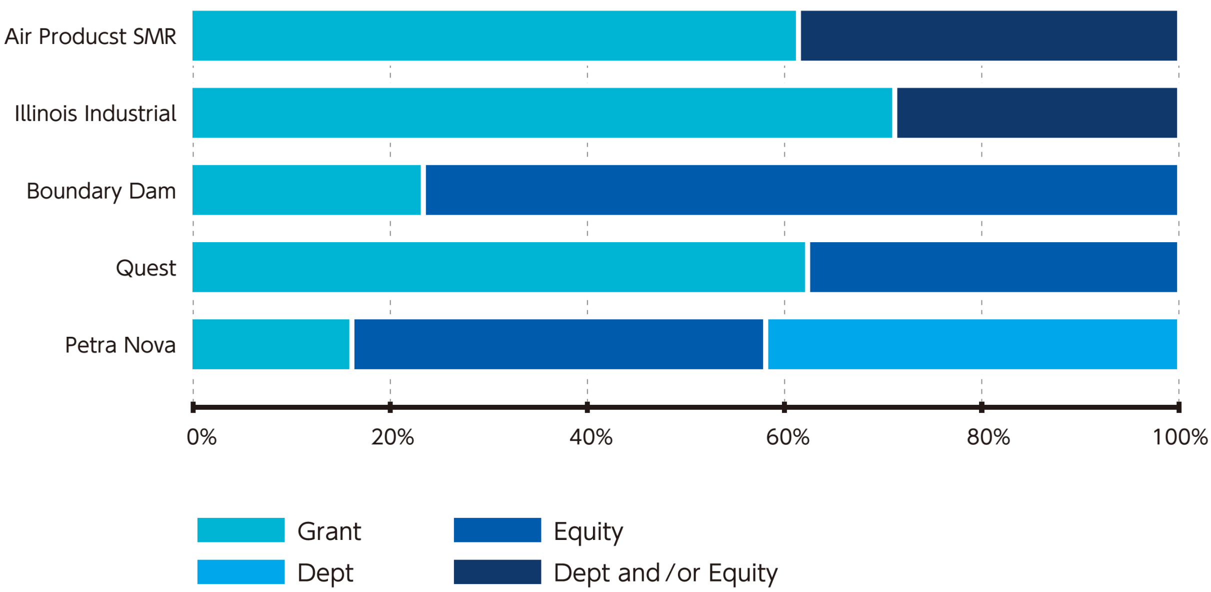


Figure 1.3.6-4 Financing of the projects shown in Table 1.3.6-1 (Zapantis et al., 2019)

(4) Overseas CCS project cases

1) The QUEST project case

In the Quest CCS Project in Canada, in which the CO_2 injection started in September 2015, actual construction work costs and annual operating costs are being disclosed. This project is to recover bitumen (blackish brown viscous heavy oil) from the oil sands in Alberta and to store underground the CO_2 emitted in the (upgrade) process of producing synthetic crude oil by adding hydrogen to the bitumen. The project plans to inject CO_2 through three wells at a rate of one million tonnes per year for 25 years by transferring CO_2 through a pipeline from the synthetic crude oil production plant, which is the CO_2 emission source, to the storage site situated 65 km away. The reservoir is composed of Cambrian sandstone rock at depths greater than 2,000 meters, and multiple shielding layers have been developed. This project's construction costs figures, supplied by Shell Canada (2016), are shown in Table 1.3.6-2.

Table 1.3.6-2 Quest CCS construction costs (Shell Canada, 2016)

Item		Cost at Completion
Capture Facilities	Can$	465.4 Million
Pipeline	Can$	124.7 Million
Storage/Wells	Can$	42.9 Million
Owner's Cost	Can$	157.6 Million
TOTAL COST	Can$	**790.6 Million**

Maas (2017) discloses the cost per tonne of CO_2 at Quest in 2016 in Table 1.3.6-3.

Table 1.3.6-3 Quest's CCS costs per tonne of CO_2 for 2016 (Maas, 2017)

Capture	Annualized CAPEX Annual OPEX	Can$	41.20 26.22	million
	Total		67.42	
Transportation	Annualized CAPEX Annual OPEX	Can$	8.97 0.35	million
	Total		9.32	
Storage	Annualized CAPEX Annual OPEX	Can$	7.42 3.62	million
	Total		11.04	
	Total CAPEX + OPEX	Can$	87.79	million
	Annual CO_2 Captured		1.11	million tonnes
	Annual CO_2 Avoided		0.95	million tonnes
	Reported Cost/Tonne Captured Reported Cost/Tonne Avoided	79.24 Can$/tonne 92.70 Can$/tonne		63 US$/tonne 74 US$/tonne (0.8 US$/Can$)

Cost per tonne of CO_2 avoided is shown in Table 1.3.6-4 by separating these values into capture, transport, and storage.

Table 1.3.6-4 Cost per tonne of CO_2

	Can$/ton (avoided)	US$/ton(avoided) (0.8 US$/Can$)
Capture	71.0	56.8
Transportation	9.8	7.8
Storage	11.6	9.3

According to McFadden (2013), this project's total costs amount to CAN$1.35 billion, which includes costs before FID, such as various evaluation costs and the initial investment and operating costs for ten years.

In comparison, Shell Canada (2018) discloses past results up to 2017 and forecasts and budgets up to 2025 in Table 1.3.6-5. Total combined income and expenditure of CAN$1.38 billion is almost on par with the aforementioned total costs.

Table 1.3.6-5 Quest Project's total income and expenditure and future expected income and expenditure (Shell Canada, 2018)

Can$

~2015 (Construction)	Funding/Grant from State and Federal	573.3 Million
2016 (Operation)	Funding/Grant from State and Federal CO2 reduction credits	29.5 Million 3.3 Million
2017 (Operation)	Funding/Grant from State and Federal CO2 reduction credits	30.1 Million 36.4 Million
2018 to 2025 Aggregate Revenues Forecast	Funding/Grant from State and Federal CO2 reduction credits	238.4 Million 465.6 Million

The CO_2 reduction credit is assumed to be CAN$30 per tonne of CO_2 based on the 2017 results (CO_2 storage volume equivalent to 1,212,182 tonnes) and CAN$60 per tonne of CO_2 from 2018 onward. The government's financial burden is considered to be CAN$865 million. And according to the contract, the federal government and the Alberta Provincial Government will bear CAN$120 million as the cost before FID and CAN$745 million for the construction and operating costs for ten years.

