Air Resources Board
Carbon Capture and Sequestration Program Concept Paper

Background: Carbon Capture and Sequestration (CCS) is an important technology for reducing carbon dioxide (CO_2) emissions from large stationary sources.[1,2] In light of California's mid and long-term climate goals,[3,4] CCS will likely grow in importance for California as a climate change mitigation measure as we approach the middle of the 21st Century. The Air Resource Board's (ARB) Low Carbon Fuel Standard (LCFS) and Cap-and-Trade Program require a quantification methodology (QM) and regulatory requirements on sequestration permanence in order for CCS projects to participate. Currently, CCS projects are not eligible as compliance options in the LCFS and Cap-and-Trade Program due to the lack of a recognized QM and relevant regulatory requirements that ensure sequestration permanence.

Staff is planning to develop a QM that would properly account for the CO_2 emissions sequestered by CCS, and a permanence protocol that would establish the requirements for permanence for CO_2 sequestration. The QM and permanence protocol would be referenced by or incorporated into the LCFS and Cap-and-Trade regulations with any appropriate modifications and through the LCFS and Cap-and-Trade Program's own and separate rulemaking processes. Although the LCFS and Cap-and-Trade Program have their own and separate rulemaking processes and require different accounting approaches (life cycle vs. facility-level accounting approaches), the requirements on sequestration permanence are the same for both programs. Staff plans to develop a single document that contains multiple parts including a permanence protocol along with two QMs for the LCFS and Cap-and-Trade Program respectively.

This concept paper lays out staff's current vision for what the draft QMs and permanence protocol could contain and what some of the requirements might be. After the release of this concept paper, staff plans to hold a workshop and collect feedback to inform development of the draft QMs and permanence protocol. At the end of this concept paper is a potential outline for the document containing the QMs and permanence protocol parts.

Concept: ARB has committed to developing a CCS QM for Board consideration[5]. Per California Assembly Bill 32[6], a QM can be adopted by the Board without an official rulemaking process; however, the AB 32 definition of what constitutes a QM is limited to quantification of emissions. Examples of QMs include the QMs for the Cap-and-Trade Program's compliance offset protocols. Some requirements such as those for site

[1] IPCC, 2014, Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
[2] California Council on Science and Technology (CCST), 2011, California's Energy Future: The View to 2050.
[3] California Senate Bill No. 32
[4] California governor's executive orders: B-30-15, S-03-05
[5] 2013 Scoping Plan update
[6] California Assembly Bill No. 32, Nuñez, Statutes of 2006

selection, monitoring plans, and well design standards are essential for the CCS program, but are not considered part of a QM. These requirements would have to be adopted through separate regulatory processes of the LCFS and Cap-and-Trade Program, respectively.

While developing the draft QMs and permanence protocol, staff will utilize the following guiding principles:

- Protection of public health and the environment
- Robust GHG monitoring, reporting, and verification that ensure reductions are real, permanent, quantifiable, and enforceable
- Focus on leak prevention
- Based on sound science
- Inclusion of expert state and federal agencies in development process
- Inclusion of environmental justice stakeholders in development process
- Transparent public process
- Serve as a model for other programs

The next section focuses on the design principles and specific content of the QMs and permanence protocol.

QM: The QMs would lay out the calculation methodology and assumptions, and would include different methods of accounting to accommodate both the lifecycle accounting approach of the LCFS and the facility-level accounting in the Cap-and-Trade Program. The QMs would also treat a metric ton injected as a metric ton sequestered, discounting CO_2 that may be emitted and assuming that the sequestration of those metric tons is validated according to the permanence protocol.

The QM would focus on the following main areas:

- Eligible activities
- CCS project system boundary
- Project emission accounting
- Reservoir type

The eligible activities will be defined in the regulations using the QMs. For the Cap-and-Trade Program, the eligible activities would be the activities by a regulated facility to emit, and subsequently capture and supply CO_2 to an injection facility for permanent sequestration. Under the Cap-and-Trade Program the eligible activities would lead to a reduction to annual compliance obligation equal to the amount of CO_2 sequestered, reported, and verified. Under the LCFS the eligible activities would be fuel production in the case of a fuel pathway provision, refinery processes in the case of a refinery investment credit provision, or the oilfield operation in the case of an innovative crude production credit provision. Under the LCFS, the eligible activities would generate either adjusted carbon intensity (CI) for their fuel in the case of fuel production, or credits for refinery processes and oilfield operation.

