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People's Republic of China: Study on Carbon Capture and Storage in Natural Gas-Based Power Plants

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Guidance for CO_2 Geological Storage Site Assessment in the People's Republic of China

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FINAL REPORT

Prepared for Asian Development Bank

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I. SUMMARY

This report provides guidance on carbon dioxide (CO_2) geological storage site assessment in the People's Republic of China (PRC). It is focused on the site assessment elements of CO_2 utilization/enhanced oil recovery and geological storage. It covers the initial stages of project development up to the final investment decision (FID), regulatory approval and permitting of storage. The primary audiences are the Government of the PRC, regulatory agencies and project developers.

The PRC has been active in the research, pilot testing and demonstration of carbon capture utilization and storage (CCUS) in recent years. It is expected that CCUS will provide an effective measure to control greenhouse gas emissions in the PRC, and will contribute to the decarbonisation of coal and other energy intensive sectors (NDRC, 2013). The long-term safety of storage is seen as a key challenge, as in other countries.

The long-term safety of geological storage underpins the legal and regulatory frameworks that have been established in some countries along with many guidance, guidelines and best practice publications. Regulatory frameworks, work flows and activities have been developed to ensure a high degree of storage safety. Site specific risk based approaches to storage integrity assessment are widely proposed. This report draws on the international learning and presents recommendations for site assessment in the PRC.

Policy and regulatory frameworks for CCUS in the PRC are at an early stage which results in uncertainty around the requirements for project development. The National Development and Reform Commission (NDRC) have stated that the PRC should:

1. Develop and formulate standards and engineering codes for industrial applications of CCUS at a large scale, based on practical experience of CCUS in the PRC;
2. Strengthen the impact assessment of CCUS, assess the health, safety and environment impacts, strengthen long-term security, environmental risk assessment and control, build up and improve related safety standards and a system of environmental regulations; and
3. Actively engage in, and provide guidance for, formulating CCUS standards and regulations.

This report reviews issues, uncertainties and gaps that need to be considered in the PRC to ensure storage integrity. The significant issues include:

- Need for legal, lease and license provisions for surface and subsurface rights for CO_2 storage, including licensing for exploration and appraisal activities;
- Need for clear regulatory frameworks designed to ensure long-term storage safety and to manage and mitigate risks. This needs to address potential requirements for site characterization, definition of storage complex, storage risk management processes, monitoring and verification, well integrity, performance targets and reporting, corrective measures, site closure, transfer of long-term storage liabilities, and financial securities;
- Need to describe the procedures, consents and approvals required for CO_2 storage, the Ministries and agencies involved and their responsibilities and procedures. The requirements at different stages of storage projects need to be identified;
- Access and availability of seismic and well data to CCUS project developers;

- Incremental site assessment activities for CO_2 storage/ enhanced oil recovery (EOR) in oilfields;
- Requirement for exploration and appraisal of CO_2 storage sites in deep saline aquifers;
- Intellectual property rights transfer and protection;
- Policy and incentives for CCUS;
- Need for a consistent definition of CO_2; and
- Project authorization requirements

Because of the long-term nature of CO_2 utilization and storage projects and the importance of long-term safety, life cycle frameworks are widely used for CCUS. A life cycle framework that could be used for CO_2 utilization and storage projects in the PRC is proposed (Table 1). This incorporates extended timeframes of CO_2 storage compared to oil and gas production, especially the requirements for additional monitoring and activity after site closure which may extend over a period of years.

Table 1: Proposed Life Cycle framework for CCUS in the PRC

Phase/Stage	Milestone	Main Storage Objectives	GCCSI Asset Lifecycle Stage
Planning			
Site Screening		• Identify Potential Sites	Identify
Site Selection	Single Site Selected/Storage Exploration Permit	• Select Preferred Site and Technology	Evaluate
Site Assessment and Characterization	Final Investment Decision (FID)/ Storage Permit	• Site Appraisal (Seismic, wells) • Detailed Site Assessment/Characterization • Storage Permitting, Consenting and Approval • Design & Development Plan • Front End Engineering and Design (FEED) Studies	Define
Active			
Development	Start Injection	• Project Execution • Select Contractors • Site Construction and Development • Baseline monitoring • Drill Injection wells	Execute
Operation	End of Injection	• Commissioning • Operate Injection and Storage • Ongoing Monitoring	Operate
Closure	Asset Decommissioned	• Decommission assets • Permit closure	Closure
Post-closure			
Post-Closure/ Pre-Transfer	Transfer of Responsibility	• Update Performance Forecast • Post closure Monitoring • Agree Transfer of Responsibility	
Post-Transfer		• Monitoring as needed	

The report describes the activities involved in storage assessment up to the FID. For each stage, the project context should document the essential inputs to the storage screening assessment including locations of current or planned emissions sources and capture sites, the mass and composition of CO_2 streams, the rates and duration of CO_2 supply (including any extensions and expansions), the total amount of CO_2 that may need to be stored over the lifetime of the proposal and the schedule of any specific CCUS concepts.

1. Site Screening Stage (GCCSI Identify)

In the site screening stage, proponents carry out early studies and preliminary assessments comparisons of options to determine the viability of the broad CCUS project concepts. In this stage, storage assessment takes the form of screening studies. These use available published information and literature to identify prospective storage formations and areas. Screening studies usually review different storage options (e.g., EOR, deep saline aquifers) and different potential storage formations. Preliminary storage capacity estimates are made; data requirements, risks and uncertainties identified. A shortlist of potential storage options is produced.

2. Storage Site Selection Stage (GCCSI Evaluate)

In the site selection stage, the broad project concept is built upon by exploring the range of possible options that could be employed. For each option the CCUS project concept, scope, costs, benefits, risks and opportunities would be identified. The stage must continue to consider, for each option, all relevant aspects of the project (stakeholder management, project delivery, regulatory approvals, and infrastructure as well as physical carbon capture and storage facilities).

The storage assessment is to select the preferred storage site(s) from the options. It is important to access or acquire all pre-existing seismic and well data to reduce uncertainty in the subsurface assessment. More detailed studies are conducted to assess and select the preferred site, e.g. a specific oilfield or an identified area within a specific saline formation. At the end of this stage, the preferred option(s) is or are selected to take forward.

3. Storage Site Assessment and Characterization Stage (GCCSI Define)

In this stage, the selected option(s) is investigated in detail by carrying out new data acquisition, detailed site characterization, feasibility studies and preliminary design or Front End Engineering Design (FEED). At the end of the stage, the project definition must be sufficient to allow a FID to be made and approval and permitting of the planned storage/injection project to be obtained.

This stage involves extensive and detailed storage characterization activity to meet investment and permitting requirements. This would be similar to assessment of a new oil and gas field prior to investment, but with additional studies for storage. New data acquisition such as laboratory analyses, injection tests, seismic surveys or wells may be needed. A storage exploration license may be needed to conduct certain activities. This stage would involve determining the specific technology to be used, the design and overall costs for the project, the permits and approvals required and the key risks to the project. A FEED study may be conducted. In addition, it involves undertaking a range of activities such as focused stakeholder engagement processes, project planning, seeking out finance or funding opportunities and preparing for project implementation.

II. INTRODUCTION

This document provides guidance on CO_2 geological storage site assessment in the PRC. It is focused on the site assessment elements of CO_2 utilization with enhanced recovery and geological storage. It covers the initial stages of project development up to the FID, regulatory approval and permitting of storage. The primary audiences are the Government of the PRC, regulatory agencies and project developers.

Chapter 2 reviews international guidelines, guidance documents, best practice manuals and standards relating to CO_2 storage. It describes the current carbon capture storage (CCS) storage policy and regulatory position in the PRC and documents potential issues, uncertainties and gaps relating to CO_2 storage. It includes a section on the optimization of CO_2 storage in enhanced oil recovery.

Chapter 3 presents a framework for the stages and activities in storage project development. It describes the principle stages up to FID and develops a framework for the full range of activities involved in project development, including CCUS project integration, technical activity, outreach, permitting and project management activities. There is a section on applicability and use of selection criteria.

Chapters 4-6 describe the activities for the three stages of storage assessment up to FID.

III. CONTEXT

A. Storage Safety and Integrity

The PRC has been active in the research, pilot testing and demonstration of CCUS in recent years. It is expected that CCUS will provide an effective measure to control greenhouse gas emissions in the PRC, and will contribute to decarbonisation of coal and other energy intensive sectors (NDRC, 2013). NDRC's 2013 Notice on promoting CCUS notes the following challenges for CCUS: cost and energy penalty of capture; and the long-term safety and integrity of storage. The aim is that pilot and demonstration of CCUS technologies would solve these challenges through development and implementation, and pave the way for large-scale application and commercialization.

The challenge of the long-term safety and integrity of CO_2 storage is also widely recognized as critical for CO_2 storage/utilization by the Intergovernmental Panel on Climate Change (IPCC) (2005) and at the national level. The issue underpins the legal and regulatory frameworks, guidance, guidelines and best practice documents that have been developed. It is also a primary consideration for project developers and stakeholders. The issue is also linked to the public perception of CO_2 storage and public acceptance of storage. The legal regulatory frameworks that have been developed are designed to ensure the safety of storage. The guidance, recommended work flows and activities are also intended to ensure a high degree of storage safety.

The long-term safety and integrity of storage are linked to the risk of leakage from storage sites. The topic is explained in detail in European Commission Guidance Document 1 that was prepared for regulators in Europe (Ref EC GD1, 2010). The safety and environmental impacts of geological storage related to the risk of release of stored CO_2 fall into two broad categories (IPCC, 2005): i) local environmental and safety impacts and ii) global effects resulting from the release of stored CO_2 into the atmosphere. The local health, safety and environmental risks and hazards arise from three principal causes:

- Direct effects of elevated gas-phase CO_2 concentrations in the atmosphere above a storage site or complex, and in the shallow subsurface and in near-surface environments;
- Effects of dissolved CO_2 or fluid movement on groundwater chemistry which could lead to water contamination, pollution and other environmental risks;
- Effects that arise from the displacement of fluids by the injected CO_2, including displacement and leakage of other formation fluids, including oil or gas, ground displacement and induced seismicity.

CCUS is intended to have global environmental benefits, in that successful storage will reduce emissions from fossil fuel use and the buildup of greenhouse gases in the atmosphere. But significant leakage from storage sites would reduce the effectiveness of CCUS as an emission reduction option.

There has been extensive research into geological storage safety and leakage. This has been used to identify the main generic potential leakage pathways, hazards and mechanisms by which CO_2 can be released from a storage site or complex. The potential leakage pathways are divided into the following categories:

- Geological leakage pathways (e.g. faults, fractures, caprocks)

- Leakage pathways associated with manmade systems and features (i.e., wells and mining activities)
- Other hazards or risks such as the mobilization of other gases and fluids by CO_2 (e.g., methane)

The emerging best practice is that the risk of leakage for all potential leakage pathways should be reviewed and evaluated for every site. The storage integrity also depends on the trapping and containment of CO_2 in geological formations. The different processes which can trap and immobilize CO_2 in the underground formations, on varying timescales, must be assessed. It is also important to understand how CO_2 behavior influences the behavior of other fluids, either through physical displacement or chemical reactions. As a final element, the impacts need to consider human safety, both from CO_2 exposure and effects, together with other potential risks (e.g. ground movement), and all possible environmental risks.

CO_2 utilization/EOR and storage in oil fields also needs to consider and address CO_2 storage integrity and the risk of leakage even though the understanding of geological integrity of storage is higher in oil and gas fields. The trapping and containment of oil and gas do provide evidence of favorable geological trapping for CO_2 storage. However introduction, injection and storage of CO_2 together with the repressurisation of the site and the requirement for long-term containment alter risks. Therefore it is necessary to address storage integrity and leakage risks. In particular geomechanical, geochemical, and well risks need to be evaluated. In addition any regulatory and carbon market related performance criteria need to be met, for example in relation to carbon credits.

B. Status of International Guidelines, Best Practice and Standards

There are many guidance documents, guidelines, best practice and other publications that the PRC may draw on. These are mostly from international partnerships and countries active in CCS, i.e. Europe, USA, Canada and Australia. The documents used for this review are shown in Table 2, which shows the relevance to the scope of this report. There are two published reviews of the best practice documents (CO_2CRC, 2011; CSLF, 2013), although further documents are now available.

The documents are generally advisory and recommended practices and are not prescriptive. They have a range of target audiences from government and regulators to project developers and other stakeholders. Scope varies according to: target audience, CCUS chain or storage focus, stages of the lifecycle, activities covered and detail. One limitation of significance to the PRC is the limited discussion of on EOR/Utilization.

This study aims to draw on these reports in relation to guidance on storage assessment in the PRC. The key aspects are included in following sections of this report. Attention is drawn to the following documents which are considered of particular importance:

- European Commission Guidance Documents 1–4 which address specific issues in relation to implementation of the EU CCS Directive and preparation of national regulatory framework by European member states. These cover Life Cycle Risk Assessment (EC GD1, 2011), Site Characterization, Monitoring and Corrective Measures (EC GD2, 2011), Site Closure (EC GD3, 2011) and Financial Mechanisms/Security(EC GD4, 2011)

- US National Energy Technology Laboratories (NETL) series of Best Practice reports covering Site Selection, Risk Assessment, Simulation/Modeling Wells, and Public Outreach (NETL, 2009–2013).
- DNV's Guidance documents and Recommended Practices for Geological Storage and Wells; both focused on the initial project stages and providing detailed workflows and guidance (DNV, 2010–2012).
- Best Practice publications of lessons learnt for international Storage/Utilization demonstration projects at Sleipner, Norway (SACS, 2008) and Weyburn EOR, Canada (IEA GHG, 2012).

Table 2: International guidelines and best practice documents considered relevant to this report

