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TECHNICAL GROUP

CSLF Monitoring Geologic Storage for Commercial Projects Task Force

Initial Compilation of Standards, Best Practices and Guidelines for CO_2 Storage and Monitoring

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CSLF IS GOING GREEN*

CSLF MONITORING GEOLOGIC STORAGE FOR COMMERCIAL PROJECTS TASK FORCE

INITIAL COMPILATION OF STANDARDS, BEST PRACTICES AND GUIDELINES FOR CO_2 STORAGE AND MONITORING

Note by the Secretariat

Background

At the 4th CSLF Ministerial Meeting, at Beijing, China in September 2011, the Technical Group approved a new multi-year Action Plan. "Monitoring Geologic Storage for Commercial Projects" is one of the twelve Actions that comprise the Action Plan, and Norway is leading a new Task Force whose mission is to perform initial identification and review of new and updated standards for storage and monitoring of injected CO_2. The planned scope of activities includes production of annual summaries of new as well as updated standards, guidelines and best practice documents regarding geological storage of CO_2 and monitoring of CO_2 sites. This report is an initial compilation of such standards, best practices, and guidelines.

Action Requested

The Technical Group is requested to review the Task Force's report.

* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.

Monitoring Geologic Storage for Commercial Projects Task Force

Initial Compilation of Standards, Best Practices and Guidelines for CO_2 Storage and Monitoring

Initial Draft

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1. Background

At the meeting of the CSLF technical Group in Bergen, Norway June 12, 2012, it was agreed that the new Task Force on "Monitoring of Geologic Storage for Commercial Projects" (TF6) should:

1. Identify and review existing standards for geological CO_2 storage and monitoring on an annual basis;
2. Identify and review existing guidelines for communication with and engagement of involved communities and regulators on an annual basis;
3. Identify shortcomings and/or weaknesses in standards/guidelines;
4. Communicate findings to the ISO CCS working group that has been established;
5. Produce annual summaries of new as well as updated standards, guidelines and best practice documents regarding geological storage of CO_2 and monitoring of CO_2 sites; and
6. Follow the work of other task forces related to CO_2 storage, e.g.:
    a. Task Force on Action Plan #7 – Technical Challenges for Conversion of CO_2-EOR to CCS (Chaired by Canada).
    b. Task Force on Action Plan #1 – Technology Gap Closure (Chaired by Australia)

In the following the term CO_2 Capture, Utilization and Storage (CCUS) will be used instead of the more commonly used CO_2 Capture and Storage (CCS), which is used only when it occurs in the title of a document.

2. Scope of this note

This note concerns point 1 above and is the first draft of an initial compilation of standards, Best Practices Manuals (BPMs) and guidelines for geologic storage of CO_2. Hereafter the term BPM is used for all three concepts. The purpose is to list relevant BPMs on CO_2 storage and give a very brief summary of the contents. Point 3 above, identifying shortcomings, as well as point 4, making proposals for improvements and communicate these to the ISO working group on CCS (ISO/TS/P 221), will be the topic of a later memo.

The note will list documents that relate to storage capacity estimation in Chapter 5 but will not go into details, as the topic may be treated by another Task Force.

Whether or not to include the second point above, related to regulatory issues, community engagement and communication, is still to be decided by the TF. Some BPMs concerned with these topics are listed in Chapter 6 but not discussed further.

This note is based on a summary by CO2CRC (2011), issued in March 2011. It summarizes the evaluations of that report, excluding documents that deal with regulatory and public engagement issues, and supplements it by brief reviews of documents issued after March 2011.

CO2CRC (2011) lists 15 BPMs or other sources for information on storage of CO_2 that were publicly released by early 2011, three unreleased BPMs and four additional references. Of the three unreleased by March 2011 one has later been published.

There exist much general literature (lessons learned, experiences etc) with content that may contribute to improving or supplementing best practices, standards etc. This literature is not included in this first overview but a selection of publications will be included in an update.

Of the 15 released BPMs ten concern technical aspects of CO_2 storage. These, along with some BPMs released after March 2011, will be discussed in Chapter 3. This chapter will also include some general references on experience from CO_2 storage projects. Chapter 4 will reference some BPMs related to storage capacity estimation, whereas Chapter 5 will just list the four BPMs included in CO2CRC (2011) that deal with regulatory or community engagement issues (the fifth reference in CO2CRC (2011) is a website). Chapter 6 contains an update on the work of ISO TS/P 221 Carbon capture and storage (CCS) and Chapter 7 gives an assessment of scope and content of the various BPMs and makes the first attempt to identify shortcomings. Additional information is given in Appendices A – G on issues that will either be treated in more detail in the next phase (Appendices B and C) or are outside the scope of TF6 (Appendices A and D – G).

A list of Task Force members can be found in Appendix H.

3. Identified standards, best practices manuals and guidelines for CO_2 storage

CO2CRC (2011) lists ten references relating to technical issues on CO_2 storage, excluding documents related to capacity estimation. One of these references, CO2NET Work Package 7 Best Practice Review from 2004, is not included here due to its age and very limited scope. The remaining nine BPMs from CO2CRC (2011) are listed in Table 1, with content and comments based on CO2CRC (2011).

A list of BPMs, guidelines or standards released after publication of CO2CRC (2011) is given in Table 2. This list is probably not exhaustive and TF6 members are asked to supplement it.

Table 3 gives brief descriptions of BPMs that have been announced but, to the knowledge of the TF6 Chair, have not been published.

Table 1. Most relevant best practice manuals listed in CO2CRC (2011), excluding those addressing regulatory and public engagement issues as well as those purely addressing capacity estimation. Sorted alphabetically by issuing organization and then chronologically. Comments are based on CO2CRC (2011).