Under GHG emissions analysis the term system boundary refers to a set of physical areas that define all of the emission sources and sinks to be analyzed. Therefore a CCS project system boundary would constitute all physical emission sources and sinks to be considered under a project's emissions accounting. This term is commonly used in lifecycle analysis but also applies to point source emissions analysis. Under the Cap-and-Trade QM, the system boundary will be defined to align with the entities that generate a compliance obligation and is likely to include the sequestration site, subsurface, and equipment. The physical boundary of a CCS project under Cap-and-Trade would likely exceed the physical boundary of a regulated entity. The amount of CO_2 sequestered through CCS would be deducted from the entity's total emissions to determine its compliance obligation. Covered GHGs under the Cap- and-Trade Program include CO_2, CH_4, and N_2O, but only CO_2 will be considered for deduction from a compliance obligation.

Under the LCFS, staff plans to draw a system boundary that includes the substantial sources of emissions for CCS projects, essentially capture, compression, transport, and injection of CO_2. Staff is considering a project system boundary that begins with generation and capture of CO_2. Emissions upstream of CO_2 generation would be assigned to the primary product causing those emissions. The project system boundary would end with injection operations. In the case of CO_2 enhanced oil recovery (CO_2-EOR) emissions associated with oil production would be considered part of the system boundary and be included in the accounting, for example by allocating in some proportion between oil production and CO_2 capture. However combustion would not be included, since oil is a primary product and its combustion emissions would be accounted for separately to the extent it is used in California. CO_2 that is recovered from produced oil and re-injected, transferred to another field, or emitted will be accounted for in the QM. Our current thinking is that CO_2 transferred to another field would be considered emitted. Covered GHGs under the LCFS include CO_2, N_2O, CH_4, CO, and VOCs; again, only CO_2 will be considered for adjusted CI or credit.

Because injection operations are different between CO_2-EOR, depleted oil and gas reservoirs, and dedicated saline reservoirs, it may be necessary to account for those operations differently. For example, the current primary purpose of CO_2-EOR operations is to maximize oil production. During CO_2-EOR operations, some injected CO_2 will remain sequestered, but some will be produced with oil, and then either reinjected, emitted as fugitive, or transferred offsite. Because sequestration in saline reservoirs and depleted oil and gas fields will normally have no oil production associated with them, the sequestration accounting typically does not involve produced CO_2. However, if there is fluid extraction from these sites (e.g., brine extraction for pressure management), produced CO_2 would need to be accounted for. For depleted oil and gas reservoirs, care will need to be taken in their treatment in case these fields could be put back into production. Therefore, there may be requirements specific to accounting for depleted oil and gas reservoirs to ensure these fields will not be put back into production. This concern would also exist for CO_2-EOR fields in the post-injection period.

Permanence Protocol: The permanence protocol would establish the requirements to ensure that a project would achieve the objective of permanent geologic CO_2 sequestration. Currently, staff is planning to incorporate the permanence protocol into the LCFS as part of the upcoming 2018 LCFS amendments rulemaking, and then to incorporate it into the Cap-and-Trade Regulation as part of its future regulatory amendments. The LCFS QM portion of the aforementioned document will also be incorporated by reference into the LCFS regulation at the same time.

The permanence protocol would focus primarily on the following areas:

- Risk-based site analysis
- Injection or Production Well Material and Structural Integrity
- Operating requirements
- Monitoring, reporting, and verification[7] of sequestration permanence

Similar to the QM concept, the permanence protocol would include different provisions based on whether the project is utilizing CO_2-EOR as the sequestration reservoir versus injecting into depleted oil and gas reservoirs or saline reservoirs. Again, a risk-based site analysis as well as most post-injection requirements for depleted oil and gas reservoirs or saline reservoirs would likely be similar. In addition, depleted oil and gas reservoirs would not be able to be put back into production; and CO_2-EOR fields would not be able to be put back into production post-closure.

Staff is considering allowing two options for satisfying the permanence protocol. The first option would be prescriptive, consisting of a list of checkbox like requirements which would primarily be based on properties on the sequestration reservoir. This set of prescriptive standards would be conservative and would be expected to be used only with ideal injection locations. Ideal injection locations would consist of sites with specific characteristics, such as geologic features with clearly minimal risk, newly built wells, and state of the art monitoring plans. Sites that meet all the expectations of this first option could require less technical analysis by ARB staff and potentially a third-party independent reviewer, and could have a more streamlined application process.