Category	Title	Reference	Date	Origin	Focus Area(s)	Relevance this Report
Guideline	Geological Storage of Carbon Dioxide - Recommended Practise (DNV-RP-J203)	DNV RP-J203	2012	DNV/Oil Industry JIP	Storage Assessment: Recommended Practise	High
Guideline	Guideline for selection and qualification of sites and projects for geologic storage ofCO_2	DNV CO2QUALSTORE	2010	DNV/Oil Industry JIP	Storage Guidance. Stage Gate framework (selected stages though lifecycle).	High
Guideline	CO_2WELLS Guideline for the risk management of existing wells at CO_2geological storage site	DNV CO2WELLS	2011	DNV/Oil Industry JIP	Wells guidance.	High
Guideline (Webbased)	openCCS: Storage: http://decarboni.se/publications/openccs-storage	GCCSI/Carbonwise	2013	International	Web-based CCS Guidelines. Covers all storage activities, includes Project Management	High
Guideline	Geologic carbon dioxide sequestration: Site evaluation to implementation	LBNL/GEOSEQ	2013	USA/LBNL	Storage Site Selection/Assessnment	High
Guideline	Best practices for: Monitoring, verification, and accounting of CO_2 stored in deep geologic formation	NETL MVA	2012	USA/NETL	Comprehensive Monitoring Best Practise and Technology review	High
Guideline	Geologic Sequestration of Carbon Dioxide: Underground Injection Control (UIC) Program Class VI Well Project Plan Development Guidance	US/EPA	2013	US EPA	Wells guidance.	High
Guideline	Guidance Document 1. CO_2 Storage Life Cycle Risk Management Framework	EC GD1	2011	European Commission	Lifecycle framework; Storage Risk Assessment.	High
Guideline	Guidance Document 2. Characterization of the Storage Complex, CO_2Stream Composition, Monitoring and Corrective Measures	EC GD2	2011	European Commission	Site Characterization, Impurities, Monitoring, Corrective Measures	High
Guideline	Guidance Document 3. Criteria for Transfer of Responsibility to the Competent Authority	EC GD3	2011	European Commission	Site Closure Planning/Transfer	Med
Guideline	Guidance Document 4. Article 19 Financial Security and Article 20 Financial Mechanism Article 20 Financial Mechanism	EC GD4	2011	European Commission	Storage: Financial Security and Financial Mechanisms	Med
Guideline	Guidelines for CCS	WRI CCS	2008	International /WRI	Guidance for Capture/Transport & Storage	Med
Guideline	Guidelines for Communitty Engagement in CCS	WRI CCS	2011		Guidance for Outreach and Community Engagement	Med
Guideline	Australian Guiding Principles for Carbon Dioxide Capture and Geological Storage(Guiding Principles)	AU1	2005	Australia	Guiding Principles for Regulation of CCS/Storage	Low
Guideline	Environmental Guidelines for Carbon Dioxide Capture and Geological Storage – 2009	AU2	2009	Australia	Environmental Guidelines for CCS in Australia(high level)	Low
Guideline	OSPAR Guidelines for Risk Assessment and Management of Storage of CO_2 Streams in Geological Formations	OSPAR	2007	OSPAR	Storage Risk Assessment. NB OSPAR covers offshore NE Atlantic	Med
Best Practise	Best practice for the storage of CO_2 in saline aquifers	SACS/ CO2STORE	2008	European JIP	Lessons from Sleipner and other R&D. Focus on Storage/saline Aquifer subsurface	High
Best Practise	A technical basis for carbon dioxide storage	CCP	2009	Oil Industry JIP/CCP	Storage specific. Includes section on EOR	High
Best Practise	Geologic carbon sequestration: Site evaluation to implementation	GEOSEQ	2004	US/Research	Storage specific	High
Best Practise	Best practices for: Site screening, site selection, and initial characterization for storage of CO_2indeep geologic formations	NETL SS	2013	USA/NETL	Storage site screening & characterisation up to FID.	High
Best Practise	Best Practises for Risk analysis and simulation for geologic storage of CO_2	NETL RA	2011	USA/NETL	Risk Analysis, Simultaion/Modelling of Storage	High
Best Practise	Best practices for: Carbon Storage Systems and Well Management Activities	NETL WM	2013	USA/NETL	Best practices for Storage Well Management including Driulling, Injection, Monitoring and Post-injection	High
Best Practise	Best Practise: Public Outreach and Education for Carbon Storage Projects	US/NETL	2009	USA/NETL	Best practises for Outreach and Eductaion	High
Best Practise	Best Practice Manual developed through learnings from Weyburn project	IEA Weyburn	2012	IEA	Storage/Utilization Lessons Learnt from Weyburn EOR/Storage Project (Canada)	High
Best Practise	Best practices for: Geologic storage formation classification: Understanding its importance and impacts on CCS opportunities in the United States	NETL GS	2010	USA/NETL	Classification of geological formations for CO2 storage in relation to lithology, depositional environments.	Med
Best Practise	SiteChar Characterisation of European CO2 storage Deliverable N° D2.4 Best practices and Guidelines developed from the SiteChar project	EC/SiteChar	2013	European research Project	Best practices and lessons for Site characterization activities in European context.	High
Best Practise	SiteChar: Characterision of European CO2 Storage: Site Characteristion Workflow	EC/SiteChar	2013	European research Project	Workflow for Site Characterisation	High
Best Practise	SiteChar: Characterision of European CO2 Storage: Public Outreaah Activities	EC/SiteChar	2014	European research Project	Guidance on Outreach	Med
Best Practise	CO2 Aquifer storage site evaluation and monitoring	CASSEM	2011	UK	Best Practise for Aquifer Site Evaluation and Modelling. UK case studies	High
Best Practise	CO2 Site Closure Assessment Research:D4.22 Criteria for decision making in site abandonment	CO2CARE	2013	European	Case Study workflow for Storage Site Closure	Med
Best Practise	CO2 Site Closure Assessment Research:: D4.12 Plan for risk management supporting site abandonment	CO2CARE	2014	European	Case Study workflow for Risk Assessment and Storage Site Closure	Med
Other	Carbon Capture and Storage Regulatory Test Toolkit	SCCSS/GCCSI	2011	UK/International	Regulatory Toolkit	Low
Other	Planning saline reservoir storage developments – the importance of getting started early	Senior et al	2010	International	Framework for Storage Assessment focused on Aquifers	Med
Other	Defining CCS-Ready: An Approach to an International Definition	GCCSI/ICF	2010	GCCSI	Includes a framework for Storage Assessment activity.	Med
Other	Review of existing Best Practise Manuals for Carbon dioxide Storage and Regulation	CO2CRC/ GCCSI	2011	International	Review of Best Practise Documents up to 2011	High
Other	2013 Annual Report by the CSLF Task Force on Reviewing Best Practices and Standards for Geologic Storage and Monitoring of CO2	CSLF	2013	International	Review of Best Practise Documents & Guidance	High
Standard	Z741-12 Geological storage of carbon dioxide	CSA	2012	USA/Canada Standard	Storage standard.	N/A
Standard	*ISO/TC 265 Standard for Storage*	*ISO*	2016-2017	*International*	*Under development-not yet available*	*N/A*

The development of international standards is at a preliminary stage. A joint national standard for CCS has been produced by Canada and USA (Z741-12). This is a voluntary standard that can be adopted by project developers. McCoy (2014) reports that this standard:

- Establishes requirements and recommendations for the geological storage of carbon dioxide. The purpose of these requirements is to promote environmentally safe and long-term containment of carbon dioxide in a way that minimizes risks to the environment and human health.
- Is primarily applicable to saline aquifers and depleted hydrocarbon reservoirs and does not preclude its application to storage associated with hydrocarbon recovery; and
- Includes, but is not limited to, the safe design, construction, operation, maintenance, and closure of storage sites.

An ISO standard (ISO TC 265) for CCS is under development. Publication of the standard is expected to take two to three years (2016-2017) and the PRC is participating in this through Standardization Administration of China (SAC) and is part of the twinned Secretariat. It is now understood that EOR Issues will be incorporated and will form work package 6.[1]

C. Status of CCUS Utilization/Storage Policy and Regulatory Frameworks in the PRC

The PRC has been active in CCUS Research, Pilot testing and Demonstration for several years. Policy and regulatory frameworks for CCUS are at an early stage. The current policy as outlined by NDRC (NDRC, 2013) is to promote CCUS pilot and demonstration activity as follows:

- Develop pilot and demonstration projects along the CCUS technology chain.
- Develop CCUS demonstration projects and sites
- Explore and establish financial incentive mechanisms.
- Strengthen strategic research and planning for CCUS development.
- Promote CCUS standards and regulation.
- Strengthen capacity building and international collaboration

NDRC also documents the need to review mechanisms and financial incentives for CCUS pilot and demonstration activity, as well as to accelerate the establishment of a CCUS financial security system with government guidance, industry investment and multiple sector engagement in order to promote associated industry development in relation to medium- and long-term plans for CCUS. In relation to regulatory frameworks and standards, NDRC require the PRC:

- To develop and formulate standards and engineering codes for industrial applications of CCUS at a large scale, based on practical experience of CCUS in the PRC.
- To strengthen the impact assessment of CCUS, assess the health, safety and environment impacts, strengthen long-term security, environmental risk assessment and control, build up and improve related safety standards and a system of environmental regulations.
- Actively engage in, and provide guidance for, formulating CCUS standards and regulations.

[1] http://www.iso.org/iso/home/standards_development/list_of_iso_technical_committees/iso_technical_committee.htm?commid=648607

D. Uncertainties & Issues for Storage Developers in the PRC

The early stage of development of the CCUS policy, legal and regulatory frameworks in the PRC creates uncertainties for project developers and stakeholders. The primary goal for all CO_2 storage and utilization is to ensure the safety and long-term security of storage. Experience to date suggests this can be achieved by promoting environmentally safe and long-term containment of carbon dioxide in a way that minimizes risks to the environment and human health. This can be achieved in the PRC through a combination of safeguards established through regulation and implementation of best practice by project developers. This section of the report documents issues, uncertainties and gaps to be considered in the PRC so as to achieve this overarching objective.

The PRC's initial approach has focused on CO_2 utilization and EOR, and there may be increasing role for storage in Saline Aquifer Formations and depleted fields in future. The licensing and regulatory frameworks for EOR/utilization are largely those already in place for the oil and gas industry, but these may need to be adapted for storage, and/or if utilization is adapted and incentivized to increase CO_2 storage. In addition the frameworks will need to be developed for CO_2 storage. The frameworks may need to apply to both onshore and offshore settings.

A draft report by the China-UK Guangdong CCS Centre (China-UK CCS Centre, in press) has recommended that "Establishing a comprehensive and competent regulatory regime for large-scale CCUS projects will require clear definitions of a few key issues, such as the overall institutional structure, the ownership, and the legal liability. Currently, no dedicated regulatory framework has been established for CCUS in the PRC, but the country has a portfolio of existing laws that may be adapted or amended to meet the requirements in developing large-scale CCUS projects."

Significant issues in relation to CO_2 utilization EOR and storage appear to be as follows.

1. Definition of CO_2

A consistent definition and classification of CO_2 is important for successful deployment of CCUS technologies, otherwise CO_2 might be considered a pollutant in one jurisdiction but not in another, making widespread deployment of CCUS, and cross jurisdiction CO_2 transport more difficult. In addition, there is a lack of legal definition and understanding on the ownership of CO_2 during the different stages of a CCUS process.

2. Access to Surface and Subsurface

There is no specific law regulating the granting and licensing of surface and subsurface rights (either onshore or offshore) or the leasing of land for CO_2 storage in the PRC. The surface and subsurface rights have significant impact on CCUS projects, because CO_2 geological storage projects will require long-term access to surface and sub-surface space. CO_2 Utilization/EOR rights may need to be adapted for long-term Storage. Licensing for exploration/appraisal activities for geological storage also needs to be addressed.

3. Regulations for Safety of Long-term Storage

Specific CCUS HSE Law and regulation for CO_2 storage doesn't exist in the PRC. However, all CCUS activities will need to comply with the relevant existing regulations for water, pollution, marine environment, industrial safety, etc. and all large-scale CO_2 utilization and storage projects will be subject to an environmental impact assessment. The Ministry of Environment Protection (MEP, 2013) released a notice designed to enhance environmental protection activities for CCUS pilot and demonstration projects. The notice outlines key environmental uncertainties for storage as “incorrect site characterization causing seepage or significant leakage that induces underground water pollution, soil acidification, biodiversity and ecology damage”. Existing regulations my need to be adapted or new regulations introduced to ensure storage risks are effectively addressed for utilization/EOR and storage, and for both onshore and offshore settings. Given the importance of ensuring safety of storage, specific regulations may need to be developed in addition to existing HSE legislation and regulation.

Regulators should consider the introduction of storage permits and associated regulations similar to the frameworks elsewhere. Regulators and project developers should consider specific regulations and activities covering:

- site characterization
- storage risk management processes
- monitoring and verification
- well integrity
- performance targets and reporting, including operating pressure limits
- corrective measures Plans
- site Closure
- transfer of liabilities
- financial securities.

4. Storage Risk management and Monitoring

Storage risk management and monitoring plans are core components of storage regulations and best practices in other jurisdictions that may be used or adapted to meet the PRC’s objectives around geological storage integrity. In this context, the risk management activity is focused on storage safety and integrity, and is therefore distinct from project risk management.

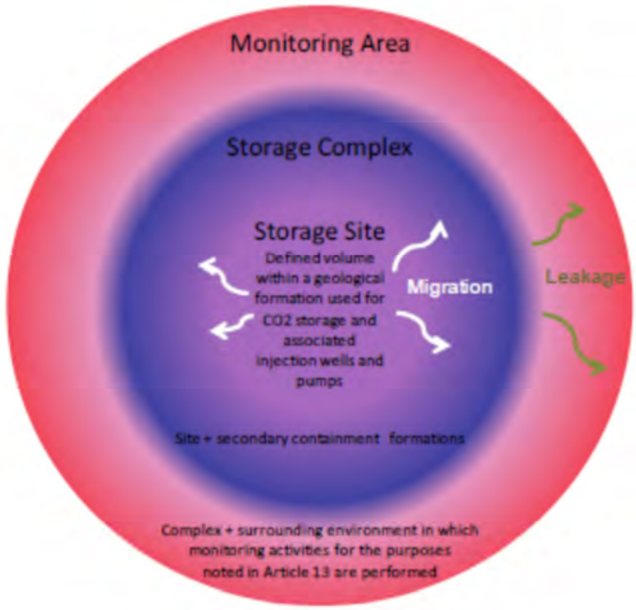
Storage risk management and monitoring plans are generally risk-based and site specific, and are closely integrated with site characterization, modeling and performance updates. They may be ongoing activities through much of the CCUS lifecycle from permitting up to closure and transfer. Corrective measures (or remediation) plans and provisional site closure plans are also required in Europe.

Any requirement for these in the PRC needs to be clearly defined in the regulatory frameworks and future standards. Any regulations should clearly delineate the division of responsibility between the project operator and the regulatory authorities.

5. Storage Complex or Area of Review

The area of interest for a given storage site includes the surrounding domain and three dimensional volume that can have an effect on, or be impacted by CO_2 injection and storage. In Europe this is referred to as the storage complex whereas it is the area of review in United States. The storage complex in Europe is shown using Figure 1 below and comprises the primary storage site (i.e. defined volume within a given formation used for storage), plus secondary containment zones and migration pathways which may be impacted in the unlikely event of any leakage. It is important for regulators in the PRC to consider whether these concepts are used and to clarify the characterization and regulatory requirements in respect of this.

Figure 1: EU Definitions of Storage Site and Storage Complex (EC GD2, 2010)



6. CO_2 Storage Liability

A CO_2 storage liability regulatory framework is considered essential to the CCS regulation scheme for large-scale commercial sequestration projects in Europe (Davies, et al, 2013). The liability provisions cover transfer of liabilities, certain future liabilities (such as well closure, monitoring), and contingent liability (such as the environmental impact, the cost of CO_2 emission allowances, the remediation cost during a CO_2 leakage event). European project developers have complained that the financial security requirements of the CCS Directive impose excessive barriers for early large-scale CCUS projects, and have caused severe delay and cancellation. There is no explicit Chinese regulation or law covering CO_2 storage liability.

7. Additional regulatory requirements for EOR with CO_2 storage

Existing CO_2 EOR operations are usually conducted under existing regulation, licensing, legal and health and safety frameworks which apply to the oil and gas production. Modification and additional requirements may be required for EOR with CO_2 storage, for example in relation to storage security and integrity as documented above, monitoring and verification of CO_2 stored, Carbon credits, finance and benefits attributable to CO_2 reduction, liabilities, etc. A comprehensive report on this topic in other countries is provided by GCCSI, 2013. At the time of writing, it is uncertain if these issues have been reviewed in the PRC. If not, that gap may need to be reviewed.

8. Data Access and availability

Access to seismic and well data is required for the assessment and characterization of storage by utilization/storage project developers. Data access provisions in the PRC may need to be reviewed to increase access to project developers.

9. Exploration and Appraisal of CO_2 Storage

Experience has shown that new seismic and well data may need to be acquired for assessment of some Deep Saline Aquifer storage sites before permitting and FID. Appraisal wells have been required by projects in Australia (Zerogen), the United Kingdom (National Grid) and Canada (Quest). This activity may be time-consuming and can involve significant expenditure (tens millions of dollars). How best to fund these activities and possible government support needs to be considered in the PRC.

10. Intellectual Property Rights Transfer and Protection

CCS technology is not a single system and it consists of combinations of different technologies along the chain. Most CCS technology patent owners are within developed countries, and consequently establishing a technology transfer mechanism is seen as a key driver for achieving successful commercial deployment and rapid cost reduction in the PRC (Liu and Liang, 2011). NDRC also highlights the importance of knowledge transfer (NDRC, 2013). A successful technology transfer process may require financing mechanisms and provisions for intellectual property right holders.

11. Policy and Incentives for CCUS

At present there is no CCS specific financial incentive program for large-scale CCUS demonstration projects or deployment in the PRC. Large-scale deployment of CCS demonstration projects in the PRC will almost certainly require a combination of financing support through major capital grants, carbon pricing support, and/or feed-in-tariffs (Reiner and Liang, 2012). Other mechanisms, such as an Emission Performance Standard and CO_2 Storage Obligations could support demonstration and deployment of CCUS projects. It has also been necessary to address the treatment of CO_2 storage in the EU Emissions Trading and similar action may be required in the PRC.