2) The Sleipner case

In the Sleipner Gas Field in the Norwegian North Sea, CO_2 contained in extracted natural gas has since 1996 been captured by the existing platform and then injected for storage into a deep saline aquifer above the gas-producing horizon. The accumulated storage volume by the end of 2014 totaled 15 million tonnes (Skalmeraas, 2014). This is a somewhat special case, since much geological information was obtained during the development of the gas field, and gas production-related existing facilities have been effectively used. The published CCS-related costs are shown in Table 1.3.6-6.

Table 1.3.6-6 CCS-related costs in Sleipner (Torp and Brown, 2005)

	US$
Preparation works ・3D seismic survey ・Coring and well logs ・Reservoir simulation	 0.4 Mill. 1.4 Mill. 0.1 Mill.
Compressor train (4 units)	79 Mill.
Injection wells drilling and completion	15 Mill.
OPEX per year	7 Mill.

3) The Boundary Dam case

The total cost and financing of the world's first large thermal power generation-CCS project, the Boundary Dam (including the power generation plant) in Canada, are shown in Table 1.3.6-7 (Bassi et al., 2015).

Table 1.3.6-7 Total costs and financing of the Boundary Dam project (Bassi et al., 2015)

Project cost		€ 1,028 Mill.
Funding	Equity (SaskPower)	€ 258 Mill.
	Debt	€ 601 Mill.
	Federal grant	€ 168 Mill.

1.3.7 Uncertainty of CCS projects

CCS projects have a short history, and neither project operators nor society has yet accumulated sufficient experience, so uncertainty, such as environmental changes, is considerable. By analyzing the uncertainties in the technical and non-technical elements of the CCS project, Markusson et al. (2011) show these elements are closely related and interlocked to constitute uncertainty in the entire project and are an influence on the project's future (Figure 1.3.7-1). A project operator must pay particular attention to the safety of the reservoir, the project's economics, and public acceptance, but the national political effect on the project's economics and public acceptance is considerable. Uncertainties about legal regulations lead to social distrust towards CCS projects; conversely, a robust policy and legal regulations lead to support for CCS. The relationship between economics, finance, and national policy is also the same, and financial support by the government directly links to a CCS project's economics. Conversely, future uncertainties about economics affect project decisions.

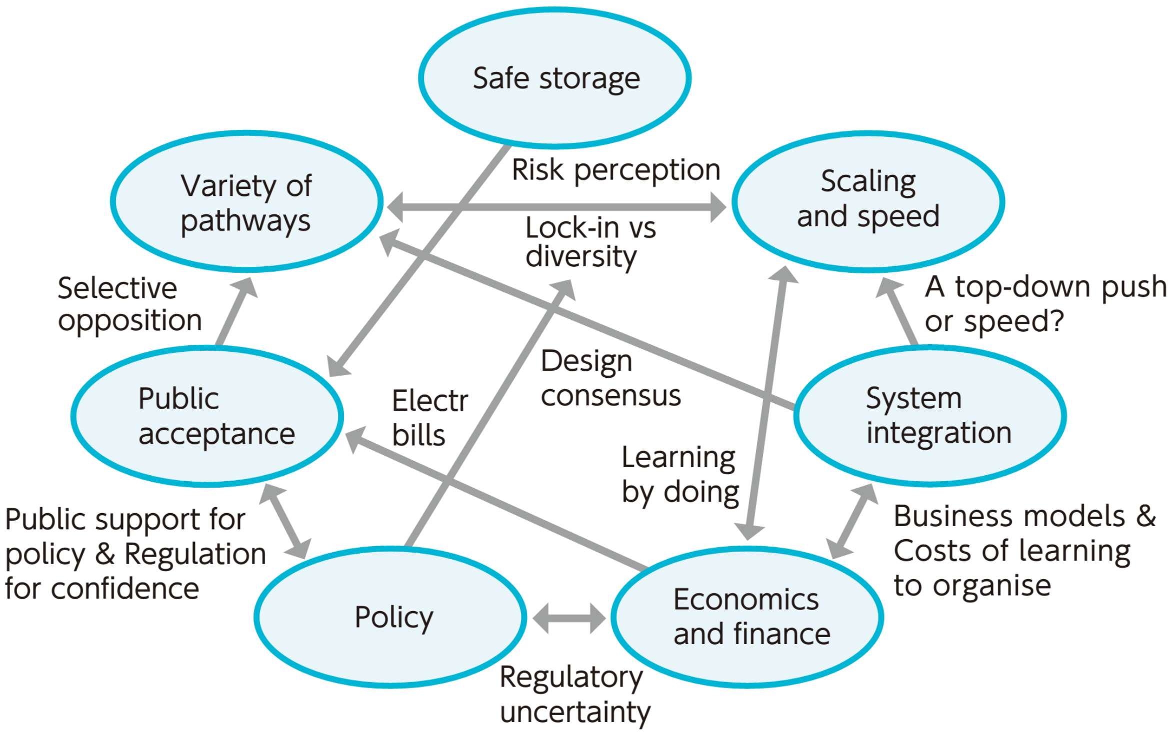


Figure 1.3.7-1 Correlations among CCS-related uncertainties (Markusson et al., 2011)

Even if an adequate survey of the geological elements is conducted, geological uncertainties originating from the heterogeneity of the reservoir cannot be eliminated. However, this uncertainty is believed to be reduced by monitoring, etc. after the start of an injection (Figure 1.3.7-2).

