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Lifecycle risk management for integrated CCS projects

Gestion du risque du cycle de vie des projets CSC intégrés

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 265, *Carbon dioxide capture, transportation, and geological storage*.

Introduction

Carbon Capture and Storage (CCS) is a process that can mitigate the CO_2 emissions from power plants and other industrial sources of CO_2. CCS draws on many decades of experience in the electricity generation, industrial gas separation, chemical and manufacturing industries, and oil and gas industries, including substantial experience with subsurface injection techniques.

Many of the individual processes (or project phases) that are linked together to comprise a CCS chain have been proven for some time, albeit often in different contexts. Others are still being developed or adapted to this new application. Additionally, bringing them together in a CCS configuration represents a new application, with which there is limited global experience to date. As a result, there is an important need for knowledge development as real experience is gained in the comprehensive application of these technologies.

As with most technologies, CCS has inherent risks which need to be analysed and managed. Integrated projects, given their especially long-term and multi-component aspects, impose particular importance and challenge upon comprehensive risk identification. Risk assessment (detailed risk description and quantification) is completed using all available data, and assessment refreshed with updated numerical simulations which enable comprehensive risk analysis throughout the project lifecycle. The project lifecycle extends across all project phases from business development to site selection through post-closure. Together, risk identification, assessment, analysis, evaluation, management, and treatment are integrated into a risk management plan. The risk management plan aids in decision-making by the owner/operator and, to the extent the results of planning are communicated, aids other stakeholders in evaluating the project.

Keys to the success of the risk management plan are the integration and iterative application of risk assessment, risk data, and risk analysis. Risk analysis and numerical simulation help to identify, estimate and mitigate risks that may arise from CCS projects. These tools are also useful to optimize the design and operation of the monitoring, verification, and accounting aspects of the projects and can serve to inform and facilitate more effective site characterization and model improvement. Importantly, risk tools can be used to shape the design and operation of preventive and remediation options at every stage in the project lifecycle. Effective risk management communication to stakeholders who may be affected is crucial to the success of the project. The risk management plan can serve as a key component of the information handled through the public outreach and communication plan.

Lifecycle risk management for integrated CCS projects

1 Scope

This document is designed to be an information resource for the potential future development of a standard for overall risk management for CCS projects. The risks associated with any one stage of the CCS process (capture, transportation, or storage) are assumed to be covered by specific standard(s) within ISO/TC 265 and other national and/or international standards. For example, the risks associated with CO_2 transport by pipelines are covered in ISO 27913. The scope of this document is intended to address more broadly applicable lifecycle risk management issues for integrated CCS projects. Specifically, the focus of this document is on risks that affect the overarching CCS project or risks that cut across capture, transportation, and storage affecting multiple stages. It needs to be noted that environmental risks, and risks to health and safety should be very low for CCS projects provided the project is carefully designed and executed. Risk identification and management is part of the due diligence process.

A list of acronyms is included in Annex A.

Clause 5 includes an analysis of how a CCS standard could address aspects of risk analysis that apply to all elements of the CCS chain, such as:

— risk identification (identifying the source of risk, event, and target of impact)[1];

— risk evaluation and rating;

— risk treatment;

— risk management strategy and reporting.

Clause 6 comprises an inventory of the overarching and crosscutting risks. These include issues such as:

— environmental impact assessment;

— risk communication and public engagement;

— integration risks between capture, storage, and transportation operators, such as risk of non-conformance of CO_2 stream to required specifications;

— integration risks associated with shared infrastructure (hubs of sources, common pipelines, hubs of storage sites);

— risks resulting from interruption or intermittency of CO_2 supply and/or CO_2 in-take;

— risks associated with policy uncertainty;

— incidental risks from activities related to the capture, transportation or storage processes without being specifically covered in the respective standards (e.g. management or disposal of water produced as a by-product of CO_2 storage).

Clause 7 describes implications and considerations for a potential standard on lifecycle risks for integrated CCS projects.

1) As defined in ISO 31000.