Date	Issued by	Title	Contents	Comment
2008	BGS	Best practice for the storage of CO_2 in saline aquifers (http://nora.nerc.ac.uk/2959/)	First published in 2003. The latest version (2008) covers all aspects of storage in saline aquifers: • Identifying ideal reservoir • Seal properties • Capacity estimation • Predictive flow modelling, • Geochemical and geomechanical site characterization • Operating the site • Cost estimation • Transport needs • Monitoring plan design • History matching based on monitoring data • Safety and risk assessment procedures.	The information is presented through case studies of what was done and learned at 5 separate projects including Sleipner and Schwarze Pumpe.
Jan. 2009	CO_2 Capture Project (CCP)	A technical basis for carbon dioxide storage (http://www.co2capturepproject.org/co2_storage_technical_book.html)	Covers: • Background and site selection • Operation • Closure • Monitoring • Detailed guide for well construction and completion that contains discussions on materials and the factors that govern which you can use and when (a significant addition that this publication includes and others do not). The BPM covers, with enough detail to be considered beyond basic, a technical understanding of the aspects of CO_2 storage.	Based on experiences from participating companies in CO_2 injection. Uses a large number of case studies, separated from the text as standalone examples, to illustrate how the advice given in each section was used in reality. It is a guide to developing a storage project.

Feb. 2010	DNV	Guideline for selection and qualification of sites and projects for geological storage of CO_2 (http://www.dnv.com.au/binaries/CO2QUALSTORE_guideline_tcm162-412142.pdf)	A step by step guide to selecting a CO_2 storage site that covers • Pre-feasibility stages of developing a screening plan • Data acquisition • Capacity estimation • Modeling and simulation • Risk assessment • Regulation • Operation and closure (but majority of the BPM is on site selection and characterization).	Covers the many different aspects that need to be considered and provides best practice for accomplishing each step often providing deliverables that could be expected. However, although it must be assumed that the best practices are based on lessons-learned; there are few direct case studies or examples that are mentioned as proof of the success of the best practices provided.
Sept. 2004	LBNL (GEO-SEQ Project Team)	Geologic carbon dioxide sequestration: Site evaluation to implementation (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/GEO-SEQ_BestPract_Rev1-1.pdf)	This manual covers • A non-detailed discussion on capacity estimation. Also covers • A section dedicated to EOR. • Characterization of brine-formation sequestration. • Monitoring • Verification • Disposal of impure CO_2 streams • Modeling and simulation	Does not cover the issues in breadth or detail and is fairly basic in general.
Jan. 2009	NETL	Best practices for: Monitoring, verification, and accounting of CO_2 stored in deep geologic formations (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/MVA_Document.pdf)	Comprehensive BPM addressing the need for and requirements of a monitoring program at a CCS project. Covers: • Atmospheric, near-surface, and subsurface monitoring • Simulation techniques • Geophysical techniques, geochemical techniques and crustal and surface techniques • Pre-operational, operational, and post-operational phases of monitoring • Discussion on possible regulatory requirements.	Utilizes numerous case studies and international projects to address what has been achieved so far and what will be required in the future.

Sept. 2010	NETL	Best practices for: Geologic storage formation classification: Understanding its importance and impacts on CCS opportunities in the United States (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM_GeologicStorageClassification.pdf)	Written for the purpose of understanding and applying geology to a CCS project. Covers background on: • Geological terminology, • Rock types and how they fit into CCS and which are most suitable. As well as more technical issues including as different depositional environments and what each one means for CCS.	This BPM covers only a very specific topic: understanding how geology affects a CCS project.
Nov. 2010	NETL	Best practices for: Site screening, site selection, and initial characterization for storage of CO_2 in deep geologic formations (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM-SiteScreening.pdf)	Relates specifically to the needs of a generic CCS project covering all possible opportunities and what is necessary to select and characterize a site. Covers • Identifying and developing all potential injection sites and requirements for each type (saline/depleted reservoir/coal) • Data analysis • Injection strategies • Model development and refinement • Capacity estimation and overall suitability analysis • Social and environmental considerations in developing and operating a site.	A 110 page comprehensive discussion of 'what you need to know' with regard to storage. It addresses this from a fundamental standpoint covering basic scientific understanding and only occasionally inserting application examples. It does not cover simulation, risk and monitoring to a technical level as there are separate BPMs published to cover these.

2008	WRI	Guidelines for CCS (http://pdf.wri.org/ccs_guidelines.pdf)	Covers the entire CCS process (Capture, transport, storage). Storage topics addressed are Recommended guidelines for: • MMV • Risk assessment • Financial Responsibility • Property rights and ownership • Site selection and characterization • Injection operations • Site closure • Post-closure	Unable to achieve the same level of detail as other BPMs, more an overview of a theoretical project development and what proponents 'should' consider and do to be successful. It is best described as a dictionary of CCS project aspects as opposed to a BPM. That being said, it does not call itself directly a best practice manual.

Table 2. Relevant best practice manuals published after the CO2CRC (2011) report (March 2011). Sorted alphabetically by issuing organization and then chronologically. Comments by Chair TF6.

Date	Issued by	Title	Contents	Comment

June 2011	DNV	CO2WELLS Guideline for the risk management of existing wells at CO_2 geological storage site (http://www.dnv.com/industry/energy/segments/carbon_capture_storage/recommended_practice_guidelines/co2qualstore_co2wells/index.asp)	Describes a transparent methodology to evaluate the integrity of wells, and risk-based procedure for re-qualification of wells for CO_2-injection. Content includes:
			• Well integrity risk
			  o Risk assessment and risk criteria
			  o Identification, analyses and evaluation of well risks
			  o Communication
			• Qualification of existing wells
			• Assess performance of and qualification of wells
				The guideline provides a tool for independent validation and verification. Contributes to build confidence among regulators and stakeholders in risk informed approaches to selection and management of storage sites.