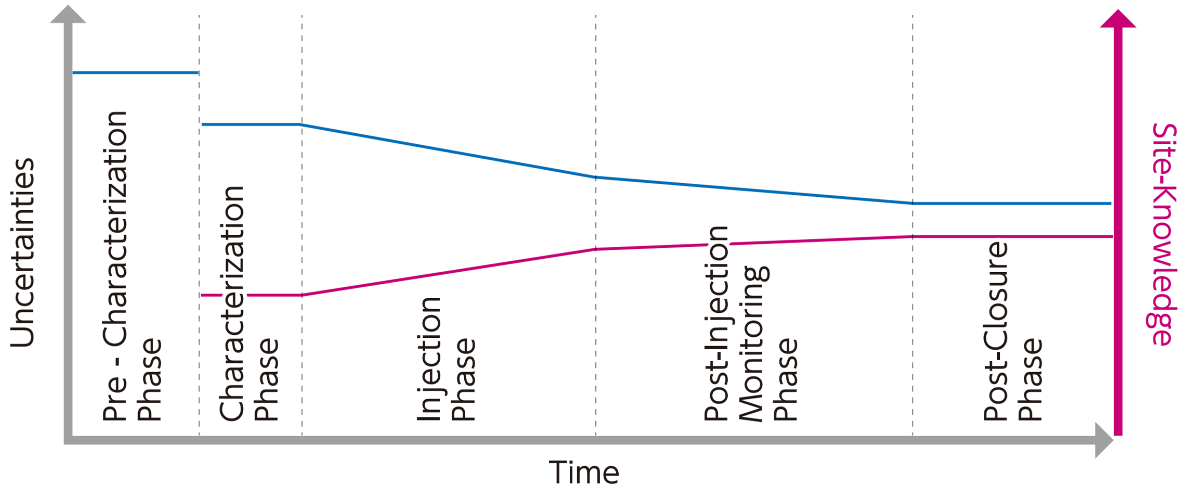


Figure 1.3.7-2 Qualitative changes in uncertainty over time for a CO_2 storage site (Pawar et al., 2015 was partially revised)

A project operator must also consider contingency plans for geological uncertainties and public acceptance in addition to making an effort to mitigate the project's uncertainty through operating activities.

(1) Geological uncertainty

The Snøhvit offshore storage project in Norway changed its injection layer to an upper depleted gas reservoir due to an unexpected pressure increase in the reservoir. Snøhvit Gas Field started production in 2007, and 3–8% of the CO_2 present in its natural gas was injected into a lower sand stratum (Jurassic Tubåen Formation) rather than the gas-producing stratum. The initial plan anticipated a 30-year operation of 2,000 tonnes per day, with CO_2 injection totaling 23 million tonnes. The subject layer has the best sandstone properties and is favored by 20% porosity and permeability reaching 12 darcys, but its sedimentary environment changes dramatically from delta formation to river formation. The reservoir quality greatly varies horizontally and vertically with lithological changes, so it has strong heterogeneity.

All kinds of monitoring activities were conducted while CO_2 was injected. As a result of simulations based on the improved model, the Tubåen Formation was judged to not have sufficient storage capacity at 8–15 million tonnes and a geopressure increase of 50 bars. Consequently, CO_2 injection into the Tubåen Formation was aborted in April 2011, and the project was changed to an upper depleted gas reservoir; the injection is still proceeding smoothly (Pawar et al., 2015).

The plan had to be changed for this project because lithological changes in the reservoir were drastic with a lack of lithological continuity, and evaluation of the reservoir's heterogeneity could not be fully reflected in the geological modeling (Hansen et al., 2013). This case indicates the need for a contingency plan that selects an alternative reservoir in case of geological uncertainty.

(2) The Uncertainty of PO and PA factors

The Barendrecht project in the Netherlands was a demonstration project by an oil company with government sponsorship. Despite government approval being granted through the environmental impact assessment procedure, the project was dropped after encountering subsequent strong opposition from the municipality and local residents living in the area of the planned storage site. One could argue that this case could have been avoided by sufficient PO and PA activities at a much earlier stage of the project.

(3) Budgetary responses

A contingency plan should also be guaranteed in terms of the budget in order to respond to technical uncertainties and unforeseen circumstances due to natural disasters, etc. Although the project was not executed, the oil giant Shell performed economic analysis of the Longannet to Goldeneye offshore CO_2 storage project in the U.K. (CO_2 was to be captured in the Longannet thermal power plant for injection into the Goldeneye depleted offshore gas field), and it allocated a contingency plan cost of US$301.9 million (equivalent to 15% of the initial investment of US$1,775.5 million) (Scottish Power CCS Consortium, 2011).

1.3.8 Risk management

(1) Risk management of an entire CCS project

1) The purpose

As with general projects, it is important to support decision-making for project promotions and project executions and to ensure health and safety, security, regulatory compliance, public acceptance, and environmental protection. During master planning, a basic policy for the risk management plan that suits the needs in each phase must be developed.

2) The process

The risk management process is shown in Figure 1.3.8-1, with work details outlined below.

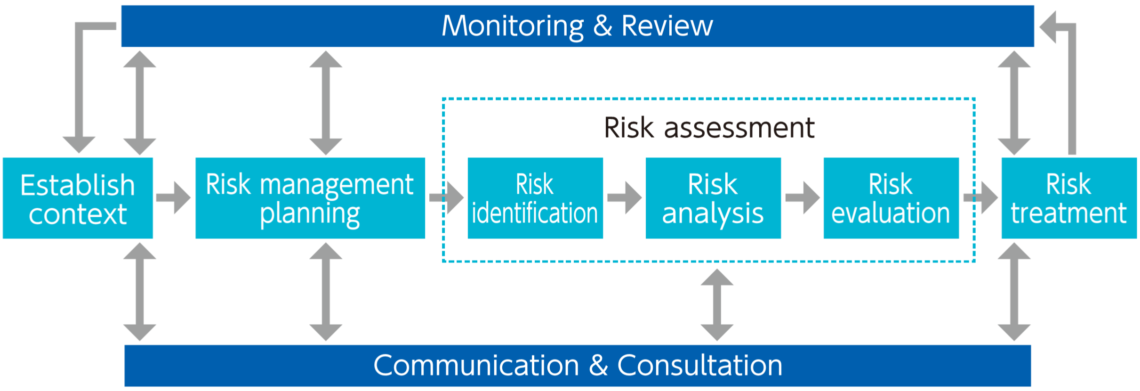


Figure 1.3.8-1 Risk management process

3) Understanding the situation

Risk is affected by both environmental changes surrounding the project and the project's progress. ISO (2017) recommends understanding the following elements in risk management:

- The natural environment and disasters
- Regional natural resources and activities
- Infrastructure and equipment
- The social, political, and economic situation
- The policy and regulatory situation
- Successful examples of effective risk management
- The project executor and subcontractors, their functions, responsibilities, division of accountability, and their respective interrelationships on risk management
- Project phases and the timing of decision-making, and their timescales

4) Development of risk management plans

A project executor must develop and implement a risk management plan that is suitable for promoting the project. When developing a risk management plan, it is necessary to discuss it with regulatory authorities and stakeholders.