The second option of satisfying the permanence protocol would be for cases in which the project does not meet all of the prescriptive requirements but still has a valid and reliable CO_2 injection site; this could include more geologically complex sites and sites with legacy wells that would need to be remediated. In the case of this second option, the requirements would be less prescriptive and more flexible, but would require a more tailored technical evaluation of the project specifics by ARB staff and potentially a third-party independent reviewer to ensure that sequestration is safe and permanent. ARB staff would need to determine that such sites are capable of safe and permanent CO2 sequestration and that if a leak occurred, it would be detected with a high degree of certainty, quantified, and mitigated appropriately.

[7] Verification in this context is separate from MRR verification, and would include third-party independent review of the site analysis (including site visit), and monitoring plan submittals and revisions.

Staff is considering whether U.S. Environmental Protection Agency (U.S. EPA) Underground Injection Control (UIC) Class VI permits might meet part of the requirements of the ARB permanence protocol. The current thinking is CCS projects would be allowed to submit their Class VI permitting material as part of their submittal to meet the permanence protocol requirements, however a parallel standard is necessary due to differences in objective; consistency in requirements; unique considerations of California regulations and stakeholders; and the potential for international projects (which wouldn't be under U.S. jurisdiction) to be covered.

CO_2-EOR projects with U.S. EPA UIC Class II permits would not be considered to meet the permanence protocol on that merit alone. Staff analysis indicates that additional stringency beyond UIC Class II requirements is needed to ensure permanence of CO_2 sequestration from CO_2-EOR projects. Additionally there is evidence that there has been loss of well integrity for some Class II wells. Staff has reviewed the U.S. EPA's Mandatory Greenhouse Gas Reporting Subpart RR requirements and a monitoring, reporting, and verification (MRV) plan for Class II wells under Subpart RR, and is considering proposing additional, California-specific MRV requirements for CO_2-EOR projects. Due to the variety and depth of expertise required to analyze CCS projects, staff is considering requiring third-party independent review and validation of all parameters in the permanence protocol prior to submittal to ARB.

The list below encapsulates design principles and content of the permanence protocol that staff is considering:

Risk-Based Site Analysis:

- Site Characterization
    - Injection zone depth, pressure, and other important information on primary containment reservoir
    - Injection zone capacity, lithology, heterogeneity (e.g., compartmentalization of high-permeability regions), and structure (e.g., anticline or dome to contain the CO_2, or a long dipping reservoir for residual gas trapping in an open structure);
    - Injection zone confining layer lithology, mechanism for CO_2 trapping (low-permeability or capillary exclusion), thickness, continuity, extent, and ductility/brittleness
    - Locations and characteristics of wells and boreholes that could serve as migration pathways
    - Injectivity (the injection rate per increment of pressure increase above the original reservoir pressure) and a plan to manage injectivity risk
    - Presence of a secondary containment reservoir and corresponding confining layer above injection reservoir, or a pressure dissipation interval
    - Thickness, permeability, and other important information about confining layer above secondary containment
    - Presence of a pressure dissipation interval and corresponding confining layer below injection reservoir, for minimizing seismicity risk in saline storage projects

    - Locations and characteristics of subsurface resources that could be impacted by CO_2 or injection-induced brine leakage and migration
    - Proximity to populous areas
    - Analysis of seismicity risk, and a monitoring or mitigation plan as appropriate
- Area of Review (AOR) and Modeling
    - AOR to match Class VI EPA requirements for saline and depleted oil and gas reservoirs
    - AOR based on computational modeling and performance data for CO_2 plume for CO_2-EOR projects (a fixed radius for AOR alone will not be sufficient)
    - Considering whether AOR should be based on pressure front or CO_2 plume
    - Identify all transmissive faults and fractures in AOR
    - No presence of faults or fractures that could serve as migration pathways within AOR

Injection or Production Well Material and Structural Integrity

- Material Integrity
    - Cement composition
    - Locations of cementing along well
    - Use of CO_2-resistant materials in injection zone
    - Review of Cement Evaluation Logs
- Leak Mitigation Plan
    - Leakage pathway identification and elimination
    - Leak detection and mitigation plan
        - Intent is that any detected leak would require investigation and, if confirmed, remediation
        - Remediation of all improperly plugged and abandoned wells, and other leakage paths, within AOR

Operating Requirements

- Pressure management such that injection zone and containing layer integrity is maintained
- CO_2 purity requirement
- Other requirements such as those for injection cessation

Monitoring, Reporting, and Verification of Sequestration Permanence

- Pre-Injection Period
    - Baseline and project monitoring
- Injection Period
    - Monitoring at wellhead and mass balance analysis could be used to determine CO_2 injected
    - Continuous pressure monitoring in injection, production, and monitoring wells, and other monitoring techniques as appropriate