12. Project Permitting, Consents and Approvals

There is not yet a formal permitting process for CCUS projects in the PRC. However, there may be potential analogues from the authorization process of thermal power generation, oil and gas pipelines, and oil and gas field developments. Authorizing a power generation project in the PRC is a substantial part of the project development process usually involving a very long lead time and communications with many government departments at local and national levels. It has been reported that approximately 50 clearances or permits are required before construction of a power plant can take place. Stakeholders consulted for this report have also indicated that multiple ministries and agencies will be involved in CO_2 utilization/EOR and storage projects.

Storage permitting and consenting is also expected to be wide-ranging and needs to be tested for different storage types, provinces and settings. Stakeholders consulted for this report have identified the need to identify and describe all procedures, consents, registrations and approvals required for CO_2 storage, the Ministries and agencies involved and their responsibilities. The requirements at different stages of storage need to be identified.

E. CO_2 EOR and Storage

Utilization of CO_2 for EOR is a priority for CCUS in the PRC and several pilot projects have been conducted. CO_2 EOR is one of several different methods of enhanced oil recovery. It can increase oil recovery at the same time as using and storing CO_2. The CO_2 used may be either naturally occurring CO_2 (e.g. from CO_2 fields) or CO_2 captured from anthropogenic sources (e.g. gas separation, chemical or power plants). The origin of the CO_2 is important in the context of CCUS and whether or not CO_2 EOR leads to reduction of anthropogenic CO_2 emissions.
The process involved in CO_2 EOR is usually as follows: natural or anthropogenic carbon dioxide is brought to the site, compressed and then injected into the oil reservoir through wells. In some cases CO_2 injection is alternated with water injection, called water alternating gas (WAG) injection. CO_2 in the reservoir dissolves in and mixes with the reservoir oil, and vice-versa causing the oil to swell, become less viscous and to flow more easily. Most CO_2 EOR projects are fully miscible however immiscible CO_2 floods can also be conducted.

As oil is produced, CO_2 will be brought to surface with the oil where it is separated, captured and then compressed and re-injected into the reservoir (together with additional "new" CO_2). This recycling reduces the purchases of additional CO_2 and avoids emitting this CO_2 to atmosphere although there may be very minor losses through fugitive emissions. Almost the entire CO_2 is retained in the reservoir during EOR resulting in storage of CO_2. This may be considered as incidental, concurrent or simultaneous storage (GCCSI, 2013). In standard, routine type of EOR operations, operators usually seek to use as little CO_2 and consequently the amount of CO_2 stored is minimized. This reflects the current lack of commercial value for reducing atmospheric emissions of CO_2. In addition the amount of CO_2 stored is not usually quantified, nor subject to monitoring and verification, all of which are generally considered key requirements for CO_2 storage.

A number of other scenarios are possible where additional CO_2 may be stored in EOR operations, and enhancing emissions reduction. There are alternative techniques that could be used to maximize the amount of anthropogenic CO_2 stored for a given quantity of oil production. Accounting, monitoring and verification activities are required. These include incremental storage during EOR operations and incremental storage in an EOR site (after EOR). The technical considerations for maximizing storage are described further in the next section. Key differences between regular CO_2 EOR and EOR with Storage are described in section g.

F. Maximizing CO_2 Storage in Enhanced Oil Recovery Operations

Operators try to use as little CO_2 as possible to minimize their costs. Recovery efficiencies can be expressed by the number of tonnes CO_2 injected to recover a barrel of oil (or some equivalent form of utilization factor such as mcf/bbl). Generally operators seek to minimize the costs of CO_2 purchases and amount of CO_2 used per barrel produced. Most operators do not implement procedures to optimize opportunities for storage of CO_2 in association with their EOR because there is no present financial or regulatory impetus to consider storage as a component of their business (GCCSI, 2013).

From a technical viewpoint there are a number of possibilities to increase the storage of CO_2 in EOR operations. These involve approaches that inject CO_2 earlier, longer, and/or instead of water (ARI, 2010). The main possibilities are:

- Deploying CO_2 EOR earlier in field development lifecycle;
- Increasing the cycles of CO_2 injection with respect to water injection (i.e. decreasing the WAG water cycles) or the oil production cycle in single wells;
- Pursuing straight CO_2 injection instead of WAG injection;
- Increasing amounts of CO_2 injected in a given operation or field, and e.g. extending CO_2 EOR to less economic zones of a field;
- Injecting into deeper zones or peripheral areas of the field using the same infrastructure;
- Co-locating CO_2 EOR and Storage operations; injecting CO_2 into deeper, adjacent or deep saline aquifer formations, both below oil-water contacts and in other formations; and
- Continuing CO_2 injection beyond economic oil recovery and/or after close of oil production in parts or the entire field.

To incentivize operators to consider these possibilities and to implement carbon storage a part of the business some form of price, it is likely that tax or policy on carbon will need to be introduced. Alternatively the taxation and fiscal treatment of CO_2 EOR may need to be modified. If regulatory or economic drivers are introduced, transitioning CO_2 EOR operations to increase storage and/or to become dedicated carbon storage sites will involve some operational modifications. It is also likely to require additional activities to meet future storage regulations than typically implemented for EOR operations at present.

G. Additional requirements for CO_2 EOR with Storage

The additional requirements for CO_2 EOR with storage depend on the factors discussed above including the origin of the CO_2, regulations, standards, whether benefits or carbon credits are received for CO_2 emissions reduction, whether stored CO_2 needs to be quantified, monitored and verified and any other funder or stakeholder requirements. The objectives of additional activities would need to meet any regulatory requirements, particularly in respect to storage integrity, leakage risk, permanence and long-term containment. The intended goal of the geological storage is to ensure that the injected CO_2 remains in the target storage formation (or storage complex) and that none has migrated laterally or vertically out of this zone, potentially impacting other resources or the surface.

Depending on these, some or all of the following additional activities may be required:

- permits/consents for CO_2 storage;
- assessment work focused on CO_2 storage integrity, permanence and performance. This may require reassessment of geological data and updating of reservoir description and models, and reassessment of the overburden and storage complex;
- assessment work, possible data acquisition and analyses focused on CO_2 integrity, potential leakage risks and long-term containment associated with CO_2 injection. Includes seal/caprock integrity, geomechanics and geochemistry;
- dynamic modeling of CO_2 plume development, evolution and trapping, both during and after the planned injection stage and site closure. Forward modeling of CO_2 containment after injection is typically on time scales up to 1,000–10,000 years with adapted or different models to standard oil production models;
- assessment of well integrity and potential well leakage risks;

- preparation, approval and update of injection plans, storage risk assessment, monitoring, remediation and provisional closure plans as required for storage permitting and regulations;
- incremental measurement, monitoring and verification (MMV) focused on long-term storage. This is likely to require additional metering and monitoring both during and after injection, with a broader scope than routine reservoir surveillance monitoring. In practice both routine and additional monitoring will be site specific, and will need to be determined and agreed on a site by site basis;
- measurement, accounting and verification of CO_2 storage;
- remedial activities in event of any leakage; and
- post-injection storage integrity assessment and transfer.

IV. FRAMEWORK

A. Stages of Project Development

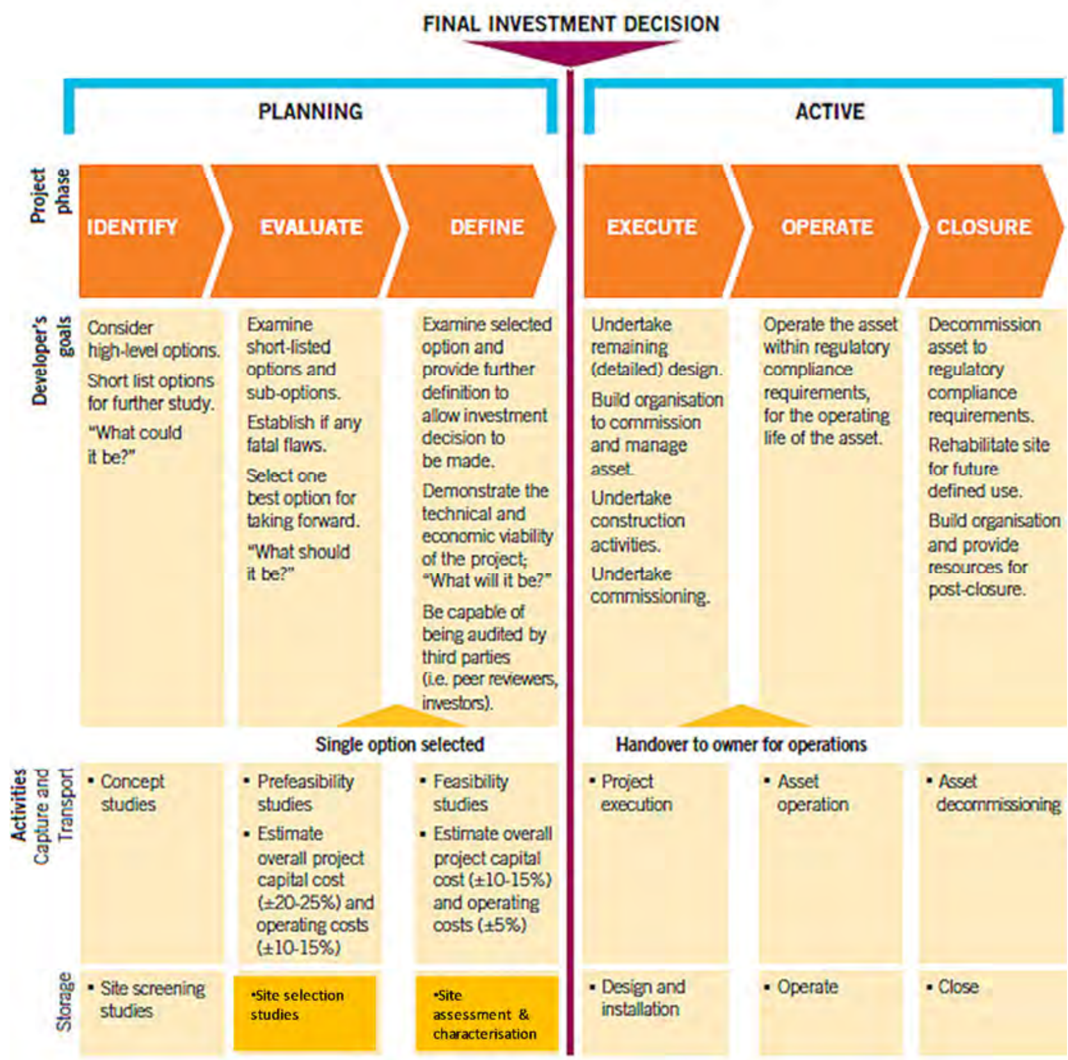
Because of the nature of projects and the importance of long-term safety, life cycle frameworks are widely used in CCUS regulatory frameworks, projects, guidance and best practices. These identify main stages and milestones for the CCUS project development activities, permitting and regulatory approvals. Lifecycle frameworks are embedded in the CCUS regulatory frameworks in several jurisdictions to provide upfront clarity about future requirements, including the post-injection phase, closure and transfer of responsibility. This enables project developers to incorporate these in site characterization, project planning and implementation. It should be beneficial for the PRC to build on the international experience. This section of the report proposes a life cycle framework and stages that could be used for CCUS in the PRC –Table 3: Proposed Life Cycle Framework for Geological Storage the PRC.

Table 3: Proposed Life Cycle Framework for Geological Storage in the PRC

Phase/Stage	Milestone	Main Storage Objectives	GCCSI Asset Lifecycle Stage
Planning			
Site Screening		• Identify Potential Sites	Identify
Site Selection	Single Site Selected/Storage Exploration Permit	• Select Preferred Site and Technology	Evaluate
Site Assessment and Characterization	Final Investment Decision (FID)/ Storage Permit	• Site Appraisal (Seismic, wells) • Detailed Characterization • Storage Permitting • Design & Development Plan • Front End Engineering and Design (FEED) Studies	Define
Active			
Development	Start Injection	• Project Execution • Select Contractors • Site Construction and Development • Baseline monitoring • Drill Injection wells	Execute
Operation	End of Injection	• Commissioning • Operate Injection and Storage • Ongoing Monitoring	Operate
Closure	Asset Decommissioned	• Decommission assets • Permit closure	Closure
Post-closure			
Post-Closure/ Pre-Transfer	Transfer of Responsibility	• Update Performance Forecast • Post closure Monitoring • Agree Transfer of Responsibility	
Post-Transfer		• Monitoring as needed	

Slightly different life cycle frameworks are presented by international stakeholders (GCCSI, European Commission, NETL, US/Canadian Standard and DNV). The major stages and milestones are broadly similar but there are some differences in detail, scope and terminology especially for the initial stages. The framework proposed here is aligned with that of GCCSI for international use: Figure 2: CCUS Asset Life Cycle Framework (modified after GCCSI, 2012) . This shows the overall phases of projects, and the overall scope of the three pre-investment stages.

Figure 2: CCUS Asset Life Cycle Framework (modified after GCCSI, 2012)



1. **Proposed Framework for Utilization and Storage Projects in the PRC**

In the proposed framework, a project is considered in the 'planning' phase up to the FID. The planning phase is divided into three stages. These are i) site screening, ii) site selection and iii) site assessment and characterization. These correspond to GCCSI's identify, evaluate or define stages. A project would then become active if it has made a positive investment decisions and has entered construction or is in operation. As a project progresses through each stage, the level of definition increases with an improved understanding of the scope, cost, risk and schedule of the project. This approach reduces the uncertainty surrounding the project while managing upfront development costs. A summary of the stages is as follows.

2. Site Screening Stage (GCCSI Identify)

In the site screening stage, a proponent carries out early studies and preliminary assessment of options to determine the viability of broad CCUS project concepts. For example, a petrochemical company may consider that it could take concentrated CO_2 from one of its coal gasification facilities and use or store the CO_2 at one of its existing fields.

Stakeholders start with preliminary desktop analysis and screening of both the plant/ capture, transport and storage requirements of the concepts to determine if the overall project concept seemed attractive. It is important that the stage considers all aspects of the project, including stakeholder management, project delivery, regulatory approvals and infrastructure as well as capture, transport and storage options. Before progressing to the next stage, all the project options that meet the overall concept should be clearly identified.

Storage assessment in this stage takes the form of screening studies. These use available published information and literature to identify prospective storage formations and areas. Early stage screening for CO_2 EOR typically involves desk-top review of available information for all oilfields in a region against published worldwide criteria for CO_2 EOR (e.g. NETL. 2012; ISRM, 2014). These are focused on reservoir criteria, while facilities, wells and commercial issues are not usually considered. Further limitations are that oil companies may not be involved and therefore data may not be up to date, and the criteria are largely derived from North American fields which may not represent the Chinese situation. Storage screening studies usually review different storage options (e.g. EOR, Saline Formations) and different potential storage formations. Preliminary storage capacity estimates are made; data requirements, risks and uncertainties identified. A shortlist of potential EOR and/or storage options is produced.

3. Storage Site Selection Stage (GCCSI Evaluate)

In the site selection stage, the broad project concept is built upon by exploring the range of possible options that could be employed. For the companies this would involve exploring:

- which plant, and possibly even plant of other companies, might be best placed to provide the CO_2 for the project;
- possible transport options and routes that could be used from each of these sites; and
- which oil field or site is suitable for CO_2 utilization/EOR based on its proximity to the concentrated CO_2, the stage of oil production at the field and other site factors.

For each option the costs, benefits, risks and opportunities would be identified. The stage must continue to consider all relevant aspects of the project.

The storage assessment is to select the preferred storage site or sites (from the options brought forward). It is desirable to access or acquire all pre-existing seismic and well data to reduce uncertainty in the subsurface assessment. More detailed studies are conducted to characterize the geology, reservoir, containment, capacity, injectivity and a preliminary risk assessment of each site. Similarly more detailed assessment is required for EOR and Storage options, which should involve the field owners and their data by this stage. This should establish the suitability of specific fields for CO_2 injection and EOR, whether miscible of immiscible EOR is likely and assess expected EOR performance, CO_2 utilization and storage capacity. Preliminary assessment of wells, facilities and infrastructure requirements and conversion is included, together with a preliminary assessment of storage risks, including well integrity.

At the end of this stage, the preferred option is selected to take forward. The preferred option must be sufficiently defined.

