A Comparative Study of Existing Standards/Protocols for Carbon Capture and Sequestration to Inform Development of a Quantification Methodology

Background

The Air Resources Board (ARB) is currently developing a quantification methodology (QM) to allow for the use of carbon capture and sequestration (CCS) in its climate change programs, and to advance the use of CCS as a greenhouse gas (GHG) reduction strategy generally. As with other ARB QM's, the CCS QM may be adopted for use in the Cap-and-Trade and Low Carbon Fuel Standard programs if and as determined appropriate in future rulemakings specific to those programs. For more information on ARB's CCS program and development of the QM please visit our website at: http://www.arb.ca.gov/cc/ccs/ccs.htm.

CCS accounting protocols provide the methodology (e.g., equations and procedures) to quantify emissions reductions associated with capturing, processing, transporting, and permanently sequestering carbon dioxide (CO_2) in geologic formations. The accounting protocol is one of several components of ARB's comprehensive CCS QM that will ensure emissions reductions are real, permanent, quantifiable, verifiable, and enforceable. There has been interest and activity worldwide on developing guidelines, requirements, and QMs for CCS projects. Some entities have published standards/protocols related to, or specifically for, CCS projects; others are in the process of producing such documents. Better understanding of what has been done to date can lay the foundations for developing ARB's QM for CCS projects.

Objective

The objective of this study is to conduct a comprehensive and thorough examination of the standards/protocols that have been developed by major countries, regions, and organizations worldwide. This study identifies the main elements of each standard/protocol, compares the description and handling of each element in different standards/protocols, and explores reasons for the differences in those standards/protocols. In addition, a focused study is conducted on the standards/protocols that also include QMs. This focused study provides details on the accounting approach, parameters, and equations for accounting CO_2 sequestered in CCS projects. It is expected that this comparative study can guide ARB in outlining the necessary elements for a QM for CCS projects. This study also helps to ensure that ARB will develop guidelines, requirements, and QMs that are based on the best available knowledge.

Summary

This study examines and compares nine existing standards/protocols. These standards/protocols cover development activities in the U.S., Canada, European Union, and a few international organizations. This study is meant to ensure that ARB is up-to-date on the best available knowledge and best practices for each of the main elements of the existing standards/protocols. See Tables 1 and 2 for the covered elements of these standards/protocols. The standards/protocols included in this review are listed below:

- US EPA 40 CFR 98 Subpart RR (2010) [1]
- ACR (2015) [2]
- ISO 14064-2 (QMR for GHG reduction)[3]
- EU Directive 2009/31/EC[4]
- 2006 IPCC Guidelines[5]
- UNFCCC Decision 10/CMP.7[6]
- CSA (2012) [7]
- Alberta Protocol (2015) [8]
- C2ES (2012) [9]

[1] The American Carbon Registry. *Methodology for Greenhouse Gas Emission Reductions from Carbon Capture and Storage Projects*. Version 1.0, 2015.

[2] ISO, ISO 14064-2:2006, *Greenhouse gases -- Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements*.

[3] Note: ISO is also working on a standard specifically for CCS. Communication with the ISO technical experts indicates that they have worked on the standard for one year as of Aug. 2015; typical timeline is three years plus two additional years for reaching consensus among member countries.

[4] 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 Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006.

[5] 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volumes 1 and 2

[6] United Nations Framework Convention on Climate Change (UNFCCC), Decision 10/CMP.7, *Modalities and procedures for carbon dioxide capture and storage in geological formations as clean development mechanism project activities*, 2012

[7] Canadian Standards Association and CSA America, Inc., *Geological storage of carbon dioxide*, Z741-12, 2012.

[8] Alberta Government, *Quantification Protocol for CO2 Capture and Permanent Storage in Deep Saline Aquifers*, 2015.

[9] Mike McCormick, *a Greenhouse Gas Accounting Framework for Carbon Capture and Storage Projects* (Center for Climate and Energy Solutions, formerly the Pew Center on Global Climate Change, 2012).