2 Normative references

The following referenced documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 27917, *Carbon dioxide capture, transportation and geological storage — Vocabulary — Crosscutting terms*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 27917 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 General information on lifecycle risk management for CCS

4.1 Usefulness and benefits of lifecycle risk management

Overarching, or crosscutting risk management may help inform future investment and regulatory decisions regarding the risks associated with a CCS project lifecycle. Such evaluations of overarching lifecycle risk already have been performed for previous CCS projects, either as part of an Environmental Impact Assessment [Gorgon (Chevron) and Shengli Dongying (SINOPEC)] or as a requirement of the regulatory or permitting process.

A future International Standard that builds on previous requirements in relevant industries could help future project developers in meeting permitting requirements and help ensure that risks associated with a CCS project are comprehensively identified, evaluated, and managed. In addition, it may promote an appropriate management of risks to health, safety and the environment in areas where regulatory frameworks are less comprehensive, and it may inform future regulatory developments.

4.2 Defining lifecycle for an integrated CCS project

Most of the organizations that have previously published guidelines or standards for CCS risks have focused on the lifecycle of the storage component of a CCS project. Figure 1 to Figure 6 present various lifecycle descriptions from published sources.

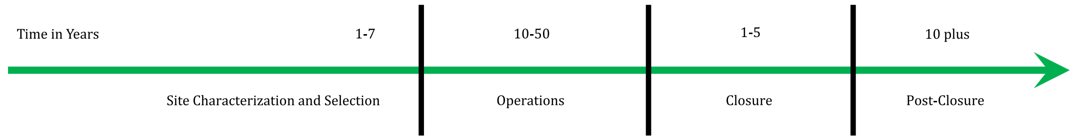

Figure 1 — Timeline for a CCS project defined in the WRI guidelines for carbon dioxide capture, transport, and storage (Forbes et al., 2008)