April 2012	DNV	Geological Storage of Carbon Dioxide (DNV-RP-J203) (http://www.dnv.com/news_events/news/2012/newcertificationframeworkforco2storage.asp)	This Recommended Practice (RP) is part of DNV´s series of RPs. The main objective is to provide a systematic approach to the selection, qualification and management of geological CO_2 storage sites. It covers:
			• Storage screening and appraisal
			• Permitting
			  o Context and requirements
			  o Risk performance targets
			  o Storage and closure permits
			• Risk management, assessment and treatment
			• Well qualification
				The RP incorporates and combines the guidance given in:
				• CO2QUALSTORE
				• CO2WELLS
				These two guidelines were the final deliverables from joint industry projects whereas this RP has been developed, and will be maintained, by DNV.

June 2012	DNV	Qualification Management for Geological Storage of CO_2 (DNV-DSS-402) (http://www.dnv.com/news_events/news/2012/newcertificationframeworkforco2storage.asp)	This DNV Service Specification (DSS) provides a framework for the certification of geological storage sites for CO_2. It covers: • Principles for selection, qualification and management of geological storage sites for CO_2 • Service overview (basically what services DNV can provide) • Examples of CO_2 storage certification documents	Not really a BPM but a description of DNV's services within selection, qualification and management of geological storage sites. As such it provides some guidance for CO_2 storage project developers and other parties, but the most important document is DNV-Rp-J203.
March 2011	NETL	Risk analysis and simulation for geologic storage of CO_2 (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM_RiskAnalysisSimulation.pdf)	The BPM includes elements that are required for accurate simulation for risk: • Fundamentals • Identification • Assessment (including quantifying) and characterization • Mitigation; • And for simulation the many different processes (thermal, chemical, biological, etc…). The BPM also covers how risk plans and numerical simulations can be applied separately and together to a CCS project in order to handle the potential risks of a CCS site.	A generic publication that provides an understanding of what risk and numerical simulation is and why it is an essential aspect to CCS. This BPM was developed from the lessons learned at numerous projects run by the Regional Carbon Sequestration Partnership (RCSP).

April 2012	NETL	Best practices for: Carbon Storage Systems and Well Management Activities (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM-Carbon-Storage-Systems-and-Well-Mgt.pdf)	This BPM covers: • Assessment Initial Site characterization • Injection design • Project cost revisions • Permitting • Establishing site security and access • Well and facility layout • Well pad preparations • Well drilling • Formation evaluation • Well construction • Well testing • Suitability of well • Pre-injection baseline • Injection system completion • Injection • Post-injection operations, including well and site closure and MVA	Purpose: to share lessons learned regarding site-specific management activities for carbon storage well systems. Builds on the experiences of the RCSPs and the petroleum and other private industry. The BPM is part of NETL's series of BPMs for CCUS.

Table 3. Announced but unreleased best practice manuals on CO_2 storage. As of September 7, 2012.

Date	Issued by	Title	Contents	Comment
	IEA	Best Practice Manual developed through learnings from Weyburn project	This BPM will be a key of the IEA's 11 year monitoring program at the Weyburn EOR injection and storage project. It will cover • Technical components (including site characterisation, monitoring and verification, wellbore integrity and performance assessment) • Policy components (including regulatory issues, public communication and outreach) • Business environment. This BPM was expected to be released in 2011.	Will be less about secific details from the Weyburn-Midale sites and more about lessons that are broadly applicable to any CO_2 sequestration site
	IPACCO2/ CSA Standards	CCS Standards Manual	This new standard focuses on: • Management • Site selection • Risk management • Monitoring and verification • Well infrastructure • Closure and decommissioning	IPAC CO_2 and CSA Standards are jointly developing a code of best practice standards for CCS to be submitted to the Canadian government. Once completed it will be the World's first implemented CCS standards guide. Public review period ended Dec. 27, 2011.

It is outside the scope of TF6 to dwell into CCUS legislation. However, it is deemed relevant to include a list of guidance documents or guidelines that have been published as annexes or similar to regulations on CO_2 storage. Such guidelines often have contents and structure that resemble standards. A selection of such guidelines is shown in Table 4. The relevant regulations and legislation is given in Appendix A.

The list in Table 4 is not exhaustive. More information on legal aspects of CCUS can be found at the general website of the Carbon Capture Legal Programme (CCLP) of the University College of London (UCL), http://www.ucl.ac.uk/cclp/, and more directly related to dedicated CCUS legislation http://www.ucl.ac.uk/cclp/ccsdedleg.php. The websites provide summarizations, analyses, and responses to global CCUS legislation and regulations. The CCLP offers both their own interpretation of the legal works as well as links to the legislation and links to position and discussion papers from other organizations. Along with the section dedicated to existing legislation, the CCLP provides several short-report style papers and presentations that address particular issues surrounding the workings of regulatory issues. Additionally, CCLP mentions also the status in selected Member States of the transposition of the EU CCS Directive (http://www.ucl.ac.uk/cclp/ccseutransposition.php).

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Table 4. Guidelines included as annexes etc to regulations

Date	Issued by	Title	Contents	Comment
2005	Australian Government	Australian Guiding Principles for Carbon Dioxide Capture and Geological Storage (Guiding Principles) (http://www.ret.gov.au/resources/Documents/ccs/CCS_Aust_Regulatory_Guiding_Principles.pdf)	The purpose of the Guiding Principles is to promote consistency in the development of a CCS regulatory framework across the Australian states and territories. The Guiding Principles address six areas of CCS activities: 1. Assessment and approval processes 2. Access and property rights 3. Transportation issues 4. Monitoring and verification 5. Liability and post-closure responsibilities 6. Financial issues The Guiding principles are non-binding.	The Australian Government has developed a regulatory framework for offshore CO_2 storage based on amendments to existing petroleum legislation. (See e.g. http://www.ucl.ac.uk/cclp/ccsoffnational-AUS.php#envregs). Two sets of non-binding guidelines have been developed to promote a consistent approach to the application of CCS activities in Australia, including offshore storage activities. These guidelines are summarised briefly in the column to the left.
2009	Australian Government	Environmental Guidelines for Carbon Dioxide Capture and Geological Storage - 2009 (http://www.ephc.gov.au/sites/default/files/Climate_GL__Environmental_Guidelines_for_CCS_20090 5_0.pdf)	Environmental Guidelines are non-binding but do provide some high level supplementary information on 1. Environmental assessment of CCS activities 2. Monitoring of injected GHG substances 3. Site closure 4. The need for co-ordination across jurisdictions.	