5) Risk assessment

Risk assessment determines the performance requirements for the risk response, so its rigor depends on the available information and the level of knowledge in the risk scenario. The risk assessment becomes generally more detailed as the risk management process is repeated.

a) Risk identification

Risk identification requires a comprehensive understanding of various events and phenomena that cause obstructions and/or delays in a project's promotion.

b) Risk analysis

Risk analysis is the study of the probability of something happening and the impact when it happens. The results of risk analysis support decision-making for the risk response and therefore do not automatically determine the response protocol.

c) Risk evaluation

Risk evaluation determines the priority of risks that should be reduced. The method of evaluating risk is to use a 2D risk map (Figure 1.3.8-2) that shows the probability of risks and the size of their impacts from data acquired through risk analysis.

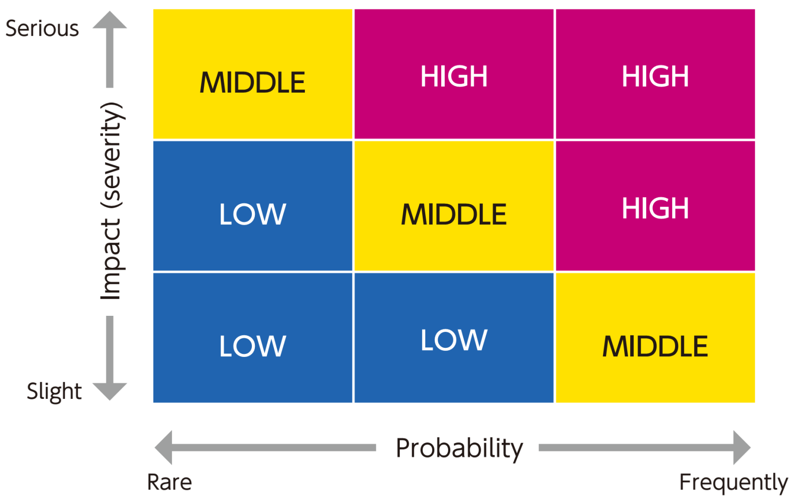


Figure 1.3.8-2 Conceptual risk map

6) Risk response

Risk response requires that after a response protocol is implemented, checks are performed to confirm if expected changes in risk have occurred. If it is insufficient, then whether to add or change a protocol needs to be considered in order to continue reducing risks to an acceptable level. In addition, when considering an option for a protocol, it is desirable to examine in detail each stakeholder's receptivity to the impact.

7) Monitoring and review

The risk management plan, risk assessment results, and risk response plan are constantly reviewed and revised, as appropriate.

8) Communication and discussions

Risk communication and discussions are conducted according to target parties and situations. Prompt and careful responses are particularly important.

(2) Risks of CO_2 leakage or seepage and induced seismicity

1) Leakage and seepage

It is assumed that if there is leakage or seepage of CO_2 to shallower strata, atmosphere, or seawater from the reservoir, it will have an impact on residents, the ecosystem, and the groundwater or other resources. These risks are considered to be infinitesimally small because of appropriate site selection and proper operation of it. But these risks should be assessed as potential risks in light of the degree of the impact and from the perspective of PA and because such assessments are required by the Marine Pollution Prevention Law.

A detailed risk management plan is generally developed in the implementation planning phase, but since this risk affects storage safety, it must be examined at an earlier stage and should be strongly reflected in the site selection and evaluation of the site's characteristics. For instance, selecting a site while trying to avoid leakage and seepage routes as much as possible, as proposed by the IPCC (2055) (Figure 1.3.8-3), will lower the probabilities in the aforementioned risk map. In the monitoring plan to be developed during implementation planning, it is also possible to further reduce impacts in the risk map through early detection of abnormalities and response protocols, taking into account the leakage and seepage routes that are assessed in greater detail.