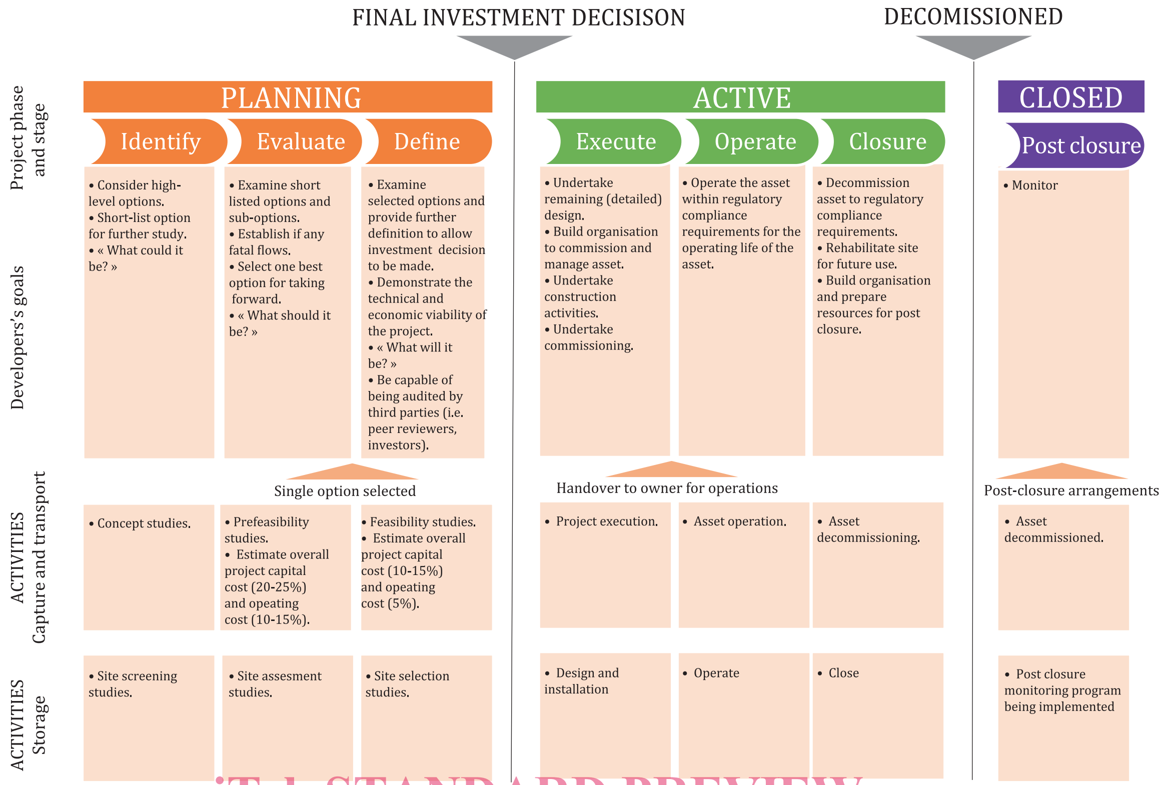

Figure 2 — The project Lifecycle Model of a CCS project developed by the Global CCS Institute (GCCSI, 2015)

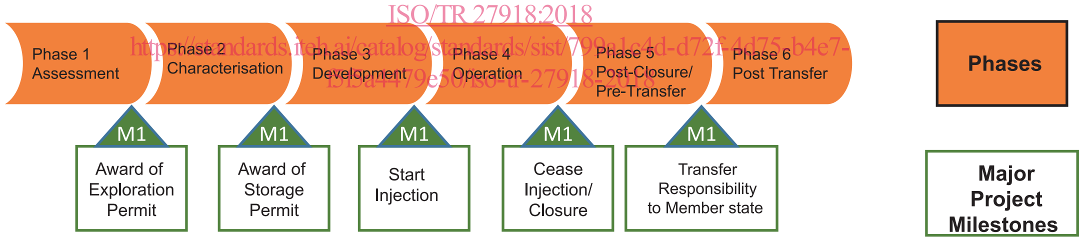

Figure 3 — CO_2 storage lifecycle phases and milestones described in the guidance document of the implementation of Directive 2009/31/EC (European Communities, 2011)[2)]

2) The EU storage project lifecycle definition includes "transfer of responsibility" which might not apply to all jurisdictions.

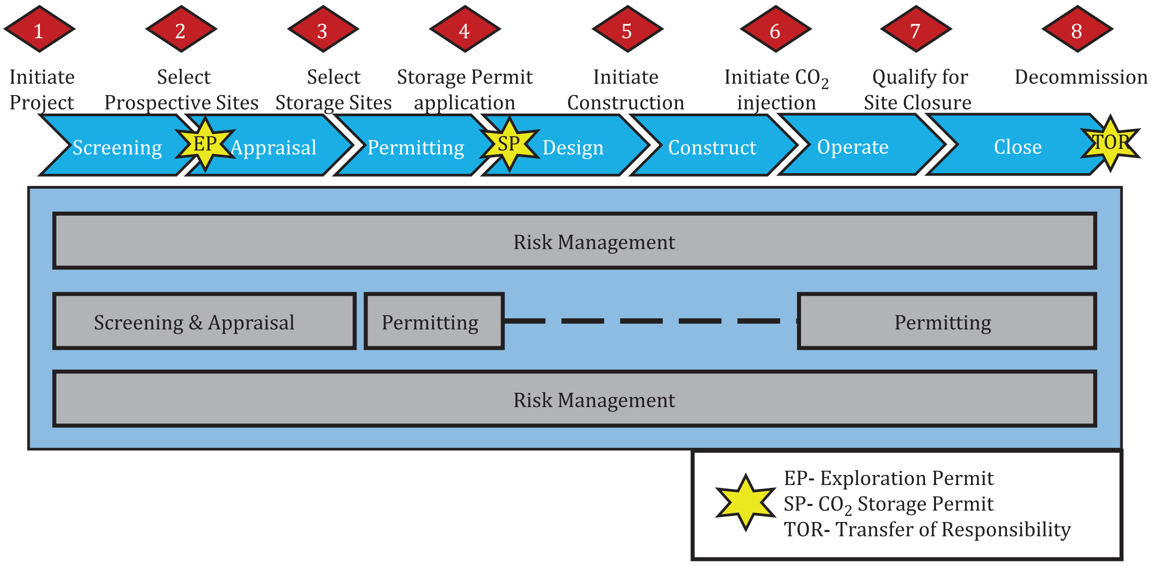

Figure 4 — Carbon dioxide geological storage project lifecycle and associated qualification statements, relevant permits and project milestones defined by DNV (DET NORSKE VERITAS AS, 2012; Det Norske Veritas, 2009)