4. Storage Site Assessment and Characterization Stage (GCCSI Define)

In this stage, the selected option is investigated in greater detail by carrying out new data acquisition, detailed characterization, feasibility studies and preliminary design or FEED. At the end of the Define stage, the level of project definition must be sufficient to allow a FID to be made and for storage permitting and project approval to be obtained.

This stage involves extensive and detailed storage characterization activity to meet investment and permitting requirements. This would be similar to assessment of a new oil and gas field prior to investment, but with additional studies for storage. New data acquisition such as laboratory analyses, injection tests, seismic surveys or wells may be needed, both for EOR and for Storage options. This stage would involve determining the specific technology to be used, the design and overall costs for the project, the permits and approvals required and the key risks to the project. FEED studies may be conducted. In addition, it involves a range of activities such as stakeholder engagement, project planning, finance /funding and preparing for project implementation.

GCCSI indicate that together, the Identify, Evaluate and Define stages can take between 4–7 years.

5. Development (Execute) Stage

In the next stage, the detailed engineering design is finalized. The procurement, development, construction and commissioning of the proposal occurs and the organization to operate the facility is established. For storage, new development wells may provide new data to update the site characterization. Baseline data acquisition may also be conducted as part of monitoring programs.

6. Operate Stage

In the operate stage, the injection takes place and the CCUS assets are operated within regulatory requirements and maintained and, where needed, modified to improve performance.

7. Closure/Post-closure Stages

In the Closure stage, the CCUS asset is decommissioned to comply with regulatory requirements. The site is rehabilitated for future defined use and resources are allocated to manage post-closure responsibilities such as longer term monitoring.

B. Activities overview

A generic table of the activities that may be required by project developers for CO_2 utilization and storage is Table . This compilation indicates the wide range of activities and disciplines involved. These activities are classified in terms of:

- project definition and integration (i.e. integrating with capture and transport);
- storage assessment activities;
- other permitting and consulting activities;
- outreach activities, which are widely viewed as essential for storage projects; and
- project management activity. These are not usually documented in Guidance or Best Practice although they are widely used for large scale CCS projects. They have been detailed by FEED projects that were conducted and disseminated in the United Kingdom (Ref).

Note that not all activities take place at each stage of a project. Further guidance on activities at different stages is detailed in Chapters 4–6.

Table 4: Framework and Classification of Project Development Activities for CO2 Storage

Project Definition/ Integration	Storage Assessment Activities	Other Permitting and Consenting	Outreach	Project Management
• Project Strategy • Project Definition • Source-Sink Matching • Technical Integration • Project Integration • Partners	• Storage Licensing • Data • Subsurface • Modelling • Wells • Storage Risk Assessment • Monitoring • Storage regulation and permitting • Development and infrastructure • Costs & economics	• Project Authorization • Environmental • Health and Safety • Other Permitting & Consents • Land Use / Resource Conflict	• Stakeholder Mapping • Communications • Outreach • Education	• Project Planning • Project Risk Management • Project Economics • Legal • Commercial • Contracting • Funding/ Financing • IP

C. Specific Storage Activities

International regulations, best practices and guidance document activities that are intended to address and manage storage safety. The activities address the differences between CO_2 storage and oil and gas development: extraction versus injection, physical properties, chemical properties, phase behavior, geomechanics/geochemistry, risk profile, leakage risk, trapping, area of interest, post-operational risk.

Regulators and developers in the PRC will need to consider which of these are required, regulated and used in the PRC. These relate to regulatory gaps and issues documented in Section 2.d of this report. They include:

- Site Characterization
  - Requirements for geological characterization of storage complex and overburden to assist in storage risk assessment and potential leakage paths and impact
  - Requirement for specific data/sampling of caprock and seals (not usually available from oil and gas fields)
  - Baseline data and assessment of hydrodynamic system
  - Geomechanical assessment
  - Geochemical assessment
  - Storage modeling requirements and specifications
  - Storage and injection performance criteria (including operating pressure limits)
  - Migration path analysis
  - Well integrity analysis
- Dedicated storage risk assessment and ongoing storage risk management focused on Storage integrity and leakage risk. This is distinct from Project Risk Management although there is overlap. This should be site specific based on site characterization and integrated with Monitoring Plans and potentially corrective measure planning.
- Monitoring, verification and accounting; focused on CO_2 integrity, performance, leak detection and quantification. To include baseline monitoring and contingent monitoring
- Corrective measures/contingency planning, linked to monitoring
- Provisional closure planning
- Provision for leakage risk and potential long-term liabilities
- Communications and outreach

D. Storage Evaluation Criteria

Some international studies have reviewed the technical/subsurface criteria that might be applicable for identification and selection of storage sites. These have considered EOR and deep saline aquifers. The most complete analysis of evaluation criteria is by IEA and is available in their report entitled CCS Site Characterization Criteria (IEA GHG, 2009). The criteria for Saline Aquifers originate from 2008 report entitled Best Practice for Saline Aquifers (SACS, 2008). Both reports are over 5 years old and needs to be updated to benchmark all storage and utilization projects conducted since then. The applicability of such criteria to storage in the PRC is a concern, in particular reservoir thickness, permeability and fault compartmentalization cut-offs.

There are also papers and reports by several authors documenting screening criteria for CO_2 EOR. These are nearly all based on and restricted to reservoir criteria, including depth, temperature, pressure, minimum miscibility pressure (MMP), permeability, oil gravity, viscosity and residual oil saturation. These have been tabulated by ISRM, 2014 in the Guohua Feasibility Study, who have recommended criteria (Table 5).

Table 5 : Criteria for screening reservoirs for CO2 EOR (ISRM 2014)

Reservoirs	(NEIL, 2012)	(Taber et., al, 1997)	(Shen, 2010)	(Shaw and Bachu, 2007)	(Debourah and Bachu, 2007)	Recommended Criteria
Depth/m	600–3000	>700	>762			
Temperature/ ºC	<121			31–121		>762
Pressure/MPn	>8.4			>7.6	<121	<121
Pressure/MMP				>0.95	>7.58	
Permeability/$10^{-3}\mu m^2$	>1				>0.95	
Oil gravity, API	>27	>26	>22	27–48	27–48	>27
Viscosity, cp	<12	<15	<10		<10	<20
Residual oil saturation, S_{or}	>0.30	>0.30	>0.20	>0.25		0.2

There are several limitations to this type of approach: facilities, wells and commercial issues are not considered (even though important), oil companies may not be involved and therefore up to date data may not be available. Also the proposed criteria are largely derived from North American fields which may be very different to the Chinese EOR situation and different thresholds are proposed by different studies. Therefore overly-prescriptive use of such criteria should be avoided and appropriate recognition of the uncertainties is required.

Further work appears to be required to develop and enhance specific storage and EOR criteria that are applicable in the PRC.

V. SITE SCREENING STAGE (GCCSI IDENTIFY STAGE)

A. Introduction

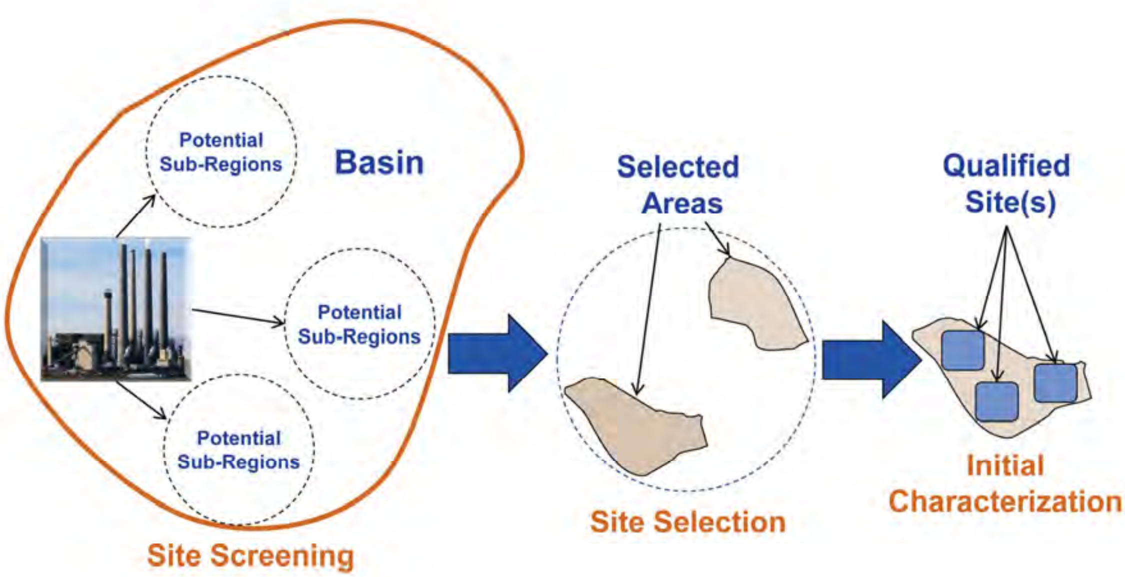
The purpose of the screening stage is to evaluate the potential for storage in a given region or geological basin to identify prospective storage sites or areas. The screening study area(s) considered will usually be in the vicinity of opportunities for CO2 capture. These might be existing or planned CO2 emissions sources such as coal gasification plant, natural gas processing plant, power plants or other industrial sites. For example the ADB sponsored Feasibility study of the Ordos basin was conducted to screen the storage potential in the Ordos basin for the planned Guohua Oxy-fuel Combustion Plant (IRSM, in press).

Site assessment work during this stage mainly uses existing information, reports, data and resources. These may be publicly available, and/or proprietary information held by project proponents. These would include any prior CO_2 storage assessments in the public domain, for example national studies or regional studies, e.g. Ordos, NZEC (Senior et al, 2011; NZEC, 2010), COACH, Guangdong (SCSIO, 2013). The scope of work varies according to the quality and quantity of available information.

The assessment work brings together i) subsurface/geological studies, ii) emissions source/storage matching and proximity analysis, and iii) geographical, social, environmental and legal factors.

The output of this stage should be a list of potential storage sites that meet the proponents' requirements and Screening Basis (DNV, 2012). Screening at the Basin or regional level is used to identify potential areas/sites for storage to be reviewed in the subsequent stage. This is also illustrated by the following graphic by NETL (Figure).

Figure 3: Schematic of Site selection and characterization progression (NETL, 2013)



B. Project Definition and CCUS Integration

At the start of screening for storage and CCUS the participants and alignment of the capture, transport and storage elements of CCUS is preliminary. Sometimes CCUS elements are progressed independently at this stage, as it precedes the formation of integrated projects and consortia.

In any case the context for storage screening must be described at the start. This will depend on the strategic rationale, project concept(s), drivers and goals of the CCUS activity that is the motivation for the work. Strategic rationale is a primary consideration which must consider whether the intent is pilot testing, demonstration or deployment, and if so whether a specific storage type is to be tested (e.g. to demonstrate deep saline aquifer storage). The context must also address whether the storage solution is intended as part of a specific project, and if that is a demonstration, full scale scheme, or CCUS cluster. An alternative is to screen an entire region and/or basin to identify prospective storage possibilities. This approach has already been undertaken for several regions in the PRC, e.g. Ordos, North China Basin, Guangdong Province.

The context should document the factors which are all essential inputs to the screening assessment:

- Locations of current or planned emissions sources and capture sites;
- The mass and composition of CO_2 streams from the sources;
- The rates of CO_2 supply and expected duration (including any extensions and expansions);
- The total amount of CO_2 that may need to be stored over the lifetime of the proposal; and
- The timing and potential schedule of any specific CCUS concepts.

C. Storage Assessment Activity

1. Screening Basis

The first step in the activity is to discuss, agree and describe the Screening Basis for the assessment. This is fully described in DNV's Site Screening Recommended Practice. They recommend that this should document a list of requirements that each storage site should meet:

Table 6: Requirements for Potential Storage Sites that should be included in Screening Criteria (DNV, 2012)

1)	A quantitative requirement for minimum total capacity (tonnes)			
2)	A quantitative requirement for minimum annual injectivity (tonnes/year)			
3)	A requirement for documents evidence of the following positive indicators of long-term containment	a)	Depth: sufficient depth of injection zone to achieve CO_2 dense phase (>300kg/m^3 at the reservoir conditions)	
		b)	Seal: presence of laterally extensive seal above the injection zone to prevent flow communications with economic and/or environment receptors	
		c)	Wells: confidence that well integrity can be established and maintained in existing wells that penetrate the primary seal and will be exposed to CO_2 or pressure changes	
		d)	Geological faults	i. Sufficiently stable geological environment to give confidence that containment will not be jeopardized by natural tectonic activity
				ii. Absence of existing flow-paths along geological faults that penetrate the storage complex
4)	A requirement for documented evidence of the following positive indicators of the potential to monitor and deploy risk treatment	a)	Legal availability of the storage site over the expected life cycle	
		b)	Physical accessibility to the storage site over the expected life cycle	

It is also emphasized that the context should also be described (see above), as well as:

- Historical, existing or planned use of the subsurface in the region, such as: ground water extractions, oil, gas or coal production (including unconventional oil/gas), geothermal energy, waste disposal, gas storage, etc.
- Land use in the region such as population centers, industry, agriculture and infrastructure
- Surface or marine conditions and environment
- Protected and sensitive areas such as national parks, drinking water sources
- Social context
- Legal and regulatory environment for CO_2 storage

2. Screening Plan

A screening plan should be developed to describe the scope of the activities to be carried out. It is recommended that this plan considers the following factors (modified after DNV's recommended practice):

- the data that will be used for screening; where this data will be obtained
- how this data will be used to identify potential storage sites
- how storage capacity will be calculated

- how existing wells will be identified and risk assessed
- how other potential leakage risks will be identified and risk assessed
- how potential conflicts with other sub-surface resources or land-use claims will be identified
- how the location of potential storage sites will be evaluated with respect to the location of CO_2 sources
- how storage cost may be estimated
- which stakeholders will be involved or informed during the screening process
- stakeholder's needs for information and involvement, providing the rationale for the communication; strategy and for future engagement
- How legal and physical accessibility to storage sites will be assessed.

The plan should also describe the scope, team, resources, schedule and budget for the activity.

3. Data Collection

As noted above, this activity is mainly based on information from existing sources. Acquisition of new information, reports or data through early stage appraisal activities may be needed in data poor areas. Data review should also document data gaps to be addressed in future stages.
The following information and data should be accessed where available:

- Reports, literature and publications on the regional geology, tectonics, stratigraphy, hydro-geology and any oil and gas fields.
- Regional well and seismic data
- Regional isopach, structure, thickness, facies maps for geological formations of interest
- Available information on oil and gas fields (geology, reservoir characteristics, production and reserves, infrastructure, etc.)
- Social and environmental data

4. Data Review and Storage Identification

The review work should assess the geological formations, structures and oil and gas fields in the region of interest to determine their potential to meet the screening criteria that have been set. This must consider and assess the potential of the major storage types:

- EOR/EGR potential in known oil or gas fields
- Depleted Field Storage, i.e. potential for storage after oil and gas production ceases when the fields are depleted.
- Deep Saline Aquifers

Less mature and unproven storage options may also be considered, such as Enhanced Coal Bed methane, storage in unmineable coals and storage in Basalts and organic shales. The status and validation and commercialization risk of these options should be reviewed.
Each oil/gas field and formation should be assessed in terms of its suitability for EOR/utilization or storage, including an assessment of:

- reservoir characteristics,
- EOR suitability screening
- capacity and injectivity,
- seal or containment,
- Availability and any conflicting resource constrains or usage (EG gas storage, water extraction).

- Potential storage risks

Usually the method and data availability and confidence are different for oil and gas fields from Deep Saline Aquifers. This reflects the data and knowledge for oil and gas fields from resource exploration, development and production history (although the data and information may not be available to the proponent).

5. Oil and Gas fields

At the screening stage the assessment is usually focused on potential for utilization and enhanced recovery, together with capacity estimation. Assessment of storage potential after field depletion should also be considered (i.e. Depleted Field storage). These are usually based on any published field information on field geology, reservoir characteristics, reserves and production. Early stage screening for CO_2 EOR typically involves desk-top review of available information for all oilfields in a region against published criteria for CO_2 EOR (E.G. NETL, 2012). Because of the limitations to this type of approach discussed in Section 3 d, overly-prescriptive use of such criteria should be avoided and the uncertainties must be carefully considered.