    - Monitoring capable of tracking the movement of CO_2 in injection zone (e.g., gravity survey)
    - Requirements on the types and location of monitoring equipment, and on frequency of measurements
    - Beyond operational surface monitoring, certain surface monitoring may be required for detecting and quantifying leaks in cases in which subsurface monitoring shows there may be surface leakage
- Post-Injection Period
    - Monitoring for a pre-determined timeframe. Staff is considering two options: a period of 50 years, which is consistent with the U.S. EPA Class VI permits requirements; and a period of 100 years, which is the monitoring requirement for sequestration under the Cap-and-Trade Program. Both the operators and pore space owner would need to commit to assurance of the permanence of sequestration. For example, there would be a requirement that pore space owners ensure any future drilling that would penetrate the confining layer be reviewed by ARB to ensure it does not compromise storage permanence. A shorter timeframe may be possible if plume stability is verified for a certain number of consecutive years
    - Requirement that CO_2-EOR reservoirs, and depleted oil and gas reservoirs not be put back into production post-closure.
- CCS Monitoring Plan
    - Designed around a principle of no assumed atmospheric CO_2 leaks
    - A monitoring plan comparable to those required in U.S. EPA UIC Class VI permits is being considered. Technologies capable of leak detection will be required. Once a leak is detected, technologies that are capable of quantifying the leak will be required to quantify the leaks. Leak remediation actions specified in a remediation plan will also be taken.
    - Monitoring plan required to be periodically reviewed and updated by the project operator, and submitted to ARB for review
    - May require that the project operator update the monitoring and leak mitigation plans based on updated modeling, monitoring, and project data

Potential Draft Outline

Air Resources Board Protocol on Carbon Capture and Sequestration Accounting and Permanence

Part I – Definitions and Applicability

Section 1. Purpose
Section 2. Definitions and Acronyms
Section 3. Applicability

Part II – Accounting for CCS Projects in Cap-and-Trade – QM

Section 1. Eligible Activities and Other Relevant Requirements– QM
- 1.1. CO_2 Enhanced Oil Recovery
- 1.2. Saline and Depleted Oil and Gas Reservoirs

Section 2. CCS Project System Boundaries – QM
- 2.1. CO_2 Enhanced Oil Recovery
- 2.2. Saline and Depleted Oil and Gas Reservoirs

Section 3. Quantifying CO_2 sequestered – QM
- 3.1. CO_2 Enhanced Oil Recovery
- 3.2. Saline and Depleted Oil and Gas Reservoirs

Part III – Accounting for CCS Projects in the LCFS – QM

Section 1. Eligible Activities and Other Relevant Requirements – QM
- 1.1. CO_2 Enhanced Oil Recovery
- 1.2. Saline and Depleted Oil and Gas Reservoirs

Section 2. CCS Project Boundaries – QM
- 2.1. CO_2 Enhanced Oil Recovery
- 2.2. Saline and Depleted Oil and Gas Reservoirs

Section 3. Quantifying CO_2 Sequestered – QM
- 3.1. CO_2 Enhanced Oil Recovery
- 3.2. Saline and Depleted Oil and Gas Reservoirs

Part IV – Permanence

Section 1. Application Procedures
Section 2. Site Analysis
- 2.1. General Requirements
- 2.2. Site Characterization
- 2.3. Area of Review (AOR)
  - 2.3.1. CO_2-EOR Project Requirements
  - 2.3.2. Saline and Depleted Oil and Gas Reservoirs
- 2.4 Modeling Requirements

Section 3. Injection or Production Well Material and Structural Integrity
- 3.1. Well Material
- 3.2. Structural Integrity

Section 4. Leak Mitigation Plan
- 4.1. Leakage Pathway Identification and Remediation
- 4.2. Leak Detection and Mitigation

Section 5. Operating Requirements
- 5.1. Pressure Management
- 5.2. Other Operating Requirements

Section 6. Monitoring
- 6.1 Pre-Injection Period
- 6.2 Injection Period
- 6.3 Post-Injection Period
- 6.4 Monitoring Plan

Section 7. Legal Understanding and Contracts between Regulated Party and Well Operators (may include provisions for bonding or other financial securities)

Part V – Reporting and Sequestration Verification in Cap-and-Trade
Section 1. Reporting
Section 2. Sequestration Verification

Part VI – Reporting and Sequestration Verification in LCFS
Section 1. Reporting
Section 2. Sequestration Verification