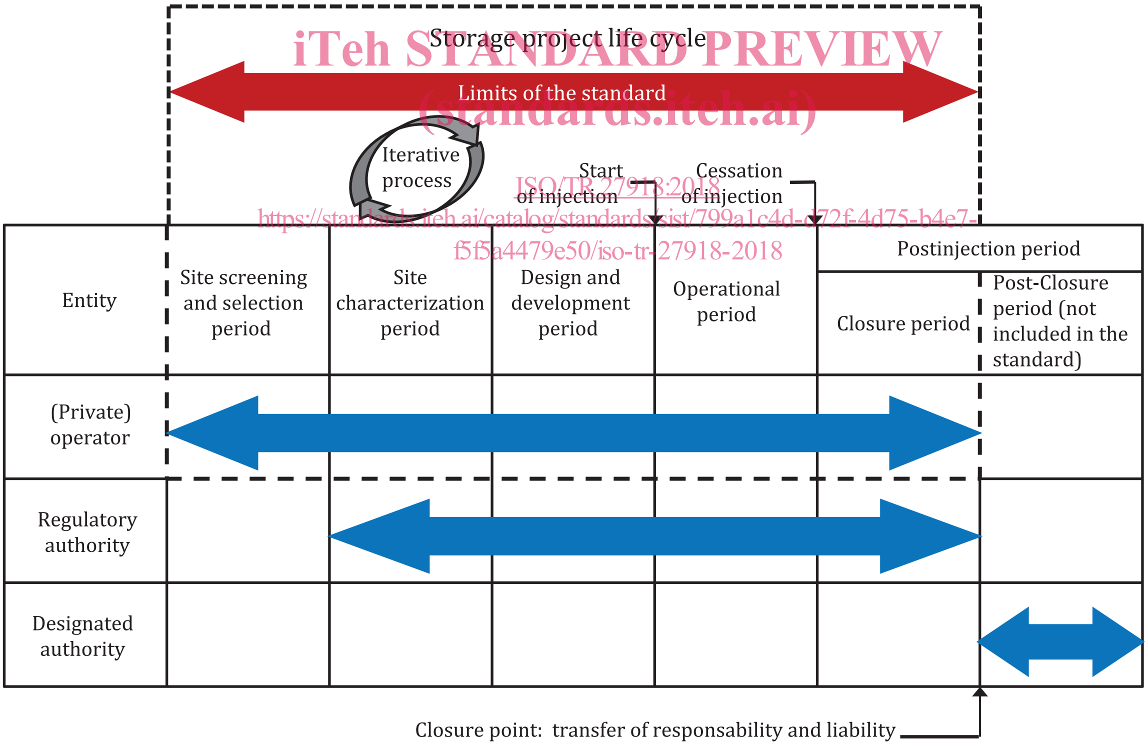

Figure 5 — Lifecycle of a CCS project as defined in Z741 (Canadian Standards Association, 2012)