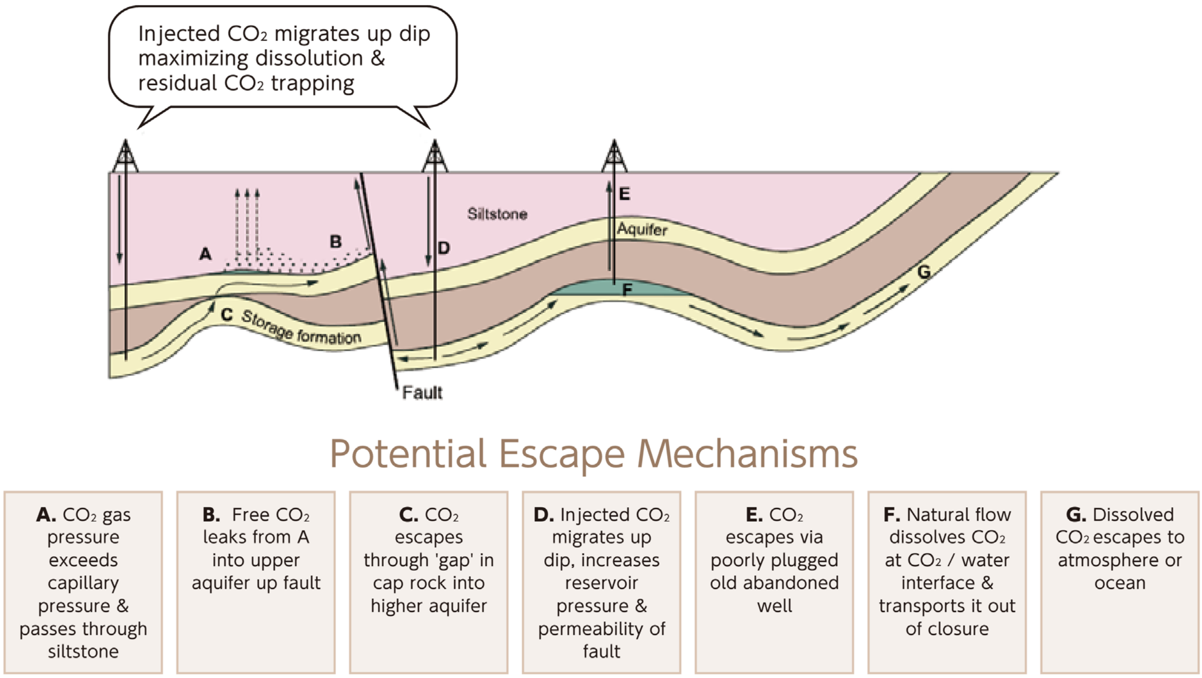


Figure 1.3.8-3 Possible leakage and seepage routes of CO_2 injected into a deep saline aquifer (IPCC, 2005)

Even after commencement of injection operations, it is still desirable to periodically update risk evaluations on the basis of the results of monitoring CO_2 underground behavior and modified predictions of the long-term behavior, and this may lead to reduced monitoring work and costs in some cases.

2) Induced seismicity

Obvious induced earthquakes, including noticeable tremors, have been reported in geothermal developments (especially ESG) and shale resource developments. It may be argued that such layers targeted for injection are inherently those geological layers in which induced earthquakes are easily triggered by fluid injections, as their porosity and permeability are low and natural cracks develop. On the other hand, reservoirs targeted for CO_2 underground storage comprise geological layers in which fluids enter easily and in which induced earthquakes are unlikely to occur because of the high porosity and permeability. In fact, no induced earthquakes beyond micro tremors have been reported in underground storage sites. However, there have been cases in which small earthquakes occur when injecting pit waste water into reservoirs similar to those used for underground storage. As is the case in CO_2 leakage and seepage, induced seismicity should be assessed as a potential risk by taking into account the degree of impact and from the perspective of PA.

The common perception of the mechanism of induced earthquakes associated with CO_2 injections is that an increase in pore fluid pressure in a reservoir lowers the effective constraint stress acting on the existing fault surface, leading to reactivation of the fault. Therefore, as is the case with CO_2 leakage and seepage, the following leads to a reduction of risk during site selection: avoid a large fault or one that would be an easy-to-move active fault that may cause an induced earthquake; and select a reservoir with enough storage capacity in which an increase in pressure is unlikely to happen, assuming propagation of pressure in a fault. During implementation planning, risk mitigation is considered to be possible by adopting a monitoring plan that aims to detect micro earthquakes and also the Traffic Light System (TLS), which is the safety management system for injections based on the monitoring plan. These assume the potential presence of small faults that cannot be identified by elastic wave exploration, etc. in addition to the injection plan in which an increase in pressure is suppressed during operations.

1.3.9 Views on PO and PA

Society as a whole is still largely unaware of CO_2 underground storage, although Japan also has a record of a demonstration project in Tomakomai and there are large CCS projects in the United States, Canada, and Norway. Non-technical activities such as public outreach (PO) and public acceptance (PA) for CCS technology commercialization are also important. In light of the fact that since the late 2000s there have been cases in which projects have been delayed or aborted because of failures to obtain the understanding of local communities (such as the European CCS Demonstration Project Network, 2012, Feenstra et al., 2010), the following common beliefs are forming for PO and PA:

- Those targeted for PO and PA as well as stakeholders, have diverse backgrounds, value judgments, and awareness of problems. A case-by-case approach, including challenges inherent in storage sites, is required.
- PO and PA activities are also called public involvement and public communication. Instead of providing information unilaterally from a project operator to stakeholders, including residents, it is important to foster a relationship through both parties' involvement and participation.
- It is desirable to start PO and PA activities aimed at a wide range of potential local stakeholders (educational institutions, media, general residents, and relevant vendors) who are not directly related, as early as possible in the master planning phase while no concrete plan has been finalized.

U.S. NETL (2013) recommends its framework as shown in Table 1.3.9-1, assuming PO activity from the initial phase of a CO_2 storage project.

Table 1.3.9-1 PO framework (NETL, 2013)

Integrate Public Outreach with Project Management
Establish a Strong Outreach Team
Identify Key Stakeholders
Conduct and Apply Social Characterization
Develop an Outreach Strategy and Communication Plan
Develop Key Messages
Develop Outreach Materials Tailored to the Audiences
Actively Oversee and Manage the Outreach Program throughout the Life of the CO_2 Storage Project
Monitor the Performance of the Outreach Program and Changes in Public Perceptions and Concerns
Be Flexible – Refine the Outreach Program As Warranted

(1) Stakeholder identification

PO activity starts with the identification of key stakeholders. As previously stated, as long as public awareness of CCS is low, various activities to enhance awareness and educate are also required with the aim of securing the community's understanding and approval for CCS, including CO_2 underground storage. A wider range of general citizens who can be potential stakeholders should be targeted in addition to the direct stakeholders in the project (residents and local municipalities around the storage site). In these activities, one should also be conscious of the media, intellectuals, and influential key persons (opinion leaders). Although the site is not officially decided on during the master planning phase, identifying direct and indirect stakeholders and organizations and promptly commencing PO activities leads to smooth progress of PA activities in subsequent phases after deciding on the site. Examples of domestic stakeholders are shown in Table 1.3.9-2.

Table 1.3.9-2 Examples of domestic stakeholders in a CCS project

Onshore	Offshore
Pore space owner	
Regulatory agency	
Local government at site	Local government of nearby site
Local residents	Local government of nearby site
Environmental protection group	local residents on nearby land
Land owner, Land user of nearby land	Fishery Industry
CCS Operator	
University, Research institute	
Mining right holder on site and nearby area	

(2) PO and PA activities in each phase (master planning)

The targeted purpose and details of PO and PA activities, which start from when the project concept is presented, vary in each project phase. An example of planning in the master planning phase is shown below (Figure 1.3.9-1).