2011	European Commission	Guidance Document 1 CO_2 Storage Life Cycle Risk Management Framework (http://ec.europa.eu/clima/policies/lowcarbon/ccs/implementation/docs/gd1_en.pdf) Guidance Document 2 Characterisation of the Storage Complex, CO_2 Stream Composition, Monitoring and Corrective Measures (http://ec.europa.eu/clima/policies/lowcarbon/ccs/implementation/docs/gd2_en.pdf)	Of the four guidance documents Directive 2009/31/EC nos. 1 and 2 are relevant for this overview. The purpose of the Guidance Documents is to assist stakeholders to implement the Directive (so-called CCS Directive Guidance). Document 1 (GD1) addresses the overall framework for geological storage in the CCS Directive for the entire life cycle of geological CO_2 storage activities including 1. The phases 2. Main activities 3. Major regulatory milestones. 4. High-level approach to risk assessment and management Guidance Document 2 (GD2) builds on GD1 provides guidance on: 1. Site selection; 2. Composition of the CO_2 stream; 3. Monitoring; 4. Corrective measures. The Guidance documents are non- legally binding.	The European Commission has issued a directive, DIRECTIVE 2009/31/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the geological storage of carbon dioxide and amending. The directive has four guidance documents, on 1. Risk management 2. Characterization and monitoring 3. Transfer of responsibility 4. Financial security and mechanism
June 2007	OSPAR Convention	OSPAR Guidelines for Risk Assessment and Management of Storage of CO_2 Streams in Geological Formations (http://www.ucl.ac.uk/cclp/pdf/OSPAR2007-Annex-7.pdf)	The Guidelines provide generic guidance for Contracting Parties when considering applications for permits to store CO_2 in geological formations under the seabed. The Guidelines have four Annexes, whereof Annex 1 – Framework for Risk Assessment and management of Storage of CO_2 Streams in Geological Formations (FRAM) – is relevant for this overview. It addresses: 1. Problem formulation 2. Site selection and characterisation 3. Exposure assessment 4. Effects assessment 5. Risk characterization 6. Risk management	The OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic has issued Decision 2007/2 on the Storage of Carbon Dioxide Streams in Geological Formations with Guidelines (http://www.ucl.ac.uk/cclp/pdf/OSPAR2007-Annex-6.pdf)

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August 2012	EPA (US Government)	Geologic Sequestration of Carbon Dioxide: Underground Injection Control (UIC) Program Class VI Well Project Plan Development Guidance (http://water.epa.gov/type/groundwater/uic/class6/upload/epa816r11017.pdf)	This document describes the required elements of each of the five plans prospective Class VI injection well owners and operators must submit with a permit application under the Class VI Rule requirements: o Area of Review and Corrective Action Plan, o Testing and Monitoring Plan, o Injection Well Plugging Plan, o Post-Injection Site Care (PISC) and o Site Closure Plan, and Emergency and Remedial Response Plan	This is a basic and non-technical guidance document with some emphasis on corrective action plans and emergency and remedial response plans. It is adapted to the US regulation for Class VI Wells and therefore also has guidance on how to prepare plans that relate specifically to US regulations.

4. Basic assessment of scope and content of identified BPMs on technical aspects of CO_2 storage

CO2CRC (2011) has assessed the scope and content of the BPMs listed in Table 1 with respect level of details for the following aspects: pre-feasibility, site selection, capacity estimation, simulation and modelling, construction, operation, closure, monitoring and verification, risk assessment, community consultation and regulation.

Table 5 repeats CO2CRC's assessment of the BPMs in Table 1 and supplements it with *suggested* assessment of the BPMs in Tables 2, 3 and 4 by the Chair of TF6. There is little information available for the BPMs in Table 4 and this marked with NA.

In line with the limitations in scope for TF6 Table 5 excludes capacity estimation, community consultation and regulation. We have also excludes the DNV DSS-402 Qualification management for geological storage of CO_2, as it is not a BPM.

The following short names are used in Table 5, with reference to the table where descriptions of the BPMs can be found:

Short name used in Table 5	Full name	Found in table
CO2STORE	Best practice for the storage of CO_2 in saline aquifers	1
CCP	A technical basis for carbon dioxide storage	1
DNV CO2QUAL	Guideline for selection and qualification of sites and projects for geological storage of CO_2	1
DNV CO2WELLS	CO2WELLS Guideline for the risk management of existing wells at CO_2 geological storage site	2
DNV RP-J203	Geological Storage of Carbon Dioxide (DNV-RP-J203)	2
LBNL/GEOSEQ	Geologic carbon dioxide sequestration: Site evaluation to implementation	1
NETL MVA	Best practices for: Monitoring, verification, and accounting of CO_2 stored in deep geologic formations	1
NETL GS	Best practices for: Geologic storage formation classification: Understanding its importance and impacts on CCS opportunities in the United States	1
NETL SS	Best practices for: Site screening, site selection, and initial characterization for storage of CO_2 in deep geologic formations	1
NETL RA	Risk analysis and simulation for geologic storage of CO_2 (	2
NETL WM	Best practices for: Carbon Storage Systems and Well Management Activities	2
WRI CCS	Guidelines for CCS	1
IEA Weyburn	Best Practice Manual developed through learnings from Weyburn project	3
IPACCO2/CSA	CCS Standards Manual	3
AU1	Australian Guiding Principles for Carbon Dioxide Capture and Geological Storage (Guiding Principles)	4
AU2	Environmental Guidelines for Carbon Dioxide Capture and Geological Storage – 2009	4
EC1	Guidance Document 1. CO_2 Storage Life Cycle Risk Management Framework	4
EC2	Guidance Document 2. Characterisation of the Storage Complex, CO_2 Stream Composition, Monitoring and Corrective Measures	4
OSPAR	OSPAR Guidelines for Risk Assessment and Management of Storage of CO_2 Streams in Geological Formations	4
EPA	Geologic Sequestration of Carbon Dioxide: Underground Injection Control (UIC) Program Class VI Well Project Plan Development Guidance	4