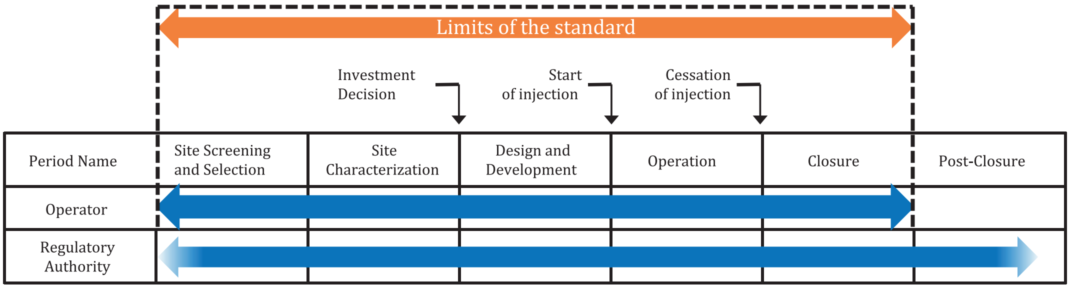

Figure 6 — Lifecycle of a CCS project as defined in in the International Standard for Carbon Dioxide Capture, Transportation, and Storage—Geologic Storage (ISO DIS/27914)

Figure 7 presents the CCS project lifecycle from the point of risk management responsibility and oversight to elucidate the risk source and interaction effect. It was developed based on the Global CCS Institute's (Figure 2) and Canadian Standard Association's (CSA) definitions of lifecycle (Figure 5). As described in Figure 7, the CCS project lifecycle includes all phases of a CCS project from start-up through operation and closure and into the post-closure period. Figure 7 also includes the components of a CCS project, the disposition of the CO_2 stream and the risk management responsibility.

A CCS project lifecycle includes the subsystems (capture, transportation, and storage) as well as temporal elements (project design and initiation, operation, closure, and post-closure). Figure 5 was used in the Canadian Standard's Association's "Z741-12 Geological storage of carbon dioxide" (Canadian Standards Association, 2012) to describe the project lifecycle for a CCS storage project and limitations to the applicability of the standard.

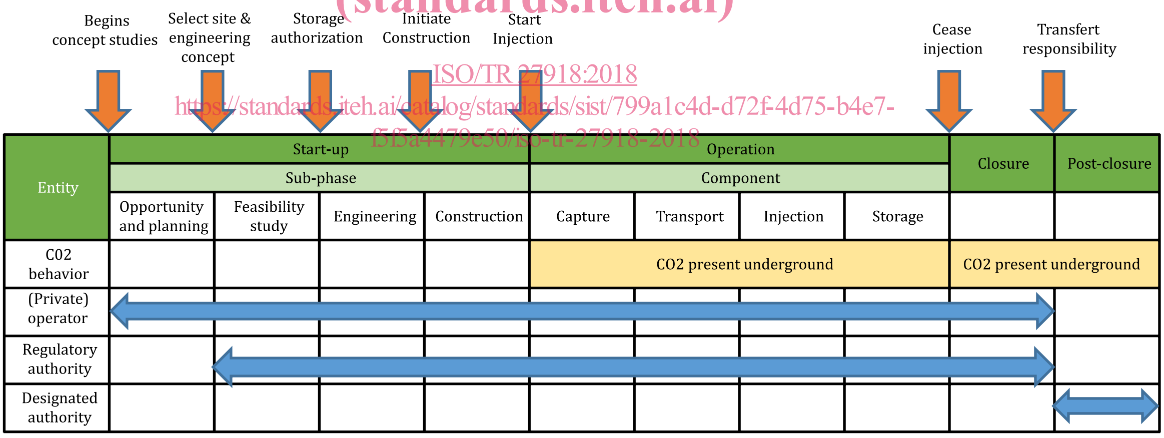

Figure 7 — Proposed CCS project lifecycle from a risk management viewpoint

For the purposes of this document, the lifecycle of a CCS project is defined as having a start-up phase which includes opportunity, planning, engineering and construction; an operational phase which includes capture, transportation and injection; a closure phase; and a post-closure phase. The "decommissioning" stage referenced in Figures 2 and 4 has been omitted because of differences in timing and interpretation across various industries and countries.

4.3 Examples of overarching risk assessment processes conducted for CCS projects

While many tools exist to plan, prepare, and execute risk assessment, analysis, and planning, the following is a brief discussion of the major processes used in the planning and execution (where applicable) of a number of CCS projects. This list includes the risk assessment tools and approaches considered or used by the following projects (operators in parentheses): Weyburn (Cenovus), Gorgon (Chevron), FutureGen 1.0 (FutureGen Alliance), Peterhead (Shell) and White Rose (National Grid Carbon), In Salah (BP), K12-B (GDF Suez), Lacq-Rousse (Total), Snøhvit (Statoil), Otway (CO2CRC), PurGen (SCS), Cemex CCS (Cemex), Aquistore (Petroleum Technology Research Centre, or PTRC), and the Regional Carbon Sequestration Partnerships (RCSP, US DOE).