Lack of up-to-date data is often a constraint for storage assessments except where field information is available from field operator. Because of the trapping of oil and gas, containment and trapping is implicit for a potential site. One of the key risks for storage in oil and gas fields is leakage risk associated with wells; lack of data can be a barrier to assessing this.

6. Deep Saline Aquifers

Each formation in the basin/study area needs to be assessed using available data and information in terms of:

- Reservoir characteristics and suitability as an injection/storage target. This should be based on thickness, depth, porosity, permeability characteristics, facies variations, heterogeneity, diagenesis and mapping.
- Sealing/containment potential of one or more overlying formations. Usually these are assessed in terms of thickness, extent and facies at this stage but additional data relating to seal properties, or evidence from oil and gas field analogs is beneficial.
- Structure mapping, cross-sections, geological maps and seismic to investigate evidence for structural trapping and faulting. Note that storage may be possible in structural traps or by a combination of capillary processes and dissolution in unstructured areas.
- Capacity estimation. Initial estimates can be made using a range of methods with a range of complexity. These may be simple volumetric methods, analytical or semi-analytical or three dimensional models/simulations. It is important that uncertainties in assumptions, methods and estimated capacities are recognized and understood.
- Injectivity estimation may be based on regional reservoir information. Uncertainties are likely to be high at this stage.
- Hydro-geology to identify potential issues with water usage.

Both the lack of access to existing seismic and well data, and lack of actual data may be major gaps for storage of this type. Any requirement for data acquisition through exploration and appraisal activities needs to be assessed and incorporated in forward plans. This may have significant cost and time implications. A storage exploration permit may be needed if required by regulations that are put in place.

7. Uncertainty

Because of data constraints and lack of information, there are likely to be high levels of uncertainty associated with the assessments of storage potential at this stage. It is very important to document and describe the uncertainties in assumptions and the assessment of potential and any estimates of e.g. storage capacity. DNV's Recommended Practice outlines a methodology for this (DNV, 2012).

8. Risk Assessment

In view of the importance of storage safety, it is recommended that an initial assessment of storage risks is conducted at this stage. This should focus on potential leakage risks and containment risks for each site. A risk register may be developed to identify potential risks and their impacts, together with mitigating actions including those that may be taken during subsequent stages of storage assessment.

9. Geographic, social and environmental screening

The second major component of site screening stage is regional screening to determine whether there are major geographical, social and environmental challenges or issues in all or part of the study area. These might include:

- Cities, towns and population areas (including any future sites)
- Industrial areas
- Protected and sensitive areas such as parks
- Existing resource development areas
- Transport and energy infrastructure

These can be evaluated using GIS mapping to high graded or to delineate accessible, inaccessible and/or areas where further issues may need to be addressed.

10. Selection of Prospective Sites

The final stage of the screening activities is to summarize and synthesize the assessment work. Each storage site or storage area (within prospective formations) should be assessed against the screening criteria. These results are likely to include a mixture of qualitative and semi-quantitative information, and the uncertainties should be described. If the findings are positive for a site or area it should be regarded as prospective for storage. If more than one site/area is prospective, the proponent should take this into account the uncertainty and risk assessment to assist in prioritizing future work. Sites should be high graded for future work. The results should be documented in a report.

11. Further Resources

Useful references providing detailed guidance on the activities are documented below:

- NETL Best practices for: Site screening, site selection, and initial characterization for storage of CO2 in deep geologic formations. (NETL, 2013). Pages 11-19.

- Recommended DNV Recommended Practice (DNV, 2012). Pages 13-17. Includes useful checklists for screening activity.

D. Other Activities

In addition to the technical work described above, other non-technical activities involving the storage team or storage input need to take place during this stage. These may include:

- Project planning and preparatory work for next stages of activity. Project plans should be developed describing further work for storage assessment, data acquisition and project integration with capture and transport. To include scope, schedule and budgets.
- Partnering strategy. Identification and selection of suitable and committed partners is important. Early dialogue and engagement with industrial partners is important, particularly where initial screening is conducted by institutes and researchers. Oil companies are likely to be key partners for data access, further assessment of storage in oil and gas fields and any industrial storage plans or CO_2 EOR in oil and gas fields.
- Policy/regulatory advocacy.
- Stakeholder engagement.
- Project funding strategy/plan.

VI. SITE SELECTION STAGE (GCCSI EVALUATE STAGE)

A. Introduction

The purpose of the site selection stage is to further evaluate previously high graded areas to develop and select a site or shortlist of high graded storage sites. It is essential that the storage database is augmented at the beginning of this stage. Unless previously available, it must be extended to existing seismic data and deep well data in the region of interest plus information from oil and gas fields, particularly those that are candidate sites. This is likely to require cooperation with or participation of oil companies. It is unrealistic to progress CO_2 utilization or depleted oil and gas field storage options through this stage without the cooperation or participation of field owners.

As for the previous stage, the assessment work is multi-disciplinary in scope and brings together subsurface/geological studies with other activities, both technical and non-technical. All the studies should be in greater detail than the previous stage so as to reduce uncertainties and risks. Closer integration is required with capture and transport activities and overall CCUS project development, policy and regulatory development, communications and outreach.

The output of the stage is a shortlist of sites or single site to take forward for further evaluation, appraisal and project development. It can be desirable to have more than one site to mitigate risk that the highest rated site is not suitable or available after further evaluation. Alternatively some projects may be planned to inject in more than one storage site or storage options type (e.g. the Guohua project proposal in Ordos is currently considering injection for EOR and Deep Saline Aquifer).

B. Project Definition and CCUS Integration

By this stage initial discussions between storage proponents and plant/capture proponents should have progressed. The overall CCUS concept(s), project(s) scope, options and potential partners should be better defined than at the start of the previous stage. As for previous stage, the context for storage site selection must be described as part of the storage assessment work and will depend on the strategic rationale, project concept(s), CCUS option(s), drivers and goals of the overall CCUS activity. The context should therefore document the following factors which are all essential inputs to the storage screening assessment:

- Strategic rationale for the project
- Pilot test, demonstration, commercial deployment and/or cluster
- Project concept(s).
- Locations of current or planned emissions sources and capture sites with mass and composition of CO_2 streams from the sources
- The rates of CO_2 supply and expected duration (including any extensions and expansions); these are the injection requirements for the project(s)
- Transportation plans.
- The total amount of CO_2 that may need to be stored over the lifetime of the proposals
- The timing, schedule and target dates of any specific CCUS concepts and projects

C. Storage Assessment Activity

1. Database

As mentioned above, the storage database needs to be augmented for this stage. It is desirable for the project team to access as much of the following as possible over the area of interest:

- Regional 2D/3D seismic datasets
- Information and data from deep well control. To include stratigraphic, log, reservoir properties, caprock properties, pressure data, core data, test data, fluid properties, etc. Where possible, drilling and abandonment data, leak off test data
- Oil and gas field information and data, including geological models, reservoir properties, reservoir models, trap and column height information, reserves data, production profile and data.
- Hydrogeological data (location and properties of drinking water aquifers)
- Environmental data

A detailed tabulation of main data types is included in Table 7.

Table 7: Summary of Main Data Types for Site Assessment (DNV CO_2Qualstore, 2010)

Assessment Type	Data Type or Format
Geologic	
Detailed subsurface maps (Stratigraphy, structures, lithofacies, paleo depositional environment, seismicity/tectonic model and structure)	3D digital model and database. Several suppliers of advanced commercial software in the O&G industry which can also be used for CO_2 storage projects.
Reservoir	
Reservoir hydraulic unit geometry and dynamic flow properties (quality)	3D digital model and database
Core analyses on target formation and primary cap rock (Microfossils, petrography, clay particle assay, paloefacies, porosity, single-phase permeability, relative permeability, capillary entry pressure, rock strength parameters, mineralogy, lithology, natural noble gas content assay, etc.)	Reports with core photographs, descriptions and documentation of sample collection, management, analytical procedures and results.
Hydraulic tests in wellbores (Repeat formation test, drill stem test, leak-off test formation integrity test)	Reports with documentation of analytical calculations and modeling results
Geochemical and Fluid	
Water salinity and composition	Reports on fluid sampling and compositional analysis
Reservoir hydrocarbon composition and PVT behavior	Reports on fluid sampling and compositional analysis
Injection stream composition	Reports on capture plant process modeling
Geophysical and Wellbore	
Seismic 2D, 3D, VSP, cross-well, etc.	Seismic data
Electrical tomography baseline and subsequent dynamic response	Electrical data
Passive seismic baseline “noise” and signal, subsequent dynamic response	Seismic data
Well integrity assessment of existing wells	Location and well/abandonment design (and operator)
Wireline logging	Well logs (Gamma ray, porosity, sonic, density, repeat formation test, cement quality, causing corrosion and borehole images)
Geomechanical	
Pore pressure, in situ stresses, regional stress regime, rock strength (reservoir & caprock), leak-off test results	Geomechanical data
Surface	
Surface deformation (vertical movement and or tilt	Both titlmeters and satellite imagery can potentially be

Assessment Type	Data Type or Format
baseline)	applied on shore. No offshore solutions currently available although prototypes of subsea tiltmeters have been proposed by specialist suppliers.
Surface gas fluxes and signals baseline response	Critical parameters are spacing and placement of measurement points. Must prioritize most likely leak spots as wells as determine an integrated baseline flux, which can vary orders of magnitude due to variations in seasonal and meteorological conditions.
Socio-economic	
Infrastructure, economic, and regulatory framework for risk analysis of leaks on surface due to storage site activities	Written reports

Note: This table is focused on subsurface data types. Additional hydrogeological and environmental data is also desirable. Production and reserves data are desirable for CO_2 Utilization and Oil and Gas field storage option.

It is also important to identify and document data gaps required for full assessment during this stage of activity. These may include the requirements for further appraisal for data acquisition in deep saline aquifers, e.g. seismic and drilling new well(s).

2. Site Assessment Activities

A plan for the storage site selection stage should be developed at the start of the stage. This should consider the basis for site selection and project context. The scope, schedule, resources, budget and deliverables should be described. One consideration is whether third party certification is envisaged and if so this should be incorporated in the plan.

The activities are undertaken to provide a more detailed characterization of each potential storage site or area based on the seismic and well data set. Each option needs to be assessed in relation to the detailed criteria in the table shown above. The scope and amount of work required differs between storage options for oil and gas fields and deep saline aquifers, as discussed further below.

Table 8 shows the activities required in this stage. This draws on the US NETL Best Practice Document (NETL, 2013) and DNV's CO_2 Qualstore (DNV, 2010). It has been modified and supplemented to provide a comprehensive list of the storage assessment activities in this stage in Chinese context. It is noted that the US NETL Best Practices criteria are developed around US regulatory requirements and DNV's focus heavily on European requirements, whereas different requirements may be developed in the PRC. However the issues covered are all important from a standpoint of ensuring storage security and managing storage risk and may be incorporated in future regulatory frameworks in the PRC.

Table 8: Site Selection Activities (supplemented, updated and modified after NETL, 2013)

ELEMENT		GUIDELINES FOR SITE SELECTION
Subsurface/ Data Analysis	Injection Zone	• Define injection zones (reservoirs) based on information, well data and seismic interpretation. Analysis should include development of a regional stratigraphic column identifying potential storage types and injection and confining zone(s), potential drinking water aquifers, and oil and gas reservoirs and seals. • Compile and map reservoir properties from well data such as lithology, depositional environment, porosity, permeability, thickness, net/gross ratio, pressure, temperature, mineralogy,

ELEMENT	GUIDELINES FOR SITE SELECTION
	• shale content, and dynamic formation evaluation data (DST, well test, production/injection data). • Review reservoir depositional environments, heterogeneity and continuity from reservoir data and field analogs. • Compile structure and isopach maps of injection and confining zone(s); regional cross-sections; well correlations, regional tectonic maps and analogs.
Topseal, caprock or Confining Zone	• Establish the areal extent, thickness, lithology, porosity, permeability, capillary pressure data, and other factors that might affect integrity of the confining interval(s) within the topseal. • Use existing well, core, outcrop and regional analog data to identify and map confining interval(s) tops, bases and thicknesses within the confining zone. • Attempt to access and review leak-off and fracture pressure data.
Seismic mapping, Structural interpretation and Geomechanics	• Existing regional 2D or 3D seismic data should be used to validate and/or help define the regional stratigraphic and structural framework. Seismic attribute data should be used to help characterize the confining zone, the injection zone, trapping mechanisms and storage risks. • Structural interpretation and geomechanics screening should be conducted and integrated with maximum injection and reservoir pressure data to assess storage risk and to avoid induced seismicity and caprock fracturing. • Perform fault seal analysis based on tectonic history, site mapping, field data and/or analogs. • Natural seismicity data should be reviewed.
Trapping Mechanisms	• There are several mechanisms that effectively "trap" injected CO2, including physical barriers, as well as physical and geochemical processes. • Evaluation of trapping mechanism should be based on the local field, well, outcrop and any available regional reservoir analyses including analogs in similar formations. Seismic data, mapping and modeling should be incorporated.
Potential Injectivity	• Use collected data and analyses to estimate potential permeability-thickness of targeted injection zone and identify boundary conditions that will affect injection estimates; assess well count, well stimulation and completion scenarios to achieve target injection rates.
Prospective Storage Capacity	• Prospective storage volumes should be calculated utilizing existing and acquired data, reporting resource volume ranges (low/medium/high) with identification of uncertainties in • calculations. The reservoir evaluation should be used in calculation of prospective storage with all parameters and sources defined, such as “efficiency” calculations. • If no other methodology is preferred, CSLF or DOE 2010 resource calculation methodology may be applicable. • All Storage Capacity Calculations should be reported assuming a maximum storage pressure and either an open or a closed system for brine displacement. Maximum injection pressure should be estimated to avoid fault reactivation and fracturing.
Well Integrity	• Review any regulations for wells that may be applicable. Consider proposed or possible future regulatory requirements

	ELEMENT	GUIDELINES FOR SITE SELECTION
		for the operation, maintenance and eventual abandonment of wells. • Identify all existing wells in the area of review. • Initiate an analysis of wellbore integrity for all existing wellbores in the study area by using existing data and identifying data needs for further evaluation. Conduct an initial review of potential corrective measures.
Modeling	Modeling Parameters	• Identify type of model(s) (static and dynamic) and modeling parameters. • Parameters should be defined by the results of the subsurface • geologic evaluation, including injection zone characteristics, confining zone mechanisms, and available rock and fluid properties. • The model should be based on subsurface data; grid dimensions and layering definition based on the reservoir analysis and likely plume extent. Analog data should be utilized to populate parameters with data gaps.
	Modeling	• Model representative scenarios for injection of CO2 consistent with project context and site characterization and injection needs. • Review plume development, pressure evolution, potential storage risks and trapping implications. Particular importance to reservoir compartmentalization. • Model enhanced oil/gas recovery and CO_2 utilization where applicable. • Water extraction for pressure control may also be modeled.
	Data Requirements and Cost	• Identify data requirements to reduce model uncertainty; construct cost analysis to determine the value of acquiring data. Data acquisition should balance the benefit of reducing uncertainty against cost of acquiring it at this stage.
	Uncertainty	• Uncertainties related to assumptions and boundary conditions should be identified, documented, and communicated to project stakeholders to avoid over extrapolation of the model results and creation of non-relevant or incorrect data. • Modeling sensitivities should include both open and closed boundaries for brine flux and future pressure estimates.
Storage Risk Assessment and Management	Regulatory Framework	• Review all applicable legal and regulatory constraints, e.g., surface/subsurface access and ownership, areas excluded from storage, • Review existing and possible future regulatory requirements for • demonstrating the long-term storage integrity, containment and trapping mechanisms. • In the absence of regulatory frameworks, initiate discussions with relevant authorities.
	Storage Risk Assessment	• Review potential containment risks for faults, caprock, pressure modeling and risk of exceeding fracture pressure. • Review pre-existing wells for well integrity. • Use all data, analysis and modeling to identify potential containment risks and potential mitigation actions. • Describe activities to mitigate risk during further site characterization (EG data acquisition) • Produce a Preliminary Storage Risk Register and Assessment
	Liability	• Consider possible provisions for addressing financial assurance

ELEMENT		GUIDELINES FOR SITE SELECTION
		and liability that may be introduced. As necessary, incorporate into the project plans.
	Monitoring	• Conduct a preliminary study to determine if there are obvious barriers to effective monitoring at the site.
Storage Appraisal	Appraisal Planning	• The adequacy of data coverage and content for the EOR and storage assessment and data gaps should be reviewed. • CO2 Utilization/EOR projects should also review the need for laboratory analyses(e.g. MMR testing), core flood, injection • or pilot testing • Storage proposals (especially Deep Saline Aquifers) need to review requirements for additional data acquisition including, seismic surveys, exploration and appraisal drilling, injection testing and laboratory analyses (e.g. caprock samples). • If required the plans, appraisal risks, budget and schedule • impacts should be determined. These need to be communicated with and explained to CCUS partners as they may have significant CCUS schedule impact
Development Concept, Costs and Economics	Wells & Development Concept	• Determine the number of wells and well types required to meet project requirements based on reservoir, injectivity analysis and modeling studies. • Determine the facilities and infrastructure concept requirements for the utilization or storage development concept(s), including options. • Review the scope to re-use existing wells and facilities for the storage project. Screen feasibility in respect to integrity, materials, safety and conversion feasibility and risk.
	Cost Estimates	• Develop preliminary capital and operating cost estimates for development concepts. • Assess costs associated with any well remediation or well and facilities conversion and re-use. • Incorporate preliminary monitoring costs (from literature).
	Economics	• Conduct screening economics for the storage site and determine storage costs (RMB/T CO_2 stored). • Integrate storage input to initial CCUS project economics.
Other (Non-technical)	Availability	• Review availability of any oil and gas fields, infrastructure and wells. Understand owner's depletion and abandonment plans and schedules.
	Conflicts of Use	• Review all potential conflicts of use of the surface and subsurface at the site, including future coal, oil and gas development (including unconventionals), gas storage, groundwater, wind farms, geothermal, etc.
	Social and environmental	• Review all potential social and cultural and environmental constraints that may impede the likelihood of project approval/public acceptance. • Acquire and review relevant environmental data, e.g., maps or regional groundwater, surface water, sensitive terrestrial and marine ecosystems, and land use (for onshore storage sites).