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Table 5. Assessment of scope and content of BPMs listed in Tables 1 – 4. For BPMs listed in Table 1 the assessment is by CO2CRC (2011). For the other BPMs the assessment is by Chair of TF6 and is to be regarded as suggestions.

BPM	Pre-feasibility	Site selection	Simulation and modelling	Construction	Operation	Closure	Monitoring and verification	Risk assessment
CO2STORE	Basic	Technical	Technical	-	Basic	Detailed	Technical	Detailed
CCP	-	Basic	-	Detailed	Detailed	Basic	Technical	Basic
DNV CO2QUAL	Detailed	Detailed	Basic	-	Detailed	Detailed	Basic	Detailed
DNV CO2WELLS	-	Technical (exiting wells)	-	-	-	-	-	Technical (existing wells)
DNV RP-J203	Basic	Detailed	Basic	Detailed (wells)	-	-	Detailed	Detailed
GEOSEQ	-	Basic	Basic	-	-	-	Detailed	-
NETL MVA	-	-	-	-	Technical	Technical	Technical	Basic
NETL GS	Technical	Technical	-	-	-	-	-	-
NETL SS	Basic	Detailed	Basic	-	-	-	-	Technical
NETL RA	-	-	Technical	-	-	-	-	Technical
NETL WM	-	-	-	Technical	Technical	Technical	-	-
WRI CCS	Basic	Detailed	Basic	Basic	Basic	Detailed	Detailed	Detailed
IEA Weyburn	NA	NA	NA	NA	NA	NA	NA	NA
IPACCO2/CSA	NA	NA	NA	NA	NA	NA	NA	NA
AU1	-	-	-	-	-	-	-	-
AU2	-	-	-	-	-	-	(Very) Basic	- (Env. risk very basic)
EC1	-	-	-	-	-	-	-	Detailed
EC2	-	Detailed	Basic	-	-	-	Detailed	- (only corrective part)
OSPAR	Basic	Basic	-	-	-	-	-	Basic
EPA	-	-	-	-	-	Basic	Basic	Basic

The following assessment grades have been used. Some BPM have limited cope and the assigned "grade" applies to the topic of the BPM.

-	Not covered specifically	Technical	Provides technical details of projects, generally comprehensive
Basic	Briefly covered in a generic way	NA	Information is not available
Detailed	Comprehensive discussion, generally generic		

Table 5 indicates that none of the identified documents cover all topics listed. It also shows that site selection, monitoring and verification and risk assessment are best covered by existing standards, BPMs or guidance documents. It is beyond the scope of this initial compilation to go into details regarding strengths, weaknesses and needs for additions or improvements of the documents listed in Tables 1 – 4, that will be Phase 2. However, as a prelude to the next phase of the work of CSLF Action Plan Task Force 6, Appendix B gives a preliminary and non-exhaustive list of monitoring tools used in operative storage projects (Table B.1) and planned used in CO_2 projects under development (Table B.2)election of risk assessment approaches, respectively.

Appendix C gives an overview of some risk assessment (RA) methodologies. These are generally classified in two main groups: qualitative and quantitative. Qualitative RA does not provide concrete or numerical results. Most common qualitative methods are the features, events, and processes (FEP), and the Vulnerability Evaluation Framework (VEF). The quantitative methods are used in well-known systems where the level of uncertainty is relatively low. Two main kinds of methods belong to this group: Deterministic Risk Assessment (DRA) and Probabilistic Risk Assessment (PRA). Table C.1 summarises some methods for RA.

5. Other related documents

It may be useful to have a picture of the storage capacity for CO_2 in different regions of the world. Appendix D lists some relevant documents and related references. The list is a combination of atlases and GIS (geodatabases and tools). Each of them bears specifity due to regional coverage (e.g. South Africa, Brazil) but also methodology (e.g. BGR, ETI, Caprock Italy). The references may not lead to the document or database itself but to a website where more information may be found

Community consultation and engagement is important to achieve understanding of CCUS has a greenhouse gas mitigating option. Appendix E lists some BPMs related to the topic. These will not be pursued further until a decision has been made on whether or not this is the responsibility of the CSLF TG. Comments are by CO2CRC (2011).

Storage capacity estimation is part of the CCUS chain and falls under storage. However, a separate Task Force on the subject may be proposed under CSLF TG Action Plan. Appendix G lists some relevant BPMs or related documents but these will not be treated further until the fate of a separate TF has been decided.

Pipelines are outside the scope for TF6 but some standards, BPMs and guidance documents are shown in Appendix G as it was suggested to include this.

6.ISO/TS/P 221 Carbon capture and storage (CCS)

TF6 shall establish communication with the ISO working group on CCS. This chapter will be updated as interface develops.

7. References

CO2CRC (2011) A review of best practice manuals for carbon dioxide storage and regulation. http://www.globalccsinstitute.com/publications/review-existing-best-practice-manuals-carbon-dioxide-storage-and-regulation

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Appendix A. Regulations

Table A.1. Legislation and regulations to which the guidelines of Chapter 3, table 4, are associated. Comments are not provided, as legislation is outside the scope for Task Force 6 "Monitoring of Geologic Storage for Commercial Projects".