Four out of the nine standards/protocols reviewed provide calculation procedures and equations for accounting for CO_2 reductions from CCS projects; the remaining five standards/protocols provide guidelines and requirements for various aspects of CCS projects but do not provide equations for calculating CO_2 reductions. The four standards/protocols that enable quantification of CO_2 reduction for CCS projects are: US EPA 40 CFR 98 Subpart RR (2010), C2ES (2012), ACR (2015), and Alberta Protocol.

US EPA 40 CFR 98 Subpart RR (2010), C2ES (2012), and ACR (2015) lack provincial or state-level implementation specifics. The Alberta Protocol provides provincial-level implementation specifics, but does not cover site selection and some other aspects of CCS projects. Instead, it refers to 13 other regulations or government documents for elements not covered. For example, it refers to the Specified Gas Emitters Regulation for emission factors and energy efficiency parameters necessary for calculation; it also refers to CSA (2012) in Table 2 for site screening, selection, and characterization, and well development. See Table 3 for further details about these four standards/protocols.

Tables 1 through 3 compare all nine standards/protocols. Tables 1 and 2 contain the same parameters but split the standards/protocols for ease of reading. Tables 1 and 2 describe all the main elements of the standards/protocols, which cover the U.S., Canada, Europe, and three international organizations. Table 3 provides details on the accounting elements and equations used for quantifying CO_2 sequestered. Table 3 includes the calculation scope, accounting approach, parameters and equations, and other information in each of the four standards/protocols.

Table 1: Elements of existing CCS protocols/standards-1

	US EPA 40 CFR 98 Subpart RR (2010)	ACR (2015)	ISO 14064-2 (QMR for GHG reduction)	EU Directive 2009/31/EC	2006 IPCC Guidelines
Scope and applicability	Specified applicable well types	For enhanced oil and gas recovery (EOR/EGR) projects storing CO_2 in oil and gas reservoirs	GHG program neutral; Specified principles, requirements, and provided guidance for quantifying, monitoring, reporting, and verifying activities intended to cause GHG emission reduction	Geological storage of CO_2; Not applicable to CO_2 storage below 100 kilotonnes, for research and development, or testing; Storage of CO_2 in water column not permitted	Methodologies for use by countries to estimate GHG inventories to report to the United Nations Framework Convention on Climate Change (UNFCCC)
Management system	No dedicated section	No dedicated section	Specified principles and requirements for management	Specified requirements and guidelines	No dedicated section
Risk Management	No dedicated section	Specified requirements on a Risk Mitigation Covenant or an alternative risk mitigation assurance described in Section 5.4.1	Mentioned in Section 5.7, paragraph 5	Risk characterization based on hazard, exposure, and effect assessment (Annex I)	Described in Chapter 5 of Volume 2
Site screening, selection, and characterization	None	None	None	Member States retain the right to determine the areas for storage sites; Provided criteria for characterization and assessment of the potential storage complex and surrounding area (Annex I)	Included in the description of emission pathways/sources and procedures for estimating emissions, Chapter 5 of Volume 2

	US EPA 40 CFR 98 Subpart RR (2010)	ACR (2015)	ISO 14064-2 (QMR for GHG reduction)	EU Directive 2009/31/EC	2006 IPCC Guidelines
Well development	None	None	None	None	Mentioned several material requirements in Section 5.5, Chapter 5 of Volume 2
Monitoring & verification (MV)	Required monitoring, reporting and verification (MRV) plan; Described requirements on measurement, etc.; Described MRV plan components, timing, etc.	Described required monitoring plans and parameters	Specified monitoring procedures; Verification should conform to the principles and requirements of ISO 14064-3	Described purposes of monitoring, and requirements on monitoring plans	Described in Chapters 2 and 6 of volume 1, and Chapter 5 of volume 2
Quantifying/accounting CO_2 stored	12 equations provided	Calculation procedures for Baseline (2 options) and Project emissions; 31 equations provided for the calculations (adapted from C2ES, 2012)	Specified requirements for quantifying the GHG emissions of the Baseline scenario and GHG project; The difference in GHG emissions between Baseline scenario and GHG project is the GHG emission reduction; No equations provided	None	General guidelines for quantifying/accounting CO_2 capture, transport, injection and storage are provided
Missing data	Provided procedures for estimating missing data	Recommended USEPA Subpart RR, 40 CFR Part 98.445, Procedures for estimating missing data	None	None	Provided guidelines for estimating missing data