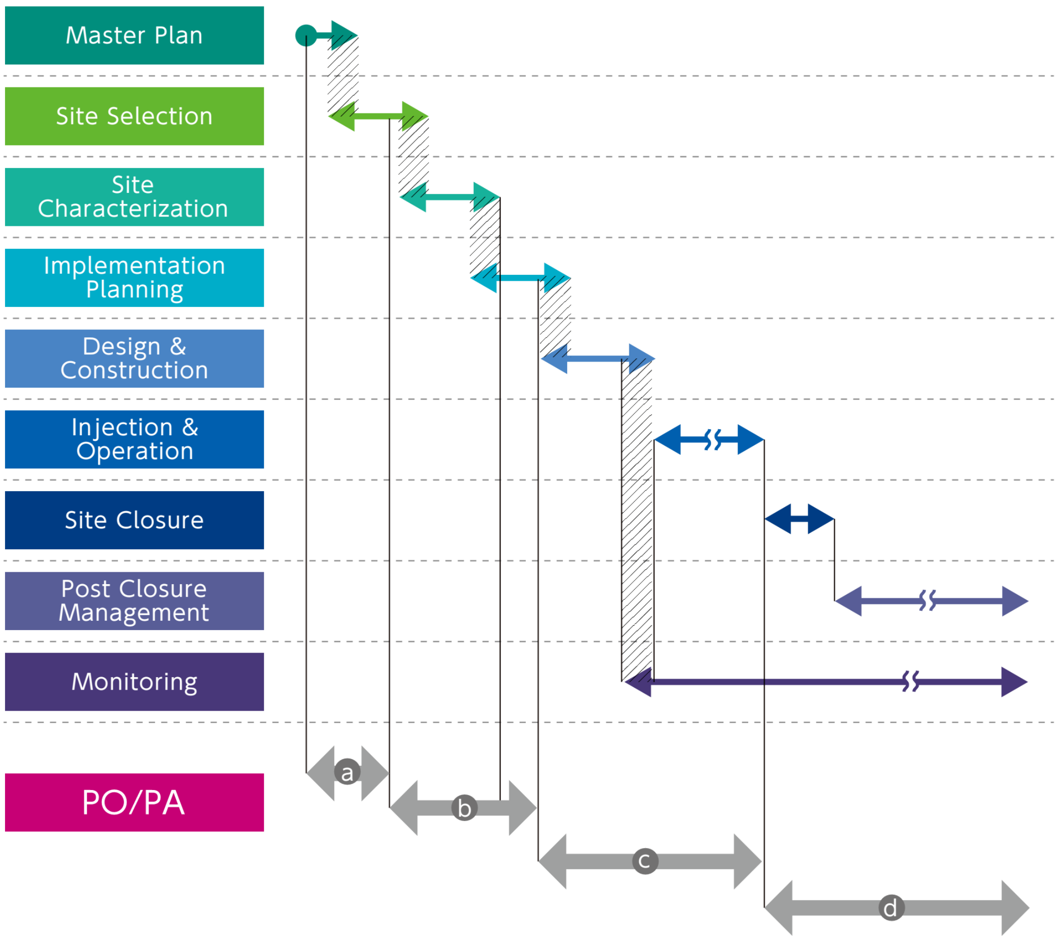


Figure 1.3.9-1 Transition of PO and PA activities in each activity phase (a, b, c, and d)

1) CCS project concept — Candidate site selection (Figure 1.3.9-1 [a])

The decision has not yet been made on the storage site, and there is insufficient information at this stage. As previously stated, improvement of CCS awareness (necessity and safety) in the general public through PO activities targeted at a wide range of stakeholders (in terms of geography and people in general) will be the main purpose. On the other hand, since the emission source has been identified, PO and PA activities targeted at stakeholders in the surrounding area can be conducted with more specific projects. Direct communication through an explanatory briefing for those who do not have expertise is an important method, but having a workshop-style briefing with resident participation is required, rather than one in which only the project operator speaks unilaterally. It may also be necessary to introduce not only the CCS project but also global warming and energy issues and various global warming mitigation technologies, etc. In addition to dialogue with residents, it is also necessary to flexibly consider use of various media and IT infrastructures, etc.

2) Work on selection of candidate injection sites — Decision on injection site — Development of implementation plan (Figure 1.3.9-1 [b])

This is the stage in which the selection of candidate sites is narrowed to some extent in the injection site selection work, PO and PA activities targeted at stakeholders around the candidate sites and those associated with the CO_2 transportation route (pipelines, etc.) are conducted, including introduction of CO_2 underground storage technologies. Subsequently, the injection site is finalized and decided upon, and a more detailed and concrete overall project plan is developed. It is also necessary to foster a relationship of trust with a wide range of stakeholders by explaining the progress.

3) Implementation plan — Project execution (Figure 1.3.9-1-[c])

PO and PA activities continue according to the project's progress, from the stage in which the concrete shape of the CCS project is being formed to the completion of the implementation plan, FID, project application, commencement and termination of operations after the project's approval. Before commencement of injection operations, more concrete and in-depth explanations are required about the risks associated with the project and how to respond to them, including materials for risk assessments submitted in the process of seeking approvals and permits and response protocols. And at the same time, the sharing of information continues to be important through interactive communication. After the start of the injection, the importance of information disclosure, such as the entire project's progress status and data on the progress of the injection and monitoring data, should be strongly recognized, and data types to be disclosed and the method of disclosure should be specifically determined during master planning.

In addition, and from the perspective of PA, monitoring for the purpose of detecting abnormalities after injection operations has significant implications in terms of confirming safety without abnormalities. Careful consideration of criteria and the baseline for judgments of abnormalities is also required to balance that with the need for smooth operations.

4) After completion of injection — Transfer of responsibility (Figure 1.3.9-1 [d])

Monitoring continues after completion of the injection and site closure. Along with the monitoring of CO_2 leakage and seepage, long-term safety is also evaluated by predicting future CO_2 behavior through confirmation of the CO_2

plume by elastic wave exploration and history matching. Project activity in this phase is limited to around the CO_2 storage site, and PO and PA activities are conducted with a focus mainly on the surrounding community. Information sharing, such as periodic disclosure of monitoring data and reconfirmation of the incident response protocol in the case of unexpected circumstances, continues to be important. Data that should be disclosed and its frequency, etc. are indicated in the master plan.