3. Oil and gas fields

Databases and information should be fairly extensive for utilization and storage options in oil and gas fields and producing regions. Pre-existing information will usually meet many of the basic site characterization requirements in relation to field geology, injection zone and reservoir

properties. All Pre-existing information, mapping and understanding should be reviewed for completeness and updated if necessary. In addition the trapping of oil and gas provides empirical evidence for the trapping and containment of CO_2, although data on caprock properties may be limited and data acquisition requirements should be assessed.
At this stage additional assessment work is usually focused on modeling and understanding performance and impacts of CO_2 utilization and storage. These would include physical and chemical and geomechanical impacts of introducing CO_2. The criteria listed in the Table should be reviewed as necessary. The following issues have arisen in international projects for EOR or depleted field storage projects and need to be considered:

- The technical feasibility of CO_2 EOR in relation to minimum miscibility pressure, injectivity and potential impacts of CO_2 on reservoir and wells.
- Need for laboratory analyses, CO_2 injection testing or pilot testing prior to scale up of EOR.
- The performance characteristics and economics of CO_2 EOR in relation to oil production, CO_2 utilization and storage.
- The availability and timing opportunities taking account of production depletion profiles, abandonment plans and alternative future uses of the site.
- Ability to re-use field infrastructure, wells and facilities, taking account of the age and integrity of the equipment, etc.
- Well integrity risk associated with pre-existing wells especially for older fields. This may be of particular importance for older onshore fields in the PRC where some wells may be over 50 years old.

4. Deep Saline Aquifers

Because databases, previous information and geological understanding are usually limited for deep saline aquifer options, considerably more geological and geophysical assessment work is usually required than for oil and gas storage in this stage. This includes study and review of the geological framework, storage injection zone(s), containment zone(s), structure and trapping based on available well and seismic data.

Data availability and data gaps need careful review during this stage in terms of their adequacy and coverage for detailed site characterization and permitting prior to investment. A major consideration for deep saline aquifer storage is the requirement for new exploration and appraisal activities in the site characterization stage to prove sites in a practical sense (Senior et al, 2010; GCCSI, 2010). This may involve seismic reprocessing, 2D/3D seismic acquisition and drilling new wells, coring and injection tests.

Large scale deep saline aquifer projects in Australia (Zerogen), Canada (Quest) and UK (5/42) have all required new appraisal wells. This can substantially increase the amount of time required from initial screening to the project investment decision to as much as ten years for some sites depending on data availability, the status of licensing and regulatory frameworks and the pace of stakeholder approvals. There are also funding considerations for this activity as Industry has been reluctant to conduct these activities without government funding. Finally there is risk that the appraisal activity may not allow the site to be validated (partly analogous to exploration risk in the oil industry).

It is essential that CCUS project plans, schedules and budgets for projects using deep saline aquifer consider these issues.

5. Uncertainty

Although the uncertainties gradually diminish as more work is conducted, it continues to be essential to understand and describe the uncertainties in the assessment through this stage.

6. Risk Assessment

The storage risk assessment at this stage should be based on all the studies conducted although it may remain fairly high level. It is important to identify all key issues and risks and activities together with data acquisition and detailed assessment work to be during the next detailed stage of assessment that may mitigate these.

7. Social and Environmental

It remains important at this stage to understand whether there are major geographical, social and environmental challenges or issues that may affect the sites being considered. These might include:

- Cities, towns and population areas (including any expansion plans)
- Industrial areas
- Land use
- Protected and sensitive areas such as parks
- Existing resource development areas
- Transport and energy infrastructure
- Public acceptance

Public attitude surveys may be initiated to understand the stakeholder attitudes to CCUS and storage and to identify possible issues.

8. Site Selection

The final stage of the activities is to summarize and synthesize the assessment work. Each of the storage site or storage area (within prospective formations) should be assessed against the screening criteria. The preferred site (s) should be selected for future work. Data gaps and data acquisition requirements for each site should be determined and the results should be documented in a report.

9. Further Resources

Useful references providing detailed guidance on the activities are documented below:

- NETL. Best practices for: Site screening, site selection, and initial characterization for storage of CO_2 in deep geologic formations. (NETL, 2013) pages 19–30.
- Recommended DNV Recommended Practice (DNV, 2012).

D. Other Activities

In addition to the technical work described above, other non-technical activities involving the storage team or storage input need to continue during this stage. These include:

- Project planning and preparatory work for next stage of activity pre-FID. It is essential that project plans should be describe further work and data acquisition, particularly any seismic, drilling or injection testing. Alignment of project schedules and integration with capture and transport is important.

- Partnering strategy. The engagement and support of suitable industrial partners is essential by the end of this stage. Oil companies are likely to be key partners for data access, further assessment of storage in oil and gas fields and any industrial storage plans or CO_2 EOR.
- Policy/regulatory advocacy. Understanding the policy and regulatory landscape and likely future requirements is of growing importance through project development. Maintaining dialogue and engagement is essential
- Stakeholder engagement.
- Project funding strategy/plan.

VII. SITE ASSESSMENT AND CHARACTERIZATION STAGE (GCCSI DEFINE STAGE)

A. Introduction

The site assessment and characterization stage is the final period before FID. It involves detailed site characterization, storage permitting, development planning, design and FEED studies ahead of the FID and permitting of project. It is therefore essential that the data acquisition and activities conducted meet all the technical, qualification, investment, permitting, regulatory, funding, financing requirements and approvals of all relevant stakeholders. These include investors, regulators, government, funders, qualifying agencies and communities.

As with previous stages a detailed plan and a multi-disciplinary team should be prepared at the start of the stage. The team size is likely to be larger than prior stages with greater involvement from specialist and non-subsurface disciplines, including geomechanics, geochemistry, drilling and wells, facilities engineering, environmental, commercial, finance and legal.

It is essential that, to the extent possible, all existing geological and seismic data, well logs, cores and production data are accessed by this stage. Data gaps should be addressed at the start of the period. Where existing data may not be sufficient or suitable to complete the characterization of the storage site(s) or storage complex, it may be decided to acquire additional data during this stage as explained above. The data acquisition may include:

- 2D/3D seismic data
- Drilling new exploration or appraisal well(s), acquiring new data such as well logs and cores, drill stem tests (DSTs), injection tests, reservoir fluid, pressure and temperature sampling.
- Analyses of existing or new core samples; including geomechanical samples, conventional and special core analyses.
- Conducting injection tests or pilot projects.

Because of data acquisition requirements and the iterative nature of some work, and the possible requirement for FEED studies, it is likely further staging of activities, sub-stages and milestones of activity may be involved. If so, clear milestones and processes should be used to decide whether the project proceeds. The risk that the project may not progress should be noted. A recent study in Europe has highlighted the iterative nature and sub-stages that may be involved in the activities and work packages through this period of activity (Figure 4: Figure illustrating iterative staged nature of Site Characterization activities (from EU SiteChar project, 2013).

Figure 4: Figure illustrating iterative staged nature of Site Characterization activities (from EU SiteChar project, 2013)

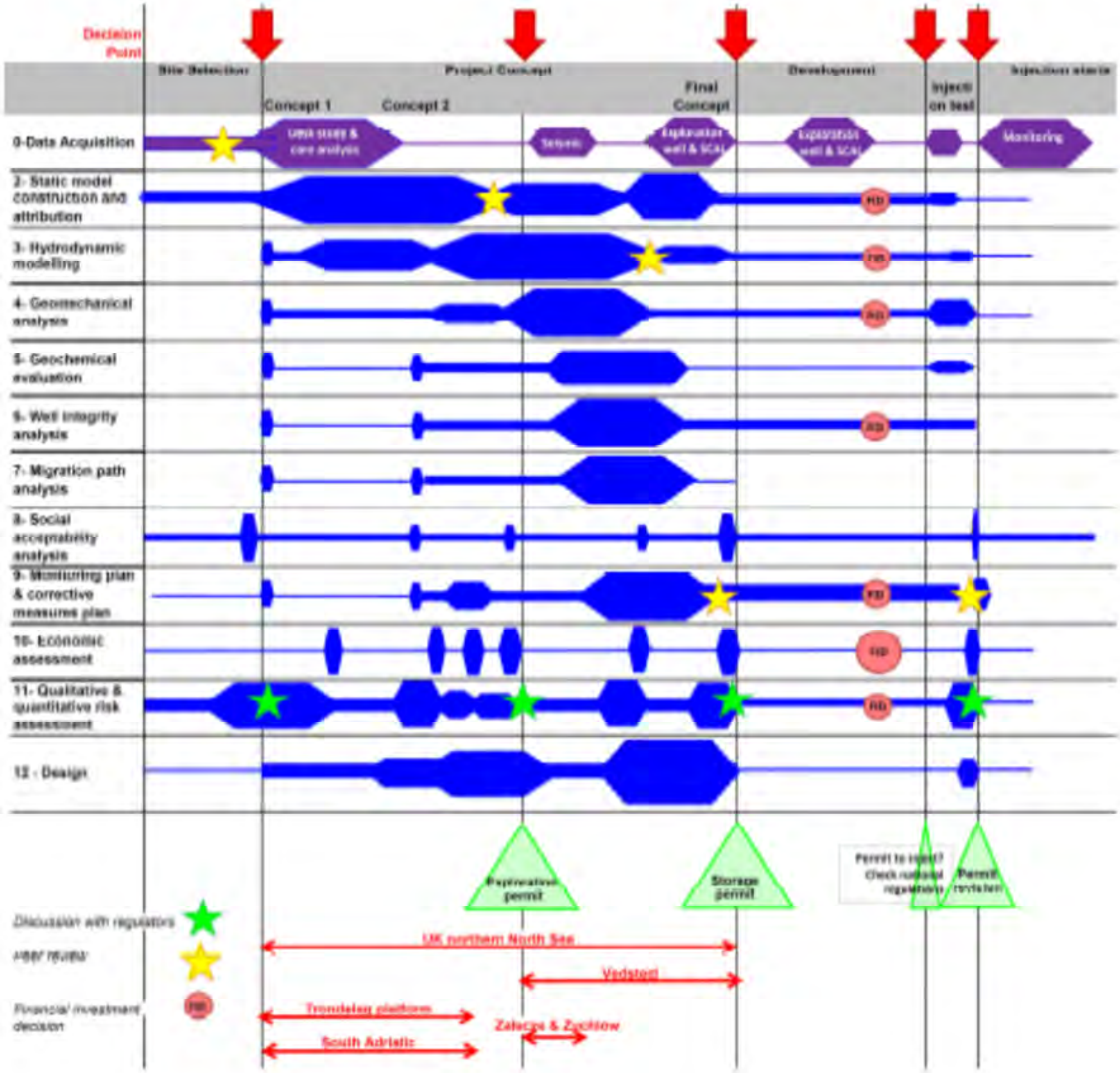


Figure 3.1a. SiteChar recommended process. This timeline has to be understood as schematic, the height of the different boxes roughly indicating the amount of work required for each step of the workflow.

B. Project Development and CCUS Integration

By this stage both the storage/utilization and overall CCUS project concepts should be agreed and the plant location, CCUS technology types, transport type and route and storage site(s) should be selected.

The storage context and concept should therefore document the following factors which are all essential inputs to the storage characterization and development planning:

- Strategic rationale for the project.
- Pilot test, demonstration, commercial deployment and/or cluster.
- Project concept(s).
- Locations of project emissions sources and capture sites with mass and composition of CO_2 streams from the sources.

- The rates of CO_2 supply and expected duration (including any extensions and expansions); these are the injection requirements for the project(s).
- Transportation plans, routes and delivery conditions.
- The total amount of CO_2 that may need to be stored over the lifetime of the proposals.
- The timing, schedule and target dates of the specific CCUS project proposal.

During this stage the Development Plan for storage is prepared. This involves detailed design and engineering. The technical interfaces and integration with capture and transport are developed and cross-chain engineering requirements have to be addressed, including CO2 composition, flow rates, operating plan, availability, metering, etc. Commercial integration activity is also required.

C. Storage Assessment Activity

Table 9 below shows the activities required in this stage. This is derived from the US NETL Best Practice Document (NETL, 2013). However it has been updated, modified and supplemented to provide a list of the technical storage assessment activities for this stage in the Chinese context.

Table 9: Site Assessment Activities during Site Assessment and Characterization stage

COMPONENT	ELEMENT	GUIDELINES FOR INITIAL CHARACTERIZATION
Subsurface/ Data Analysis	Geological	• Develop site specific geologic baseline of qualified site(s) including type log/stratigraphic column; detailed correlation of reservoir architecture including injection intervals within the injection zone and potential confining intervals within confining zone; detailed structural maps; interpreted depositional model and facies distribution; porosity maps for potential injection and confining intervals and zones; and porosity/permeability log transforms. • Use site geological characterization as input to Static Geomodel. • These evaluations should be updated as additional information is acquired (seismic and well data). • Develop geological models and characterization of overburden to assist in leakage pathway analysis and storage risk assessment. Identify secondary reservoir and containment zones.
	Geochemical	• Develop baseline of groundwater in all overlying aquifers using fluid and fluid level data collected in shallow aquifer formations in offset wells. • If available, collect rock and fluid property data (composition, geochemistry, pH, conductivity, mineralogy) from the injection zone to study and model formation fluid-CO_2- rock reactions in the injection zone and at confining zone interfaces.
	Geomechanical	• Analyze advanced logging suites from offset wells and characterization wells (if any exist) to identify faults and fractures, in-situ stresses. • Analyze new or existing core to determine geomechanical properties of intact rock, fractures, and faults. • Develop baselines for injection rates and pressures utilizing drilling data on formation strength and modeling. • Assess the impact of changes in pore pressure on stress and the potential for induced seismicity.