Date	Issued by	Title
2008 - 2011	Australian Government	Offshore Petroleum Amendment (Greenhouse Gas Storage) Act 2008 (OPGGS Act); Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009; Offshore Petroleum and Greenhouse Gas Storage (Management of Greenhouse Gas Well Operations) Regulations 2010; Offshore Petroleum and Greenhouse Gas Storage (Management of Greenhouse Gas Well Operations) Regulations 2010; Offshore Petroleum and Greenhouse Gas Storage (Resource Management and Administration) Regulations 2011 (RMA Regs); Offshore Petroleum and Greenhouse Gas Storage (Injection and Storage) Regulations 2010 Draft), see also http://www.ucl.ac.uk/cclp/ccsdedlegnat-AUS.php .
Dec. 2010	Alberta, Canada	Carbon Capture and Storage Statutes Amendments Act 2010, see also http://www.ucl.ac.uk/cclp/ccsdedlegnat-CAN.php
April 2009	European Commission	DIRECTIVE 2009/31/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0114:0135:EN:PDF)
June 2007	OSPAR Convention	OSPAR Decision 2007/2 on the Storage of Carbon Dioxide Streams in Geological Formations (http://www.ucl.ac.uk/cclp/pdf/OSPAR2007-Annex-6.pdf);(http://www.ucl.ac.uk/cclp/ccsoffeuropeospar.php) (http://www.ucl.ac.uk/cclp/pdf/OSPAR_Convention_e_updated_text_2007.pdf); 8 http://www.ucl.ac.uk/cclp/pdf/OSPAR2007-Annex-5.pdf)
2008	UK	Energy Act 2008 (http://www.legislation.gov.uk/ukpga/2008/32/pdfs/ukpga_20080032_en.pdf). See also .ucl.ac.uk/cclp/ccsdedlegnat-UK.php
July 2008	EPA (US Government)	Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO_2) Geologic Sequestration (GS) Wells; see also http://www.ucl.ac.uk/cclp/ccsdedlegnat-US-Federal.php
Dec. 2010	EPA (US Government)	Final rule for Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO_2) Geologic Sequestration (GS) Wells (http://water.epa.gov/type/groundwater/uic/class6/gsregulations.cfm)

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Appendix B. Monitoring tools and techniques used in some projects

Table B.1.Monitoring technologies used at some present storage sites. The list is based on the references supplemented by Myer (2011) and should not be regarded as complete. Supplemented by information from Jones and Chadwick (2012).

	Site					
	Sleipner [1]	Weyburn [2]	In Salah [3]	Snøhvit [4]	Otway [5]	Ketzin [6]
Seismic	x	x	x	x	x	x
Electrical (EM, ERT)	x					x
Gravity	x					
Tiltmeters			x			
Downhole P, T			x	x	x	x
Acoustic (echo sounder, sonar)	x					
Soil gas		x	x		x	x
Microseismic (passive seismic)	x	x	x		x	x
Observation wells		x	x		x	x
Tracers		x	x			x
Microbiology			x			x
Wireline logs			x			x
Fluid samples		x			x	x
Atmospheric CO_2					xx	

[1] CO2STORE (2006); [2] Wilson and Monea, (2005); [3] (Mathieson et al., 2010; Wright et al., 2010); [4] Myer (2011); [5] CO2CRC (2012); [6] Würdemann et al. (2010)

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Table B.2.Monitoring technologies used at storage sites under development (October 2012)

	Site				
	Quest	Gorgon	Illinois Basin-Decatur Project	Boundary Dam (EOR)	Kemper County (EOR
Seismic					
Electrical (EM, ERT)					
Gravity					
Tiltmeters					
Downhole P, T					
Acoustic (echo sounder, sonar)					
Soil gas					
Microseismic (passive seismic)					
Observation wells					
Tracers					
Microbiology					
Wireline logs					
Fluid samples					
Atmospheric CO_2					

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Appendix C. Risk Assessment (RA)

Table C.2. Some methodologies for risk assessment of geological storage of CO2 (Condor et a.,, Energy Procedia 4(2011) 4036-4043)

Method	Goal	Data needed	Industrial application	Application for GSC
DRA	Analytical point estimate calculations	Numerical and qualitative expert estimation for scenario development and model development	Safety engineering (sensitivity analysis)	Initial risk assessment. No uncertainty estimations
PRA	Predict the probability of safety failures of complex system	Numerical qualitative expert estimation for scenario development, model development quantifying PDFs	Safety engineering	Detailed risk assessment. Uncertainty estimation
FEP	Scenario development	Qualitative expert estimation for scenario development	Scenario analysis	Screening and Site selection
VEF	Conceptual framework for regulators and technical experts	Qualitative expert estimation to identify which areas should be in-depth studied	Hazard identification and potential consequences	Framework for site selection and regulator guidance
SWIFT	Elaborate hypothesis	Qualitative expert estimation to identify hazards	Hazard identification in engineering	Hazard and consequence mapping
MCA/MAUT	Evaluation of alternatives in multiple objective	Qualitative and numerical expert estimation for data input utility	Decision making	Framework for screening and site selection
RISQUE	Systemic process with participation of expert panels estimation in event-tree approach	Qualitative and numerical expert	Hazard identification and potential consequences	Hazard and consequence mapping
CFA/SRF	Estimation of risk based on probabilities of occurrence in individual features	Qualitative and quantitative estimation of risk and uncertainty	Development of simple probabilistic models	Managing risks in GSC sites
MOSAR	Identifying and preventing risks	Qualitative and quantitative data for a well-known system	Risk reduction in complex systems	Systematic risk analysis for well-known sites
ESL	Identification of uncertainties in decisions	Qualitative and quantitative understanding of uncertainties	Reduction of uncertainties in well-known systems	Detailed PRA and dealing with uncertainties
P&R	Risk mapping in wellbores under the criteria of degradation scenarios	Qualitative and quantitative data for wellbores	Risk evaluation under the concept of ALARP	Long-term well integrity
SMA	Estimation of risk based on probabilities.	Quantitative estimation of risk and PDFs	Development of complex models in well-known systems	PRA for the whole CCS chain

Appendix D. Selection of CO_2 Storage Atlases

This list is a combination of Atlases and GIS (geodatabases and tools). Each of them beares specifity due to regional coverage (e.g. South Africa, Brazil) but also methodology (e.g. BGR, ETI, Caprock Italy).