(3) Lessons learned from the failure of the Barendrecht project in the Netherlands

The Barendrecht project planned for the city of Barendrecht (population: 44,000) near Rotterdam in the Netherlands was a small demonstration project in which CO_2 captured from a hydrogen production plant (oil refinery) was to be stored in an onshore depleted gas field. The storage site was selected because of its proximity to the emission source, adequacy of the reservoir, likelihood of using the existing well in the depleted gas field, and monitoring being possible throughout the injection period (three years), etc. The environmental impact assessment was concluded in accordance with government guidelines that storage risks, noise, waste, impacts from increased traffic, etc. would be at acceptable levels for both site workers and local residents, and the authorities' approval was gained. However, the project subsequently failed to receive the support of residents, and the project was aborted. The following reasons were noted (Feenstra et al., 2010):

- Lack of resident participation in the initial stage and a lack of dialogue with the community
- Lack of consideration for local interests and an unfair bidding procedure
- Lack of information credibility and a lack of consideration for offering background information on CCS
- Lack of opportunities for unofficial dialogue

Based on the above failure, the following recommendations are made (Feenstra et al., 2010):

a. Stakeholders, including regional and local communities, should be involved in the project from an early stage in order to mutually foster a relationship of trust, and they should proceed with the project together.

b. Value judgments and requests and opinions of stakeholders and communities should be summarized and referred to when discussing the project design.
c. Any changes in the project, schedule, procedures, etc. should be discussed officially or unofficially with all stakeholders.
d. Information not only about the CCS project but also the background of domestic and overseas CCS projects, why CCS is needed, what other kinds of projects are available, and policies for handling CCS should be provided and discussed with stakeholders.
e. In the dialogue with the community, specific demands must be responded to. However, before commencing dialogue, appropriate materials and channels and officers in charge can be selected by investigating and understanding the information, including that about the community. It is assumed that the information that will be demanded is the project's technical or economic information and/or information on the environmental impact. It is necessary to understand the groups that are partners in the dialogue, such as their degree of background knowledge about CCS and a summary of the stakeholders involved (careers and their relationships with the community), and also to be aware of ongoing discussions and issues that may be related to the project.
f. PO and PA officers for the project operator (those who convey information) must first gain the community's trust. A message from an officer who does not have the confidence of the community will not be trusted.

1.4 Conclusion

CCS projects arise from the intention to inject CO_2 into an underground storage site after separating and capturing CO_2 emitted from a specific emission source. At this point, it is assumed that the location of the emission source, the assumed injection volume, and rough constraints on project costs have been clarified. Therefore, the purpose of master planning at the early stage of a project with limited information available is to summarize the goal of the project and the basic idea of how to proceed and with what kind of policy in order to realize the master plan. This will be the basis for the project operator to provide an explanation internally and to the regulatory authorities and to conduct the initial PO and PA activities targeted at stakeholders.

Large CO_2 underground storage projects have been implemented mainly by Norway (offshore), the United States, and Canada (onshore) and knowledge and know-how are accumulating, but a CCS project's economics and building a business model, etc. are issues. We would like to hold out hope for political support and public outreach for such projects in addition to technical innovations by the project operators.

References

1) Bassi, S., Boyd, R., Buckle, S. Fennell, P., MacDowell, N., Makuch, Z., Staffell, L. (2015): Bridging the gap: improving the economic and policy framework for carbon capture and storage in the European Union, The Centre for Climate Change Economics and Policy (CCCEP)
2) DET NORSKE VERITAS AS (DNV) (2013): Geological Storage of Carbon Dioxide, RECOMMENDED PRACTICE DNV-RP-J203
3) European CCS Demonstration Project Network (2012): Lessons learned from the Jänschwalde project, Summary Report, Knowledge Sharing Event Cottbus, May 2012, http://decarboni.se/sites/default/files/publications/77476/lessons-learned-janschwalde-project-summary-report.pdf
4) Feenstra, C.F.J., Mikunda,T., Brunsting,S.(2010): What happened in Barendrecht? Case study on the planned onshore carbon dioxide storage in Barendrecht, the Netherlands, Global CCS Institute, Energy Research Centre of The Netherlands, https://hub.globalccsinstitute.com/sites/default/files/publications/8172/barendrecht-ccs-project-case-study.pdf
5) Hansen,O., Gilding,D., Nazarian,B., Osdal,B., Ringrose,P., Kristoffersen,J., Eiken,O., Hansen,H. (2013): Snøhvit: The history of injecting and storing 1 Mt CO_2 in the fluvial Tubåen Fm., Energy Procedia,Volume 37, GHGT-11,2013, Pages 3565–3573, Elsevier
6) IPCC (2005): IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change. [Metz, B, Davidson, O., de Coninck, H. C., Loos, M., Meyer, L. A. (eds.)]. Cambridge University Press
7) ISO (2017): International Standard ISO 27914:2017 Carbon dioxide capture, transportation and geological storage — Geological storage
8) ISO (2019): International Standard ISO 27916:2019 Carbon dioxide capture, transportation and geological storage — Carbon dioxide storage using enhanced oil recovery (CO_2EOR)
9) Maas, W. (2017): Quest CCS Project Cost, Proceedings: CCS Cost Network 2017 Workshop, 13–14 September 2017, London, UK, IEAGHG Technical Report
10) Markusson, N., Kern, F., Watson, J. (2011): Assessing CCS viability — A socio-technical framework, Energy Procedia, 4, 5744–5751
11) McFadden, S. (2013): QUEST CCS PROJECT, IEA-GHG Symposium, Regina, Saskatchewan, May 10th, 2013,

http://www.cslforum.org/publications/documents/rome2013/McFadden-Workshop-Rome0413.pdf