— **Features, Events, and Processes (FEP) database [Quintessa]**: This is an online database tool developed by Quintessa, a scientific and mathematical consulting firm. The database covers technical, operational, and programmatic risks and is used as a qualitative screening tool for health, safety, and environment (HSE), causalities, and environmental (water and air) impacts. Expert input is required both to describe chains of events by which impacts could occur (scenarios) and to describe and quantify the associated risks. This tool has been employed at the Weyburn (Cenovus) and In Salah (BP) projects (Quintessa, 2013).

— **Performance Assessment (PA) Framework for CO_2 [Quintessa]**: In addition to the FEP database, Quintessa has also developed an evidence-based qualitative and quantitative tool which covers technical, operational, and programmatic FEPs. PA allows for the stakeholder assessment of decisions and uncertainty of a project. This tool has been employed at the In Salah (BP) and Quest (Shell) (Quintessa, 2008).

— **Risk Assessment Methodology [TNO]** The TNO methodology covers technical and programmatic risks, focusing on human causality, environmental and groundwater risks. Expert input is required to establish the probability and consequential matrices that can demonstrate long-term safety performance of the underground storage of CO_2 (TNO, 2016). TNO has also developed Carbon Storage Scenario Identification Framework (CASSIF) (Sijacic et al., 2014) which is a qualitative tool requiring expert scenario input to identify storage performance and multiple-site screening.

— **CO_2 QUALSTORE [DNV]**: This product provides guidance on the process and third-party verification for full geologic storage life-cycle risk assessment and analysis as both a qualitative and quantitative tool, using multiple category inputs (VERITAS, 2010). This tool has been used to actively inform discussions between project developers and regulators, including Schwarze Pumpe (Vattenfall) and Quest (Shell). The tool also provided a basis for the DNV-RP-J203 (DET NORSKE VERITAS AS, 2012) certification which has been used for certification by the CarbonNet project (Victorian Department of Economic Development, Jobs, Transport and Resources).

— **URS Risk Identification and Strategy using Quantitative Evaluation (RISQUE) [URS]**: This semiquantitative tool focuses on technical and community impacts using key performance indicators. This tool has been employed at Weyburn (Cenovus), Otway (CO2CRC), Gorgon (Chevron), and In Salah (BP) (GCCSI, 2010a) (Dodds et al., 2010).

— **Screening and Ranking Framework (SRF) [Oldenberg]**: This Microsoft Excel based tool uses technical data to allow for expert assessment and assignment of certainties (Oldenberg, 2005). The tool focuses on technical and community HSE aspects and is employed at Ventura oil field and Rio Vista gas field. The definitions of primary containment, secondary containment and attenuation potentially increase data requirements, and the primary and secondary containment are difficult to define for some sites, such as the Ordos basin which has multiple layers. The modified SRF applied to Shenhua CCS pilot project in China discusses these problems, but does not fully overcome them.

— **Vulnerability Evaluation Framework (VEF) [US EPA]**: This qualitative tool addresses HSE, ecosystem, and underground source of drinking water (USDW) impacts to the geosphere utilizing technical input data. The tool can be applied across all aspects of a GS project (US EPA, 2008).

— **Carbon Work Flow [Schlumberger]**: This tool uses expert input to quantify technical and programmatic risks of the project and project goals. The tool requires expert and lay input and is employed at the RCSPs (US DOE), PurGen (SCS), Cemex CCS (Cemex), and Aquistore (PTRC) (US EPA, 2008).

— **Performance and Risk Methodology (P&R) [Oxand and Schlumberger]**: This tool combines qualitative and quantitative risk evaluation in a matrix fashion, focusing on public acceptance, financial, technological, HSE, and USDW impacts(Guen et al., 2009). The tool is employed by the RCSPs (US DOE).