	US EPA 40 CFR 98 Subpart RR (2010)	ACR (2015)	ISO 14064-2 (QMR for GHG reduction)	EU Directive 2009/31/EC	2006 IPCC Guidelines
Data reporting requirements	No threshold for reporting CO_2; Provided details on requirements (e.g., flow rate, reporting frequency, identifiers, etc.)	Required reporting in the MRV plan, and mentioned USEPA Mandatory Greenhouse Gas Reporting requirements	Specified requirements for reporting a GHG project and its assertion of GHG reduction	All results of monitoring; Quantities and properties of the CO_2 stream delivered and injected, etc.	Guidelines for reporting emissions on CCS provided in Chapter 5 of Volume 2, and relevant chapters in other volumes
Record-keeping	Specified required records, and lengths of records retaining	Mentioned in the monitoring plan section and Section 6	Mentioned in many sections such as 5.9, 5.10, and 5.11	Negligible	Guidelines for record keeping on CCS provided in Chapter 5 of Volume 2, and relevant chapters in other volumes
Closure	None	Post-injection monitoring and term requirements	None	Closure obligations	None
Post-project (marked by transfer of responsibility) Long term stewardship	None	Permanence, liability, and mitigation are discussed; End of project is marked by transfer of responsibilities	None	Post closure obligations; Transfer of responsibility; Financial security and mechanism	None

Table 2: Elements of existing CCS protocols/standards-2

	UNFCCC Decision 10/CMP.7	**CSA (2012)**	**Alberta Protocol (2015)**	**C2ES (2012)**
Scope and applicability	CO_2 capture and storage in geological formations under the clean development mechanism	Requirements and recommendations primarily for saline aquifers and depleted reservoir; No requirements targeting at EOR/EGR	CO_2 offset credit generating; Cover the full CCS chain; CO_2, methane, and nitrous oxide must be quantified; Does not apply to EOR/EGR	Accounting approaches; Applied to capture in power plants and industry sources; CO_2 transported by pipelines only; Storage in saline aquifers, depleted oil and gas fields, and EOR/EGR sites
Management system	No dedicated section	Activity scope, project boundary, principles, and planning, etc.	A chapter dedicated to data management	None
Risk Management	Specified requirements on a risk and safety assessment	Risk management objective and process are consistent with ISO 31000; Other issues with risk management such as risk assessment are also addressed	Provides procedures to address the uncertainty in estimating emissions from subsurface to atmosphere	Policy options for managing the risk associated with leaks
Site screening, selection, and characterization	Requirements listed in Appendix B; No significant seepage, health and environmental risk; No site in international waters, etc.	Included in Chapter 5	No coverage, but referred to CSA (2012)	None
Well development	None	Materials, design, construction, corrosion control, etc.	No coverage, but referred to CSA (2012), which describes materials, design, construction, corrosion control, etc.	None

	UNFCCC Decision 10/CMP.7	**CSA (2012)**	**Alberta Protocol (2015)**	**C2ES (2012)**
Monitoring & verification	Described objective of monitoring; Specified requirements to meet the objective, refer to Appendix B	Described MV purpose, periods, and program design	Mentioned monitoring requirements in related regulation; Described additional requirements for monitoring, measurement, and verification (MMR)	Described required monitoring plans and parameters for quantification; Provided list of technologies for monitoring reservoirs
Quantifying/accounting CO_2 stored	General guidelines provided in Appendix A; No detailed approach or methodology	None	All emission sources and sinks are identified; Calculation procedures for Baseline and Project emissions; 4 main equations and multiple sub-equations provided for the calculations	Calculation procedures for Baseline (2 options) and Project emissions; 34 equations provided for the calculations
Missing data	None	None	Nearly none (only mentioned for the estimate of total quantity of fuel consumed)	None
Data reporting requirements	No sections dedicated to reporting requirements	No specifics	A chapter dedicated to data management; Reporting required in the MMV plan	Required reporting in the MRV plan; Mentioned ISO 14064-2 and USEPA Mandatory Greenhouse Gas Reporting requirements
Record-keeping	None	Mentioned in many sections such as 4.1.2, 5.4.6, and 7.2.5.7	Specified record keeping requirements	Negligible
Closure	Described definition of closure phase	Described the plan, activities, process, and decommissioning	Discussed monitoring during closure	Post-injection, post-closure monitoring mentioned