12) NETL (2013): Best Practice of Public Outreach and Education for Carbon Capture and Storage, revised edition, DOE/NETL-2013/1606
13) NETL (2017): BEST PRACTICES: Operations for Geologic Storage Projects, 2017 REVISED EDITION, NETL (National Energy Technology Laboratory), DOE/NETL-2017/1848
14) Pawar, R.J., Bromhal, G.S., Carey, J. W., Foxall, W., Korre, A., Ringrose, P. S., Tucker, O., Watson, M.N., White, J.A. (2015): Recent advances in risk assessment and risk management of geologic CO_2 storage, International Journal of Greenhouse Gas Control 40, 292–311
15) RITE (2013): Trends and Challenges on Innovative Environmental Technology, RITE Today
16) RITE(2005): Year 2005 Achievement Report of the project for CO_2 fixation and effective utilization technologies/R&D on CO_2 underground storage and sequestration technologies
17) Scottish Power CCS Consortium (2011): UK Carbon Capture and Storage Demonstration Competition, SP-SP6.0-RT-15, FEED Close Out Report
18) Shell Canada (2011): Quest storage development plan, Crouch, S. (Ed.), 07-0-AA-5726-0001, pp. 296 http://www.energy.alberta.ca/CCS/StorageDevelopmentPlan.pdf
19) Shell Canada (2016): Quest CCS Project, Project Close-Out and Lessons Learned Report, January 2016, https://open.alberta.ca/dataset/67f52cd3-8dce-4f56-ad62-a00ff7948fd0/resource/729b0c09-8b46-4465-ba69-05c34453c432/download/closeoutreport.pdf
20) Shell Canada (2018): Quest Carbon Capture and Storage Project, Annual Summary Report – Alberta Department of Energy: 2017, March 2018, https://open.alberta.ca/dataset/00bafb16-6e20-407b-9752-77acec295ff7/resource/c9d793d5-2381-4508-be37-6af329828c68/download/quest-2017-annual-summary-report.pdf
21) Skalmeraas, O. (2014): The Sleipner CCS experience, UNFCCC - Bonn, October 21, 2014, http://unfccc.int/files/bodies/awg/application/pdf/04_sleipner-statoil_olav_skalmeraas.pdf
22) Torp, T.A., Brown, K.R. (2005): CO_2 underground storage costs as experienced at Sleipner and Weyburn. Greenhouse Gas Control Technologies. Rubin, E.S., Keith,

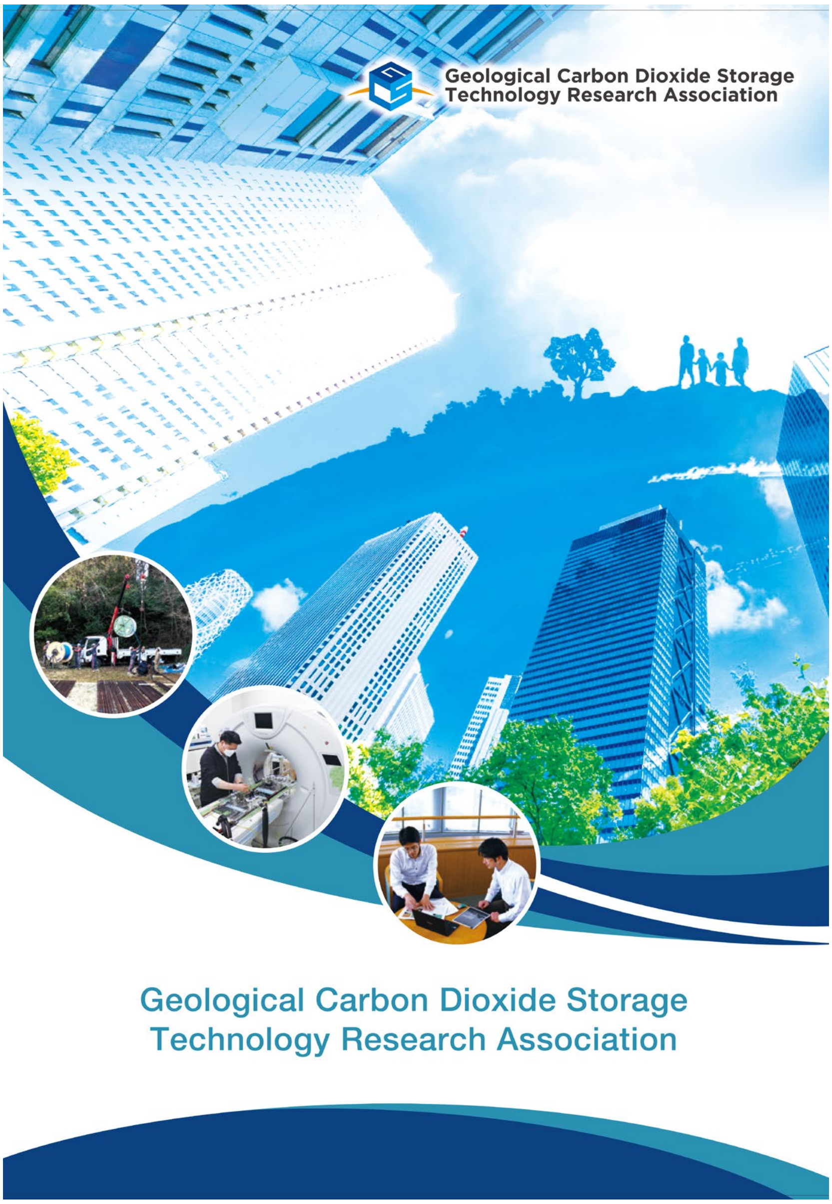
D.W., Gilboy, C.F. ed., Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies, 5–9 September 2004, Vancouver, Canada Volume I, Peer reviewed papers and overviews. Elsevier

23) WRI (2008): CCS Guidelines: Guidelines for Carbon Dioxide Capture, Transport, and Storage, World Resources Institute, 144 p

24) Zapantis, A., Townsend, A., Rassool, D. (2019): Policy Priorities to Incentivize Large Scale Deployment of CCS, THOUGHT LEADERSHIP REPORT, GCCSI

25) ZEP (2011): The Costs of CO_2 Storage, Post-demonstration CCS in the EU, IEAGHG https://hub.globalccsinstitute.com/sites/default/files/publications/119816/costs-co2-storage-post-demonstration-ccs-eu.pdf

26) ZEP (2014) Business models for commercial CO_2 transport and storage — Delivering Large-scale CCS in Europe by 2030, June 2014, 35 p, European Technology Platform for Zero Emission Fossil Fuel Power Plants



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