— **CO_2-PENS [LANL]**: This tool developed by Los Alamos National Laboratory (LANL) uses evidence-based input to consider technical, economic, and community risks. The tool focuses on the full geological sequestration (GS) lifecycle and is employed by the RCSPs (US DOE). It was also used for a risk assessment of the Rock Springs Uplift in Wyoming.

— **MANAUS approach [BRGM]:** BRGM has developed in the framework of the MANAUS project a practical approach for performing a preliminary quantitative risk assessment in an uncertain context. This approach follows the risk assessment principles from the international standards (ISO 31000:2009), which are adapted to account for the specificities and challenges of subsurface operations. In particular the relatively high level of uncertainties expected at early stages of a storage project is accounted for, enabling fully informed decision-making while evaluating risk acceptability (de Lary et al., 2015).

— **CO_2RISKEYE [IRSM-CAS]**: This is an assessment prototype for environmental risk assessment of CO_2 geological storage that is being developed by Li, et al. (Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, IRSM-CAS), which corresponds to the related regulations and guidelines in China. It combines different assessment methods for different purposes, including a modified version of Oldenburg's SRF, Bachu's site-screening method, a fuzzy Analytic Hierarchy Process (AHP) method, and others (Li and Liu, 2016; Liu et al., 2016).

— **National Risk Assessment Partnership (NRAP) [US DOE]:** This performance quantification approach relies on reduced-order models to probe uncertainty in the system. Toolset was built to address key questions about potential impacts related to release of CO_2 or brine from the storage reservoir, and potential ground-motion impacts due to injection of CO_2 (see Table 1). Eight NRAP tools are available for beta testing, e.g. Integrated Assessment Model-Carbon Storage (NRAP-IAM-CS), Natural Seal ROM (NSealR), Reservoir Evaluation and Visualization (REV), Wellbore Leakage Analysis Tool (WLAT), Aquifer Impact Model (AIM), Design for Risk Evaluation and Monitoring (DREAM), Short Term Seismic Forecasting (STSF), and Integrated Assessment Model for Carbon Storage and Reservoir ROM Generation (RROM-Gen). Hypothetical cases have been applied to the tools for demonstration purposes.

Table 1 — Key features of risk assessment tools

Tool	Application	Start-up				Operation			Closure	Post-closure
		Opportunity	Planning	Engineering	Construction	Capture	Transportation	Injection		
Features, Events, and Processes (FEP) [Quintessa]	Weyburn (Cenovus), In Salah (BP)	x	x	x	x	x	x	x	x	x
Performance Assessment (PA) Framework for CO_2 [Quintessa]	In Salah (BP), Quest (Shell)	x	x	x	x	x	x	x	x	x
Risk Assessment Methodology [TNO]	n/a	x	x					x	x	x
CO_2QUALSTORE [DNV]	Schwarze Pumpe (Vattenfall), Quest (Shell)	x	x	x	x			x	x	x
Risk Identification and Strategy using Quantitative Evaluation (RISQUE) [URS]	Weyburn (Cenovus), Otway (CO2CRC), Gorgon (Chevron), In Salah (BP)	x	x	x	x	x	x	x	x	x

Table 1 *(continued)*

Tool	Application	Start-up				Operation			Closure	Post-closure
		Opportunity	Planning	Engineering	Construction	Capture	Transportation	Injection		
Screening and Ranking Framework (SRF) and Certification Framework (CF) [Oldenburg]	SRF: Ventura oil field, Rio Vista gas field; modified for Shenhua. CF: In Salah (BP)	x	x	x	x			x	x	x
Vulnerability Evaluation Framework (VEF) [US EPA]	n/a	x	x	x	x			x	x	x
Carbon Work Flow [Schlumberger]	RCSPs (US DOE), Pur-Gen (SCS), Cemex CCS (Cemex), Aquistore (PTRC)	x	x	x	x	x	x	x	x	x
Performance and Risk Methodology (P&R) [Oxand and Schlumberger]	RCSPs (US DOE)	x	x	x	x			x	x	x
CO_2-PENS [LANL]	RCSPs (US DOE), Wyoming Rock Springs Uplift	x	x	x	x	x	x	x	x	x
MANAUS approach [BRGM]	n/a	x	x	x	x			x	x	x
CO_2RISKEYE [IRSM-CAS]	n/a	x	x	x	x			x	x	x
National Risk Assessment Partnership (NRAP) [US DOE]	n/a	x	x	x	x			x	x	x