COMPONENT	ELEMENT	GUIDELINES FOR INITIAL CHARACTERIZATION
	Hydrogeological	• Determine fluid compositions and injection zone flow units from new or offset well data, fluid samples, and hydrologic and other tests; integrate into dynamic injection zone models and compare to the existing hydrological model. • Conduct multi-well tests where possible. • Injection zone fluids and hydraulic tests should be further • investigated during the Site Characterization Phase and fluid samples should be collected if a new well is drilled or an existing well(s) is further tested.
Dynamic Modeling	Test Model	• Models should be optimized to allow for numerous model runs with varying parameters and boundary conditions; tested for mode functionality; and assumptions, uncertainties and impact parameters of model should be documented.
	Input Data / Scenario Analysis	• Continue to integrate new data and analyses into the static and dynamic models this should include offset well data parameters such as porosity, permeability, and potential baffles, heterogeneity or sealing faults in the reservoir. • Develop and run various modeling scenarios for a range of parameters in order to test the injection design, optimize plume migration, and verify the expected definition of area of review, subsurface processes, and prospective storage estimates. • Assess cost and benefit of formation water (brine) withdrawals.
	Compare Outputs	• Compare results of previous models runs with newly modeled data to ensure consistency and model functionality. Update the preliminary models if necessary.
Storage Risk Assessment and Management	Regulatory Framework	• Review all applicable legal and regulatory constraints, e.g., surface/subsurface access and ownership, areas excluded from storage, • Review the current national and provincial regulatory requirements for site characterization activities including permitting and acquiring seismic data; permitting stratigraphic, injection, or monitoring wells. • Review existing and possible future regulatory requirements for demonstrating the long-term storage integrity, containment mechanisms and trapping mechanisms. • Identify data gaps requirements, lead agencies and timelines for permitting process; update project timelines accordingly. • Collaborate with identified agencies for initial approval for both the well plan and any potential development plans to confirm that assessments are in alignment with relevant regulations. • Identify and assess existing well bores (locally and regionally) within the storage complex for well integrity. Review all requirements for carbon storage (e.g., pipeline development, land access, pore rights) in site area, plan for compliance and understand cost implications to project. • In the absence of regulatory frameworks, discuss and seek approvals from relevant authorities.
	Storage Risk Assessment	• Review potential containment risks for faults, caprock, pressure modeling and risk of exceeding fracture pressure. • Review pre-existing wells for well integrity. • Use all data, analysis and modeling to identify potential containment risks and potential mitigation actions. • Describe activities to mitigate risk i) during further site

COMPONENT	ELEMENT	GUIDELINES FOR INITIAL CHARACTERIZATION
		• characterization (EG data acquisition), ii) during development and ii) during operations stage • Conduct an Impacts assessment for potential leakage of CO_2 from the site. • Produce a Storage Risk Register and Storage Risk Assessment
	Monitoring Plan and baselines	• Develop a site specific monitoring plan. This should be based on the site characterization and Storage Risk assessment. • Plan baseline data acquisition to establish baseline readings of near surface, ground level, and shallow subsurface fluxes. • Baseline monitoring could be conducted during Initial • Characterization (or planned for prior to injection) and conducted for at least a year to account for changes in flux reading due to seasonal changes. • Conduct review and cost benefit analysis of monitoring wells. • Nearby urban, industrial or agricultural expansions and developments may require re-establishing a baseline prior to injection.
	Remediation Plans	• Prepare corrective measures (remediation) plans as needed based on regulatory frameworks, site characterization, storage risk assessment and monitoring plans.
	Liability	• Consider possible provisions for addressing financial assurance and liability that may be introduced. As necessary, incorporate requirements into the project plans, budget and economics.
	Closure Plan	• Consider possible provisions for site closure that may be introduced. As necessary, incorporate requirements into the project plan and budget.
Site Development Plan	Well Plan	• Develop plan for well design, construction, testing, completions, injection and monitoring in compliance with current and anticipated regulations and industry best practices for all types of wells being planned. • Update cost estimates for wells and booster compressors, if needed.
	Initial Development Plan	• Develop a site development plan. • Address all aspects of a commercial site based on surface, subsurface and modeling analyses and the criteria established in Project Definition. • Plan should be site specific and include data acquisition plan for the Site Characterization Phase • Plan should describe required infrastructure - number of wells (injection, monitoring, and reliability, and water production if needed), compression, pipelines, processing, • platforms or subsea equipment (offshore). • Plan should include water extraction and disposal for pressure management as applicable. • Plan should address all applicable Health, Safety and Environmental risks and regulations. • Plan should include MVA and reporting plans, Operating Plan and mitigation plans and outreach plans. • Update analysis of project economics and review results with investors and regulators.
	FEED Study	• Conduct a front end engineering and design (FEED) study in alignment with the initial Site Development Plan to identify any

COMPONENT	ELEMENT	GUIDELINES FOR INITIAL CHARACTERIZATION
		• engineering or design issues. Note this should be conducted after results of any appraisal seismic/wells are incorporated. • Update project costs and economics based on FEED and review results with investors and regulators.
	Develop Tender Requirements	• If project is viable and approved, develop tender requirements to implement the Site Development Plan should be written and potential contractors asked to qualify for tender. This will aid in further defining the total costs associated with specific sites and validate that the site meets project defined economic thresholds.

As at the previous stage, the scope, nature and duration of the assessment activities differs between utilization and storage options in oil and gas fields and deep saline aquifers. Specific considerations for these are discussed below.

1. Oil and gas fields

Although there is extensive legacy data in oil and gas fields, it may be desirable to acquire additional data in some cases. For example further laboratory analyses of core samples may be conducted to provide data on caprock or reservoir properties. Additional analyses, injection or pilot tests may be required for CO_2 enhanced oil recovery.

Although generally well understood, the site characterization and modeling of oil and gas fields may need reassessment if previous geological studies and/or reservoir models are not up to date or if there have been difficulties history matching production. In addition the site characterization activity needs to evaluate the impact of CO_2 injection and storage on the storage site and complex particularly in respect to CO2 trapping, containment and leakage risk. The subsurface activity should include geomechanical, geochemical studies, dynamic modeling of the reservoir with CO_2 injection under representative scenarios, and activities related to trapping, storage integrity assessment, risk assessment and risk management. These may need to encompass the storage complex, including the overburden (which may not have been studied in detail) and wells. Review well integrity long-term CO_2 storage for all existing wells, based on drilling and abandonment records is a key task, of particular importance for older oil fields. Further detail and methodology is provided in DNV's CO_2WELLS report (DNV, 2011).

CO_2 enhanced recovery projects will need to assess EOR performance. This should include modeling of incremental production, CO_2 utilization and the amount of CO_2 storage in the process. Opportunities to increase CO_2 utilization and storage should be investigated. EOR projects also need to determine the extent of CO_2 storage related activities that are conducted and implemented, and this may depend on the regulatory and any support mechanism for CO_2 storage.

For both EOR and simple storage projects in oil and gas fields (i.e. without continued production), the opportunity to re-use field wells and infrastructure may be beneficial in reducing development costs. The feasibility of re-use and conversion will need to be evaluated and any remediation activities and costs identified. These would need to audit the safety and integrity of materials, equipment and wells in event of conversion to CO_2 use, taking account of the planned project duration. The risks associated with brown field facilities and process conversions need to be evaluated and incorporated in Project Risk Management.

Utilization/storage project planning and scheduling and risk assessment must also factor in the operator's plans for the field redevelopment, depletion and abandonment. These determine the availability of the subsurface pore space, wells and infrastructure for use. In one UK project, an offshore platform that had been proposed for EOR as part of the Peterhead-Miller CCUS project was decommissioned after the project was cancelled, removing the possibility for future re-use. These issues become more problematic where the field owner is not actively involved in the project.

2. Deep Saline Aquifers

As previously discussed new data acquisition is likely to be required for Deep Saline Aquifers storage to reduce uncertainties in the site characterization. The purpose of this is to fill data gaps, improve areal coverage and reduce the uncertainty and risk. These activities are similar to field appraisal for oil and gas. The appraisal activities may take up to 2–3 years depending on scope and contractor markets and availability. In practice result in an additional sub stage(s) of activities and appraisal should take place before detailed design and FEED. Additional stage gate and milestones may be introduced to overall plans to review whether data acquisition and appraisal objectives have been met enabling the project to proceed. In some cases negative results could result in downgrading of the storage option.

3. Storage Risk Assessment

Evaluating the long-term safety and integrity of the proposed storage scheme is recommended as a core component of the activity in this phase. The precise requirements will depend on the eventual regulatory requirements that are put in place.

The proposed activities are based on an integrated site-specific risk-based approach for Storage Risk Assessment and Risk Management. This would be similar to the European approach outlined in EC Guidance Document 1 (EC, 2010). This should cover all aspects of potential leakage and its impacts including the potential leakage mechanisms (geological and wells), trapping, containment over the project lifecycle and including post-closure phases. The overall approach integrates site characterization, modeling and Storage Risk Assessment with ongoing risk management through Monitoring, Corrective Measures and performance updates.

During this stage, this requires more extensive activity on Storage Risks Assessment as detailed in 7. There are a range of methodologies and best practices for these activities, which are usually qualitative in nature and occasionally semi-quantitative. These are described further in EC Guidance Document 1, DNV's CO_2Qualstore and Recommended Best Practice. The UK FEED Study Knowledge Transfer Deliverable provides a worked up case study (Scottish Power Consortium, 2013)

4. Monitoring Plan

It is recommended that a detailed monitoring plan is developed during this stage of the project. The scope will depend on the regulatory requirements that are introduced in the PRC. Meanwhile the overall approach and general principles laid out in Europe (EC GD 2, 2011), which are comprehensive in their nature should be considered. These state that monitoring and monitoring plans should be:

- Risk based, linked to identified risks from site characterization and the overall Storage Risk assessment;
- Specific to the storage site and complex;

- Sufficiently extensive to cover the storage complex (including where possible the CO_2 plume), migration and behavior of formation waters and where appropriate the surrounding environment;
- That monitoring is linked to preventive and corrective measures;
  Technology used will be based on the best practice available at the time of design;
- Regular and routine reporting of monitoring data and interpretations of results will take place;
- Monitoring plans will be regularly updated to take account of changes to the assessed risks to the environment and human health, new scientific knowledge, and improvements in best available technology;
- Monitoring activities and plans should be adapted to specific conditions of the offshore marine environment.

There is extensive documentation on monitoring technology, best practice and lessons learnt which the PRC can build on. These include Europe's Guidance Document 2 focused on regulatory principle sand guidance and NETL's Best Practices report (2012). It is important that the Plan considers the applicability, potential benefits and costs of different technologies at the site in question. Requirements for baseline data acquisition should be documented and monitoring costs estimated for the project. It is important to plan and schedule the baseline data acquisition that is needed prior to injection, taking account of the environmental conditions and project schedule. Some of this may need to take place either during the Site Characterization Stage and/or during the development stage.

5. Corrective Measures

A corrective measures plan may also be required to indicate what action may be taken in event of leakage of irregularities during injection. The requirement would also depend on the regulatory framework in the PRC.

Again this may follow the European general principles for the overall approach for corrective measures where they are similar to, and closely linked to, the risk assessment and monitoring of the complex. In Europe it is required that Corrective Measures should be:

- Risk based; linked to identified risks from site and complex characterization (and risk assessment) and subject to the limitations of available technologies
- Specific to the storage site and complex;
- Suitable for use to address leakage or significant irregularities from identified leakage pathways and specific leakage mechanisms out of the storage complex and any leakage to the surface;
- Closely linked to monitoring plans and monitoring, which should provide triggers for use of corrective measures by identification of leakage or irregularities;
- Used when there is any leakage or significant irregularities

6. Design and Development Planning

The design and engineering of the wells, infrastructure and equipment for the CO_2 injection and storage scheme is another major activity that needs to take place during this period. This must be designed to meet the needs of the overall project and storage scheme, and integrated with transport and capture elements. The specific activities for storage must cover wells, site infrastructure, offshore platforms, in-site pipelines, compression and processing equipment.

Therefore expertise is required in drilling, wells, completions, relevant engineering disciplines, projects and operations. These activities are summarized above. They are similar to an oil company's activities for the design and preparation of the development plan for a new field.

The purpose of these activities is to progress the design and engineering of the project from concept to pre-investment definition. Again, further staging and progression of the activities usually occurs as the scope and definition increases in order to reduce risk and uncertainty. Cost estimation uncertainty is also reduced as definition improves. The activities typically culminate in Front End Engineering Design (FEED). In practice there may be as many as three sub stages: Concept, Pre-FEED or Feasibility) and FEED stages.

7. FEED Studies

FEED stands for Front End Engineering Design and usually describes the engineering activity which comes after the conceptual design or Feasibility study. The FEED study focuses on the technical requirements as well as investment costs for the project. The FEED package is used as the basis for bidding the Execution Phase Contracts (EPC, EPCI, etc.) and is used as the design basis.

FEED studies have been conducted for several large scale CCUS projects around the world, in most cases with significant government funding for the FEED activity. FEED studies for CCS projects take 1-2 years. Learning and information from FEED studies conducted in the UK with DECC support is available through Knowledge Transfer arrangements.[2]

The Longannet FEED material and summary report illustrates the scope of activities conducted during an integrated CCUS project (ScottishPower CCS consortium, 2012). The FEED comprised over 300 reports and documents, covering all sections of the CCS chain, including subsurface and wells, and encompassing learning from the 11 key areas developed during FEED including:

- the programme for FEED and for full demonstration;
- the cost of performing the FEED study;
- the CCS chain design;
- operation of the CCS chain and its individual elements;
- decisions and design changes;
- health, safety and environment;
- risk management;
- consents and permitting;
- knowledge transfer stakeholder profiling; and
- the cost of the full demonstration project

A table of the main deliverables for the storage parts of the FEED is included as Chapter 9, Appendix II.

8. Storage Permitting and Authorization

The activities during this stage also need to meet the storage permitting and regulatory requirements ahead of development and injection period. Although these have yet to be defined in the PRC, it is likely that a Storage Permit or equivalent will be required authorizing the

[2] https://www.gov.uk/uk-carbon-capture-and-storage-government-funding-and-support.

developer to go ahead with injection. The subsurface, risk assessment and project activities will need to meet this and/or other regulatory and permitting requirements for the project(s).

D. Other Activities

1. Outreach

Outreach and communications have been recognized as essential activities for CCUS and storage projects in many regions. Early engagement is considered essential to manage and mitigate issues of community and public acceptance. Therefore the project developers should initiate activity in this area from early in the stage alongside the technical activities. NETL's best practice recommends the following activities to establish a plan:

- A critical path analysis should be carried out to determine requirements for an outreach program.
- An outreach team should be established with personnel proficient in the implementation of an outreach plan.
- Identify stakeholders and continue to assess their concerns and perceptions of carbon storage.
- Evaluate community data to develop an appropriate public outreach program. The plan should identify stakeholders, key messages, planned activities, timing, resource needs and other relevant information.

2. Other Permitting, Consents and Approvals

The work program will also need to cover any further permitting, consenting and approvals for the utilization or storage project. These would include but not be limited to safety, environmental, land use, etc. Where required an Environmental Impact Assessment may be needed.