Carbon Sequestration Atlas of the United States and Canada I, II and III (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasIII/index.html)

The North American Carbon Storage Atlas 2012 (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/NACSA2012.pdf)

The CO2 Storage Atlas Norwegian North Sea 2011 (http://www.npd.no/Global/Norsk/3-Publikasjoner/Rapporter/PDF/CO2-ATLAS-lav.pdf)

Queensland carbon dioxide geological storage atlas. Compiled by Greenhouse Gas Storage Solutions on behalf of Queensland Department of Employment, Economic Development and Innovation. (http://www.cgss.com.au/Assessement%20of%20Qlds%20CO2%20geological%20storage%20prospectivity_web%20version.pdf)

South Africa CO2 Storage Atlas (http://www.sacccs.org.za/wp-content/uploads/2010/11/Atlas.pdf)

BGR Germany CO2 Storage "Atlas" (GIS) (http://www.bgr.bund.de/DE/Themen/CO2Speicherung/Downloads/Speicherkataster_Kartenanwendung.html. Description in: http://www.bgr.bund.de/DE/Themen/CO2Speicherung/Downloads/Speicherkataster_synthese.pdf?__blob=publicationFile&v=4; http://www.bgr.bund.de/DE/Themen/CO2Speicherung/Downloads/Speicherkataster_Nachweissystem.pdf?__blob=publicationFile&v=1)

ETI UK SAP (GIS)

The Brazilian Carbon Geological Sequestration Map (CARBMAP Project, some info at http://www.pucrs.br/cepac/index_e.php?p=programas)

The geo-database of caprock quality and deep saline aquifers distribution for geological storage of CO2 in Italy (GIS) (http://www.sciencedirect.com/science/article/pii/S036054421100137X)

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Appendix E. BPMs on regulatory issues, community engagement and communication

Table E.1. Best practices etc. that considers regulatory issues, community engagement and similar (based on CO2CRC, 2011)

Date	Issued by	Title	Contents	Comment
Nov. 2010	CCP	Update on Selected Regulation Issues for CO_2 Capture and Geological Storage (http://www.co2capturereproject.org/reports/regulatory_report.pdf)	Covers the following sections • Carbon capture readiness • permitting and licensing, • impurities in injected CO_2 streams • pore space ownership, • liability issues • Monitoring, reporting and verifiaction requirements Each section has a general overview followed by a country by country description of how some nations handle the particular issue.	Dedicated to understanding regulation, this manual is structured by regulatory subject. Although it does not cover as many issues as the IEA framework, the inclusion of thorough reviews of existing legislation on key issues merits regarding this BPM as a valuable resource.
Nov. 2010	IEA	CCS Model Regulatory Framework (http://www.iea.org/ccs/legal/model_framework.pdf)	Covers • the entire CCS chain from capture through to storage site closure and provides a comprehensive discussion of the issues regulators face • reporting and classification issues, liability, hazards and risk, inspections and monitoring, financial aspects • areas that need to be standardized such as fluid composition.	This framework provides a guideline for understanding what must go into developing regulations for CCS. It uses existing regulations as examples of how the guidelines proposed have been used. Although, focused on only one aspect of storage (regulation) it does so thoroughly.
Dec. 2009.	NETL	Best Practices for: Public outreach and education for carbon storage projects (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM_PublicOutreach.pdf)	This BPM covers • The importance of public outreach • How public outreach should be integrated into the development of the project • Identifying stakeholders, an information gathering practice termed ‘social characterization • Developing plans and strategies, • Clarification on what key messages should be and how to tailor them to a public audience.	This BPM takes the short social outreach discussion from the site screening BPM and expands it using a generic approach combining lessons learned from numerous projects in a non-specific way.

Oct. 2010	WRI	Guidelines for community engagement in CCS (http://pdf.wri.org/ccs_and_community_engagement.pdf)	Includes understanding • The importance of community engagement • The needs of different stakeholders • of applying community engagement to the specifics of CCS throughout the entire life of a project • Of how to cover impacts and risks effectively and what reactions to expect • The best practice for presenting and exchanging information.	Comprehensive review of the CCS community engagement process. Provides numerous examples from around the world of the case studies where these lessons were learned.
2010	USGS	A probabilistic assessment methodology for the evaluation of geologic carbon dioxide storage: U.S. Geological Survey Open-File Report 2010–1127, 31 p., (http://pubs.usgs.gov/of/2010/1127)		

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Appendix F. BPMs on CO_2 storage capacity