	UNFCCC Decision 10/CMP.7	**CSA (2012)**	**Alberta Protocol (2015)**	**C2ES (2012)**
Post-project (marked by transfer of responsibility) Long term stewardship	Described requirements for financial provision; Discussed liability issues	None	Discussed liability and reversal issues	Permanence, liability, and mitigation are discussed; End of project is marked by transfer of responsibilities

Table 3 Elements of quantification methodology for CCS from existing CCS protocols/standards

	US EPA 40 CFR 98 Subpart RR (2010)	**C2ES (2012)**	**ACR (2015)**	**Alberta Protocol**
Calculation scope	CO_2 received, injected, produced/recycled, leaked, and sequestered (does not account for capture and transport)	CO_2 capture, pipeline transport, injection and storage	Anthropogenic CO_2 capture, transport, injection, and sequestration during EOR operations into an oil and gas reservoir located in the U.S. or Canada	CO_2 injected, produced/recycled, leaked, and sequestered (EOR/EGR operations not included)
Accounting approach	Using mass balance approach starting at the point of CO_2 receipt; Emissions associated with electricity and heat use are not included	Calculate GHG emissions reductions by comparing baseline emissions (without CCS) to project emissions (with CCS)—the difference between the two represents the GHG reductions due to capturing, transporting and sequestering CO_2	Calculate GHG emissions reductions by comparing baseline emissions (without CCS) to project emissions (with CCS)—the difference between the two represents the GHG reductions due to capturing, transporting and sequestering CO_2; Modified based on C2ES (2012)	The baseline and CCS project conditions are assessed against each other to determine the reductions; Emission sources and sinks are either included or excluded depending on whether there are expected emission changes between baseline and project condition
Accounting baseline emission (emission that would have been released without CCS)	Not included	Using Equation 2.0 for calculating Projection Based Baseline GHG emissions; Using Equation 3.0 for calculating Standards Based Baseline emissions; CH_4 and N_2O are not included in the Baseline calculations to be conservative	Using Equation 4.1 for calculating Projection Based Baseline GHG emissions; Using Equation 4.2 for calculating Standards Based Baseline GHG emissions; CH_4 and N_2O are not included in the Baseline calculations to be conservative	One equation provided to calculate this (this is defined as CO_2 injected with the expectation that no emission changes between baseline and project condition for some releases)

	US EPA 40 CFR 98 Subpart RR (2010)	**C2ES (2012)**	**ACR (2015)**	**Alberta Protocol**
Accounting GHG/CO_2 emission during capture	Not included	Using Equation 5.0 to calculate total emissions from CO_2 capture; Total capture emissions calculation needs to account for non-captured CO_2 (Equation 5.1), emissions from on-site use of fossil fuels (Equation 5.2), and emissions from purchased electricity and thermal energy (Equation 5.3)	Use Equation 4.4 to calculate total annual project emissions from the capture segment; Total capture emissions calculation involve non-captured CO_2e (Equation 4.5, and 4.5a-c), emissions from on-site use of fossil fuels (Equation 4.6), and emissions from purchased electricity and thermal energy (Equation 4.7, and 4.7a-c)	Equations provided (emissions due to electricity, heat, and material use)
Accounting GHG/CO_2 emission during transport	Not included	Total emissions from transport include vented, fugitive, and emissions from stationary fossil fuel combustion and consumed electricity and heat; Use Equation 6.0 (pipeline only)	Total emissions from the transport segment include combustion, vented, fugitive, and emissions from purchased and consumed electricity and heat; Use Equations 4.8, 4.9, 4.10, 4.10a-b, 4.11, 4.12 to calculate (pipeline, barge, rail or truck)	Emissions associated with electricity and other energy consumption are included; Venting and fugitive emissions during transportation are excluded because there are no expected emission changes between baseline and project condition