3. Project Management and Delivery

Finally, it is important to note that the Storage activities are part of an overall project and CCUS. Project Management and Business activities increase as the project moves towards FID. Depending on the scope, scale and nature of project value chain his may therefore leads to additional resourcing and activity in the areas of:

- Project Delivery
- Partners
- Future Work Planning
- Project Risk Management
- Project Economics & Financial Analysis
- Management Systems
- Resourcing
- Legal
- Commercial Negotiations
- Contracting and Procurement
- Funding/Financing
- IP Management
- Operating Philosophy/Plan

VIII. REFERENCES

A. Listing of Guidelines, Guidance and Best Practice Reports

Author	Date	Title	Acronym	Category
DNV	2012	Geological Storage of Carbon Dioxide - Recommended Practise (DNV-RP-J203)	DNV RP-J203	Guideline
DNV	2010	Guideline for selection and qualification of sites and projects for geologic storage ofCO_2	DNV CO2QUALSTORE	Guideline
DNV	2011	CO_2WELLS Guideline for the risk management of existing wells at CO_2geological storage site	DNV CO2WELLS	Guideline
GCCSI/Carbonwise	2013	openCCS: Storage: http://decarboni.se/publications/openccs-storage		Guideline (Web based)
LBNL	2013	Geologic carbon dioxide sequestration: Site evaluation to implementation	GEOSEQ	Guideline
NETL	2012	Best practices for: Monitoring, verification, and accounting of CO_2 stored in deep geologic formation	NETL MVA	Guideline
EPA	2013	Geologic Sequestration of Carbon Dioxide: Underground Injection Control (UIC) Program Class VI Well Project Plan Development Guidance		Guideline
European Commission	2011	Guidance Document 1. CO_2 Storage Life Cycle Risk Management Framework	EC GD1	Guideline
European Commission	2011	Guidance Document 2. Characterization of the Storage Complex, CO_2Stream Composition, Monitoring and Corrective Measures	EC GD2	Guideline
European Commission	2011	Guidance Document 3. Criteria for Transfer of Responsibility to the Competent Authority	EC GD3	Guideline
European Commission	2011	Guidance Document 4. Article 19 Financial Security and Article 20 Financial Mechanism Article 20 Financial	EC GD4	Guideline

Author	Date	Title	Acronym	Category
		Mechanism		
WRI	2008	Guidelines for CCS		Guideline
WRI	2011	Guidelines for Community Engagement in CCS		Guideline
Australian Government	2005	Australian Guiding Principles for Carbon Dioxide Capture and Geological Storage(Guiding Principles)		Guideline
Australian Government	2009	Environmental Guidelines for Carbon Dioxide Capture and Geological Storage – 2009		Guideline
OSPAR	2007	OSPAR Guidelines for Risk Assessment and Management of Storage of CO_2 Streams in Geological Formations		Guideline
SACS/ CO2STORE	2008	Best practice for the storage of CO_2 in saline aquifers	European JIP	Best Practise
Carbon Capture Project	2009	A technical basis for carbon dioxide storage	CCP	Best Practise
US/Research	2004	Geologic carbon sequestration: Site evaluation to implementation	GEOSEQ	Best Practise
NETL	2013	Best practices for: Site screening, site selection, and initial characterization for storage of CO_2indeep geologic formations	NETL SS	Best Practise
NETL	2011	Best Practises for Risk analysis and simulation for geologic storage of CO_2	NETL RA	Best Practise
NETL	2013	Best practices for: Carbon Storage Systems and Well Management Activities	NETL WM	Best Practise
NETL	2009	Best Practise: Public Outreach and Education for Carbon Storage Projects	US/NETL	Best Practise
IEA GHG	2012	Best Practice Manual developed through learnings from Weyburn project	IEA Weyburn	Best Practise
NETL	2010	Best practices for: Geologic storage formation classification:	NETL GS	Best Practise

Author	Date	Title	Acronym	Category
		Understanding its importance and impacts on CCS opportunities in the United States		
European research Project	2013	SiteChar Characterisation of European CO2 storage Deliverable N° D2.4 Best practices and Guidelines developed from the SiteChar project	SiteChar	Best Practise
European research Project	2013	SiteChar: Characterisation of European CO2 Storage: Site Characterisation Workflow	SiteChar	Best Practise
European research Project	2014	SiteChar: Characterisation of European CO2 Storage: Public Outreach Activities	SiteChar	Best Practise
CASSEM	2011	CO2 Aquifer storage site evaluation and monitoring	CASSEM	Best Practise
CO2CARE	2013	CO2 Site Closure Assessment Research: D4.22 Criteria for decision making in site abandonment	CO2CARE	Best Practise
CO2CARE	2014	CO2 Site Closure Assessment Research:: D4.12 Plan for risk management supporting site abandonment	CO2CARE	Best Practise
SCCCS	2011	Carbon Capture and Storage Regulatory Test Toolkit	SCCSS/GCCSI	Other
Senior et al	2010	Planning saline reservoir storage developments – the importance of getting started early		Other
GCCSI	2010	Defining CCS-Ready: An Approach to an International Definition	GCCSI/ICF	Other
CO2CRC	2011	Review of existing Best Practise Manuals for Carbon dioxide Storage and Regulation	CO2CRC/ GCCSI	Other
CSLF	2013	2013 Annual Report by the CSLF Task Force on Reviewing Best Practices and Standards for Geologic Storage and Monitoring of CO2	CSLF	Other
CSA	2012	Z741-12 Geological storage of carbon dioxide	CSA	Standard
ISO	In Prep	ISO/TC 265 Standard for Storage	ISO	Standard

IX. OTHER REFERENCES

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Figure 5: CO_2CRC Assessment of Scope of Best Practice Manuals (2011)

CO2CRC assessment of scope and content of various best practice manuals

	Pre-feasibility	Site Selection	Capacity Estimation	Simulation and Modelling	Construction	Operation	Closure	Monitoring and Verification	Risk Assessment	Community Consultation	Regulation
SACS	Basic	Technical	Technical	Technical	-	Basic	Detailed	Technical	Detailed	Basic	Basic
NETL (SS)	Basic	Detailed	Technical	Basic	-	-	-	-	Basic	Basic	Detailed
NETL (RA)	-	-	-	Technical	-	-	-	-	Technical	-	-
NETL (MV)	-	-	-	-	-	Technical	Technical	Technical	Basic	-	Basic
NETL (GS)	Technical	Technical	-	-	-	-	-	-	-	-	-
NETL (PO)	-	-	-	-	-	-	-	-	-	Technical	-
WRI (CCS)	Basic	Detailed	Basic	Basic	Basic	Basic	Detailed	Detailed	Detailed	Basic	Detailed
WRI (CE)	Basic	Basic	-	-	Basic	Basic	Basic	Basic	-	Detailed	Basic
DNV	Detailed	Detailed	Detailed	Basic	-	Detailed	Detailed	Basic	Detailed	-	Detailed
CO2Cap	-	Basic	Basic	-	Detailed	Detailed	Basic	Technical	Basic	-	-
GEOSEQ	-	Basic	Basic	Basic	-	-	-	Detailed	-	-	-
CO2NET	-	Basic	Basic	Basic	-	Basic	-	Basic	-	-	-
IEA	-	-	-	-	-	-	-	-	-	-	Technical
CO2Cap (R)	-	-	-	-	-	-	-	-	-	-	Technical

-	Not covered
Basic	Briefly covered in a generic way
Detailed	Comprehensive discussion, generally generic
Technical	Provides technical detail of projects, generally comprehensive

NETL (SS)	Best Practices for: Site screening, site selection, and initial characterization for storage of CO_2 in deep geologic formations
NETL (RA)	Risk analysis and Simulation for geologic storage of CO_2
NETL (MV)	Best Practices for: Monitoring, verification, and accounting of CO_2 stored in deep geologic formations
NETL (GS)	Best Practices for: Geologic storage formation classification: Understanding its importance and impacts on CCS opportunities in the United States
NETL (PO)	Best Practices for: Public outreach and education for carbon storage projects
WRI (CCS)	Guidelines for CCS
WRI (CE)	Guidelines for community engagement in CCS

Table 10: Screening studies checklist (DNV, 2010)

Table 4-2 Screening check-list		
Legal, regulatory, social and commercial	1	Is the regulatory process and the requirements for CO_2 geological storage in the target region understood by the relevant competent personnel?
	2	Have all applicable legal and regulatory constraints been identified, e.g., surface/subsurface access and ownership, areas excluded from storage, trans-boundary issues and access for future field studies, such as seismic surveys?
	3	Have all social and cultural constraints that may impede the likelihood of project approval/acceptance been identified and assessed, including public perceptions of CO_2 geological storage and related issues in the region?
	4	Have all potential conflicts of use of the surface and subsurface at the target region been identified?
	5	Have the sources, volumes and compositions of the CO_2 streams to be injected and stored been adequately defined?
	6	Have opportunities for cost-effective transport from source to sink been adequately assessed?
Geology and Environmental	7	Has the stratigraphy at each storage site been compiled and documented? Have all potential storage reservoirs, primary seals and formations that may represent a conflict of interest been identified? For example hydrocarbon or groundwater bearing formations. Have structural and isopach maps of injection and confining zones been examined? For example regional cross sections and tectonic maps. Has the regional hydrogeology been studied?
	8	Has sufficient data on the injection zone(s) been compiled and reviewed, including depth, thickness, reservoir dip, lithology, pressure, temperature, porosity, permeability, salinity, mineralogy, interstitial shale content and potential rock-fluid interactions?
	9	Has sufficient data on each confining zone been compiled and reviewed, including depth, thickness, areal extent, lithology, capillary pressure data, and other factors that may affect integrity of the confining zone(s)?
	10	Does the data reviewed on the confining zone(s) (for example fracture strength) provide adequate confidence in the ability to ensure containment of injected CO_2 streams to enable the decision to invest in further storage site characterization?
	11	Are the contributions from the four trapping mechanisms adequately understood at this stage of the project?
	12	Has storage capacity and injectivity of each potential storage site been estimated and the level of uncertainty in these estimates been quantified?
	13	Have all existing wells within each of the delineated areas for the potential storage sites been identified and the corresponding well completion logs and well records been obtained?
	14	Has the industrial history of the potential storage sites been reviewed, e.g., mining, groundwater production, disposal of waste, natural and town gas storage, well abandonment history?
	15	Have all environmental and economic receptors surrounding the potential storage site been identified?
	16	Has relevant environmental data required for screening been acquired and reviewed, e.g., maps or regional groundwater, surface water, sensitive terrestrial and marine ecosystems, and land use (for onshore storage sites)?
	17	Ability to monitor the storage site: has it been established that there are no obvious barriers to effective monitoring?
Risk	18	Have all relevant consequence categories been defined?
	19	Are the project specific risk evaluation criteria for the respective consequence categories appropriate?
	20	Does the risk register comprehensively document how risks have been assessed for each element of concern?
	21	Is the basis and rationale for the evaluation of identified risks documented in a sufficiently transparent way to support differentiation of potential storage sites based on legal, regulatory, technical, commercial, social and cultural factors?

X. UK GOLDENEYE STORAGE FEED DELIVERABLES

This is a listing of Shell's storage FEED deliverables for Goldeneye that are in the public domain from the DECC's first CCS Demonstration Programme. These are documented in

UK Carbon Capture and Storage Demonstration Competition

FEED Close Out Report, by Scottish Power/National Grid/Shell CCS Consortium

These are available online from DECC at:

http://webarchive.nationalarchives.gov.uk/20121217150422/http://decc.gov.uk/en/content/cms/emissions/ccs/ukccscomm_prog/feed/scottish_power/design/design.aspx

Design Outputs and Reports

C.1. End-to-End Basis of Design
C.1.1. UKCCS - KT - S7.2 – E2E -001 Outline Solution End-to-End Basis of Design
C.1.2. UKCCS - KT - S7.1 - E2E -001 Post-FEED End-to-End Basis of Design

C.2. Process Flow Diagrams (PFDs)
C.2.1. UKCCS - KT - S7.8 - E2E - 001 End-to-End Process Flow Diagram
C.2.2. UKCCS - KT - S7.8 - ACC - 001 Aker Clean Carbon Process Flow Diagrams
C.2.3. UKCCS - KT - S7.8 - NG - 001 National Grid Process Flow Diagrams
C.2.4. UKCCS - KT - S7.8 - Shell - 001 Shell Process Flow Diagrams
C.2.5. UKCCS - KT - S7.9 - OS - 001 Outline Solution Process Flow Diagrams

C.3. Heat and Mass Balances (HMBs)
C.3.1. UKCCS - KT - S7.10 - E2E - 001 End-to-End Heat and Mass Balance
C.3.2. UKCCS - KT - S7.10 - ACC - 001 Aker Clean Carbon Heat and Mass Balance
C.3.3. UKCCS - KT - S7.10 - NG - 001 National Grid Heat and Mass Balance
C.3.4. UKCCS - KT - S7.10 - Shell - 001 Shell Heat and Mass Balance
C.3.5. UKCCS - KT - S7.11 - OS - 001 Outline Solution Heat and Mass Balance

C.4. Piping and Instrumentation Diagrams (P&IDs)
C.4.1. UKCCS - KT - S7.12 - ACC - 001 Aker Clean Carbon P&IDs
C.4.2. UKCCS - KT - S7.12 - NG - 001 National Grid P&IDs
C.4.3. UKCCS - KT - S7.12 - Shell - 001 Shell P&IDs

C.5. Layout and Construction
C.5.1. UKCCS - KT - S7.14 - E2E - 001 End-to-End Plant and Site Layout Drawings
C.5.2. UKCCS - KT - S7.14 - ACC - 001 Modularisation Study

C.6. UKCCS - KT - S7.13 - E2E - 001 End-to-End Major Equipment List

C.7. Plant and Equipment Specifications
C.7.1. UKCCS - KT - S7.15 - ACC - 001 Aker Clean Carbon Datasheets
C.7.2. UKCCS - KT - S7.15 - NG - 001 National Grid Datasheets

C.7.3. UKCCS - KT - S7.15 - Shell - 001 Shell Datasheets

C.8. Subsurface Engineering – Material and Concept Select Reports
C.8.1. UKCCS - KT - S7.16 - Shell - 001 Material Selection Report
C.8.2. UKCCS - KT - S7.16 - Shell - 007 Cement Concept Selection
C.8.3. UKCCS - KT - S7.17 - Shell - 001 Component Concept Select
C.8.4. UKCCS - KT - S7.17 - Shell - 002 Completion concept select

C.9. Subsurface Engineering – Well Reports
C.9.1. UKCCS - KT - S7.16 - Shell - 002 Well Abandonment Concept
C.9.2. UKCCS - KT - S7.16 - Shell - 004 Well Proposal
C.9.3. UKCCS - KT - S7.16 - Shell - 003 Well Program – Draft
C.9.4. UKCCS - KT - S7.16 - Shell - 006 Well Technical Specification
C.9.5. UKCCS - KT - S7.16 - Shell - 005 Well Functional Specification

C.10. Subsurface Engineering – Production Technology Reports
C.10.1. UKCCS - KT - S7.18 - Shell - 001 Temperature and Pressure Modelling
C.10.2. UKCCS - KT - S7.18 - Shell - 005 Operations Support
C.10.3. UKCCS - KT - S7.18 - Shell - 002 Injectivity Analysis Preparation
C.10.4. UKCCS - KT - S7.18 - Shell - 003 Flowline Well Interactions
C.10.5. UKCCS - KT - S7.18 - Shell - 004 Injection Fraccing Conditions

C.11. Subsurface Engineering – Geosciences, Reservoir Engineering, Production Chemistry, Monitoring and Reservoir Management Reports
C.11.1. UKCCS - KT - S7.19 - Shell - 001 (Wells) Fluid Flow Assurance & Technical Design
C.11.2. UKCCS - KT - S7.19 - Shell - 006 Seismic Interpretation Report
C.11.3. UKCCS - KT - S7.19 - Shell - 007 Petrophysical Modelling Report
C.11.4. UKCCS - KT - S7.21 - Shell - 002 Static Model (Field)
C.11.5. UKCCS - KT - S7.22 - Shell - 001 Static Model (Aquifer)
C.11.6. UKCCS - KT - S7.22 - Shell - 002 Static Model (Overburden)
C.11.7. UKCCS - KT - S7.21 - Shell - 005 FFM Dynamic Model Report
C.11.8. UKCCS - KT - S7.21 - Shell - 001 PVT Report
C.11.9. UKCCS - KT - S7.21 - Shell - 003 IIP Volumes Estimate
C.11.10. UKCCS - KT - S7.21 - Shell - 004 CO2 Storage Estimate
C.11.11. UKCCS - KT - S7.19 - Shell - 004 Geomechanics Summary Report
C.11.12. UKCCS - KT - S7.21 - Shell - 006 Pore Pressure Prediction
C.11.13. UKCCS - KT - S7.19 - Shell - 003 Geochemical Reactivity Report
C.11.14. UKCCS - KT - S7.19 - Shell - 002 SCAL Report
C.11.15. UKCCS - KT - S7.19 - Shell - 005 Production Chemistry Operability Review
C.11.16. UKCCS - KT - S7.23 - Shell - 003 Asset Reference Plan
C.11.17. UKCCS - KT - S7.20 - Shell - 002 MMV Plan
C.11.18. UKCCS - KT - S7.20 - Shell - 003 Monitoring Technology Feasibility Report
C.11.19. UKCCS - KT - S7.23 - Shell - 001 WRM Plan
C.11.20. UKCCS - KT - S7.20 - Shell - 001 Corrective Measures Plan
C.11.21. UKCCS - KT - S7.23 - Shell - 002 Technology Maturation Plan
C.11.22. UKCCS - KT - S7.23 - Shell - 004 Storage Development Plan