Table F.1. Best practices and similar that relates to capacity estimation

Date	Issued by	Title	Contents	Comment
March 2003	Stefan Bachu	Screening and Ranking of sedimentary basins for sequestration of CO2 (http://www.geology.wmich.edu/bachu_Barnes_2003.pdf) Screening and Ranking of hydrocarbon reservoirs for CO2 storage (http://www.netl.doe.gov/publications/proceedings/01/carbon_seq/p21.pdf)		Some of the first articles on the subject of site selection for CO2 storage. The subject matter is very broad and applied to regional scale assessment but nonetheless represents one of the first thorough attempts to provide a guide and understanding to CCS site screening.
March 2008	CO2CRC	Storage Capacity Estimation, Site Selection and Characterisation for CO_2 Storage Projects (http://www.ukerc.ac.uk/support/tiki-download_file.php?fileId=2395)		A comprehensive, although generic, report on what is necessary to select and characterize a site and assess the storage capacity. We have not considered this a best practice manual because, although it provides a thorough and valuable resource on site selection, it is presented as more of a 'what to consider' as opposed to what practices should be undertaken.
2005, 2007 and 2008	CSLF Task Force for Review and Identification of Standards for CO_2 Storage Capacity	Measurement, Phase I, II and III (http://www.cslforum.org/publications/index.html?cid=nav_publications)		
	NETL	Methodology for Development of Geologic Storage Estimates for Carbon Dioxide (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/methodology2008.pdf)		Although this could be considered a BPM, presented as a technical guide to storage capacity estimation, it is included as an additional reference due to its limited scope and the fact that it has been superseded by NETL's site screening BPM which contains a technical section on storage capacity.

2010	CHINA(country based not BPM)	Chinese methodologies of storage capacity estimation. Near-term mega-scale CO2 capture and storage demonstration opportunities in China Zheng et. al., 2010. doi:10.1016/j.fuel.2011.07.004		
2011	JAPAN (country based not BPM)	Japanese methodology of storage capacity estimation. Saline-aquifer CO2 sequestration in Japan-methodology of storage capacity assessment. Ogawa et al., 2011. http://dx.doi.org/10.1016/j.ijggc.2010.09.009	National onshore and offshore assessment for Japan	A nationwide saline-aquifer CO2 storage capacity assessment carried out in Japan. The multiplication of S_f and S_g is analogous to efficiency factor in US DOE methodology and Capacity coefficient of CSLF methodology ranges from 1% to 20%
Others *	UK (country based not BPM)	UK CO2 Storage Appraisal Project (ETI 2011)	National offshore resource estimate for UK	Estimate of the storage resource that is theoretically accessible without recurse to pressure management and chase water injection. Chances of success and economics of each storage unit assessed.
	DE (country based not BPM) (http://www.bgr.bund.de/DE/Themen/CO2Speicherung/Downloads/Speicherkataster_Kartenanwendung.html)	GIS-basierte Kartenanwendung „Informationssystem Speicher-Kataster Deutschland“ (ArcReader 10 erforderlich, issued by BGR	Regional capacity assessment onshore and offshore for Germany	Capacity in structural and stratigraphic traps estimated. GIS/Spreadsheet

*source S. Holloway (IEA Seminar 2011). Please note also ongoing efforts towards a common methodology worldwide for CO2 Storage Capacity Assessment – S. Brennan et al, 2011. GHG 11 Abstract. Towards international guidelines for CO2 storage capacity estimation.

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Appendix G. BPMs and current guidance and standards conveying CO_2 in pipelines in connection with CCS projects

Table G.1. Some standards, BMPs and guidelines related to CO_2 transport in pipelines

Date	Issued by	Title	Contents
ALARP	HSE (UK)	Reducing risk As Low As Reasonably Practicable http://www.hse.gov.uk/pipelines/co2conveying.htm#a9	Application of good practice at the design stage is essential to demonstrating reduction of (ALARP). HSE expects duty holders to apply relevant good practice. Depending on the level of risk and complexity involved, it is possible the adoption of good practice alone may not be sufficient to comply with the law.
1996	PSR	Pipelines Safety Regulations	Regulation 5 requires that the design of a pipeline, or any modification to it, takes account of the operating regime of the pipeline and the conditions under which the fluid is to be conveyed as well as the environment to which the pipeline will be subjected. In particular with regard to the re-use of existing pipelines, any proposal to change the fluid conveyed will require a re-assessment of the original pipeline design to ensure that the pipeline is capable of conveying the fluid safely. European Standards implemented in the UK as British Normative Standards (BS EN series) and supported by published documents (such as the British Standards PD series) provide a sound basis for the design of pipelines. Other national or international codes e.g. a relevant standard or code of practice of a national standards body or equivalent body of any member state of the European Union are likely to be acceptable provided the proposed standard, code of practice, technical specification or procedure provides equivalent levels of safety.
	European Standards	PD 8010: 2004; BS EN 14161: 2003; Institute of Petroleum Pipeline Code IP6; DNV OS-F101 - Submarine Pipeline Systems (2007)	Codes IP6, BS EN 14161, BS PD 8010 and DNV OS-F101 are all applicable to pipelines transporting CO2; the last three categorising it as a non- flammable, non-toxic fluid which is gaseous at ambient temperature and pressure. IP6 also treats CO2 as a gas.

	US Pipeline Codes	US Federal Code of Regulations, Title 49, Volume 3, Part 195 – Transportation of Hazardous Liquids by Pipeline and the associated ASME standards B31.4 and B31.8	Main American codes which address the transportation of liquids and gases by pipeline respectively. The US Federal Code only applies to pipelines transporting CO2 in the supercritical phase and is therefore only relevant to proposals to use pipelines to convey supercritical CO2. There does not appear to be any equivalent code which addresses the transport of gaseous or liquid CO2.
April 2010	DNV	Recommended Practice DNV-RP-J202. Design and operation of CO2 pipelines	The Recommended Parctice (RP) ws developed to address the need for guidance for how to manage risks and uncertainties specifically related to transportation of CO_2 in pipelines. The document provides guidance and sets out criteria for the concept development, design, construction and operation of steel pipelines for the transportation of CO_2. It is written to be a supplement to existing pipeline standards and is applicable to both onshore and offshore pipelines. The RP is intended to assist in delivering pipelines in compliance with international laws and regulations. The pipeline operator will also have to ensure that the project is in compliance with local laws and regulations.

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