	US EPA 40 CFR 98 Subpart RR (2010)	**C2ES (2012)**	**ACR (2015)**	**Alberta Protocol**
Accounting CO_2 received	For pipeline option using CO_2 received Equations RR-1 to RR-3, or following procedures in §98.444(a)(4) to calculate total annual mass of CO_2 received; For the container option using Equations RR-1 and RR-2 with small modifications	CO_2 Transferred from CO_2 pipeline to CO_2 Storage Site; Use Equation 6.2.B to calculate	Accounting approach does not require this step	Accounting approach does not require this step
Accounting CO_2 injected	Using injection Equations RR-4 to RR-6 to calculate total annual mass of CO_2 injected; Flow and concentration measurements must be made according to §98.444	Accounting approach does not require this step	Accounting approach does not require this step	Estimated based on direct measurement of injected volume
Accounting CO_2 produced/ recycled	Using production/ recycling Equations RR-7 to RR-9 to calculate total annual mass of CO_2 produced for each gas-liquid separator that sends a stream of gas into a recycle or end use system; Some assumptions needs to be made during the calculation, which should be documented in the approved MRV plan	Produced CO_2 from an enhanced oil or gas operation transferred outside project boundary; Use Equation 8.5 to calculate	Produced CO_2 from an EOR/EGR operation transferred offsite in each year (tCO2/yr); Use Equation 4.18	EOR and EGR are not included in this protocol

	US EPA 40 CFR 98 Subpart RR (2010)	**C2ES (2012)**	**ACR (2015)**	**Alberta Protocol**
Accounting surface and subsurface CO_2 leakage	Must report the annual mass of CO_2 emitted by surface leakage in accordance with approved MRV plan; Must calculate total annual mass of CO_2 emitted using surface leakage Equation RR-10	Fugitive CO_2 emissions from underground CO_2 storage formations; Use Equation 9 to calculate	Use Equation 19 and 20 to account for CO_2 leakage emissions from geologic storage formations to the atmosphere during injection and after the injection, respectively	Engineering estimates with a maximum overall uncertainty of ±7.5%
Accounting GHG/CO_2 emission from CO_2 injection and storage	Not included	Total GHG emissions include emissions from combustion of fossil fuels, vented and fugitive release, leakage from reservoir, and emissions from purchased electricity and heat; Produced CO_2 from an EOR/EGR operation transferred offsite is also considered as emissions; For non-producing formations, use Equations 7.0-7.4, and 9; For producing formations, use Equations 8.0-8.5, 8.3A-B, and 9	Total GHG emissions include direct CO_2, CH_4, and N_2O from stationary combustion, CO_2 and CH_4 from venting and fugitive releases, indirect CO_2e emissions from purchased electricity use, CO_2 produced and transferred offsite, and leakage from the reservoir; Use Equations 4.13-4.20, and 4.16a & b	Equation provided to calculate this (emission associated with electricity, heat, materials use; venting and fugitive release is also included)

	US EPA 40 CFR 98 Subpart RR (2010)	**C2ES (2012)**	**ACR (2015)**	**Alberta Protocol**
Accounting CO_2 sequestered	Must calculate the annual mass of CO_2 sequestered using sequestration Equation RR-11, if producing oil, gas or other fluids; Using Equation RR-12, if not producing	GHG emission reductions from CCS equal Baseline Emissions (BE) minus Project Emissions (PE); Use Equation 1 to calculate	GHG emission reductions (ERs) from the CCS project equal Baseline Emissions minus Project Emissions; Use Equation 4.21	GHG emission reduction from the CCS project equal Baseline Emissions minus Project Emissions