4.4 Examples of ISO risk standards that may be applied to CCS projects

There is a globally accepted ISO 31000:2018, *Risk management approach — Guidelines*, which may be applied to CCS risk management, including:

— ISO Guide 73:2009, *Risk management — Vocabulary*;

— IEC 31010:2009, *Risk management — Risk assessment techniques*.

Annex of IEC 31010 contains almost all well used risk assessment techniques, including Delphi, fault tree analysis (FTA), event tree analysis (ETA), bowtie diagrams, health risk assessment (HRA), hazard and operability study (HAZOP), and risk matrices.

For CCS specifically, an eventual ISO Standard addressing the CO_2 storage aspects of CCS may include a risk management clause that addresses the following steps:

— establishing the context;

— risk assessment:
  — risk identification;
  — risk analysis;
  — risk evaluation;
— risk treatment;
— monitoring and review;
— communication and consultations;

4.5 Description of how risk is addressed in other standards and regulations

4.5.1 General

The risks associated with CCS are addressed at the national and international level in agreements and regulations. Previous standards and best-practice guidelines have also addressed risk. However, many of these existing standards and regulations focus exclusively on geological storage of CO_2 and therefore may not adequately address the crosscutting and overarching risks identified and described in this document. 4.5 provides a brief overview of the treatment of CCS risk in international agreements, regional and national regulations, and best-practice manuals.

This subclause focuses on CCS-specific risk assessment provisions which would be applied to integrated CCS projects, however capture and transportation risk assessments are sometimes required for a capture unit or pipeline as a separate measure. For example, in the United States a capture plant would need to comply with the following laws in the Code of Federal Regulations (CFR): 29 CFR §1910.38 (Emergency Action Plans), 29 CFR §1910.119 (Process Hazardous Analysis and Hazardous and Operability Analysis) and 40 CFR Part 68 (Risk Management Plans). These laws ensure that risk management planning is conducted during the design, project management, and construction, pre-start-up and operations life of a facility or part thereof (such as a capture unit).

4.5.2 Treatment of CCS risk in international agreements

4.5.2.1 London Convention and London Protocol

The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (London Convention) and the Protocol of 1996 (London Protocol) have been amended to allow and manage sub-seabed geological storage (Annex 6). The amendments developed and adopted a framework for risk assessment and management of geological storage projects and guidelines for managing geological storage projects. The Annex 6 amendments allow sub-seabed injection of CO_2 when the injected gas or liquid consists “overwhelmingly of CO_2” (it is permissible for it to contain incidental associated substancees derived from the source material, and the capture and sequestration processes used). Additionally, no wastes or other matter are to be added to the CO_2 for the purpose of disposing of those wastes or other matter. In other words, the Protocol’s amendment adopts a non-quantitative standard for the CO_2 content and non-waste quality of the injected CO_2 streams and requires monitoring and controls to maintain that quality. The Annex 6 amendments allowing for sub-seabed storage came into force in February 2007. In 2012, the London Convention adopted “Specific Guidelines for the Assessment of Carbon Dioxide for Disposal into Sub-Seabed Geological Formations (LC34/15, Annex 8) (IMO, 2012). The Guidelines require that the risk assessment describes the risks in terms of the likelihood of exposure and the associated effects on habitats, processes, species communities and uses. The Guidelines also reference mitigation measures, using the risk assessment to inform monitoring programs, and updating the risk assessment at various stages in project to account for short-term and long-term risks. The assessment “should” also take leak mitigation into account.

