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Defining an end state for CO_2 sequestration and EOR in North America

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Abstract

CO_2 capture and storage (CCS) presents a challenge to long-range planners, economic interests, regulators, law-makers, and other stakeholders and decision makers. To improve and optimize the use of limited resources and finances, it is important to define an end state for CCS. This ends state should be defined around desired goals and reasonable timelines for execution. While this definition may have substantial technology, policy or economic implications, it need not be prescriptive in terms of technology pathway, policy mechanism, or economic targets. To illustrate these concerns, this paper will present a credible vision of what an end state for North American might look like. From that, examples of key investment and planning decisions are provided to illustrate the value of end-state characterization.

Keywords: CO2, carbon storage, carbon sequestration, enhanced oil recovery,

Introduction

If you don't know where you are going, any road will take you there.

-- Lewis Carroll (1832 - 1898)

As the world becomes increasingly constrained for GHG emissions, CO_2 capture and storage (CCS) has emerged as a key technology to management of carbon emissions. Often, research and planning for CCS has proceeded on an as-needed basis, with noteworthy gains in science and technology development and understanding of regulatory frameworks. However, this approach is likely to result in sub-optimal infrastructure deployment, incomplete closure of S&T gaps, limited R&D application and funding, and early convergence on today's approaches as tomorrow's solutions. This presents a challenge to long-range planners, economic interests, regulators, and law-makers who may wish to design a framework for action that is safe, secure, enduring, and appropriate.

To improve and optimize the use of limited resources and finances, it is useful to define a desired end state. Delineation of such an end state can help to point out the most challenging aspects of technology deployment, including the non-technical aspects. An end state may also provide insight into staging, prioritization, and contingencies which are not revealed by a conventional or short-term road-mapping exercise. Finally, it may illuminate places where key stakeholder interests are not met, and as such provide insight into how long-term problems may be circumvented and avoided. In this regard, delineation of an end-state vision differs from scenario analysis, which looks towards alternative images of a future world [1]. Rather, it uses a single vision to which many parties subscribe as a basis for decision making.

End-state Defined

An end state for CCS deployment should be based on three basic conceits:

- Goals and targets that are readily acceptable to all stakeholders (e.g., safety)
- A description of large-scale physical deployment
- A specific time frame for culmination of this vision

These constraints require delineation in some richness, which provides a basis for agreement or disagreement among stakeholders. It need not be correct, but should be accurate and credible.

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Similarly, an end state should not be defined in these terms:

- A specific technology or blend of technologies (e.g., IGCC vs oxy-firing combustion)
- Specific policy prescriptions (e.g., carbon tax vs cap-and-trade discussion)
- Hard economic targets (e.g., $10/ton CO_2 for capture)

These constraints are based on the demonstrated inability of experts to predict energy futures or economic performance [2]. By avoiding policy prescriptions, stakeholders can find consensus on goals and then debate over the appropriate instrument to reach them. Those discussions may necessarily flow from an end state definition, but should not be part of it.

An End-state Delineated

To date, there is no clear picture of what a fully rendered CCS economy might look like. Many workers have proposed roadmaps to highlight key incremental components of R&D [e.g., 3] and various workers have proposed that CCS might provide 100's of Gt CO_2 abatement before 2100 [e.g., 4]. That level of global emissions reduction serves as one anchor for an end-state delineation: it would most likely require a functioning CCS economy by 2025. A rendering of that economy should include distribution and volumes of injection, infrastructure descriptions, and the key actors and instruments.

Several important aspects rapidly emerge. For example, one Gt C abatement (~3.6 Gt CO_2) will require injection of roughly 60 million barrels of supercritical CO_2 each day, or 2/3 the current global petroleum production volume. This raises questions about water displacement, pipeline optimization, and matching of storage capacity with source. This raises the need for national and regional assessments, basin-scale hydrological models, and potential regulatory or policy changes to pipeline routing. Identification of key points is sufficient to drive discussion in key areas and prioritize action.

Below is one example of one vision for a 2025 end-state. The aim is to present points of general consensus that might serve as a point of discussion or organization. Future political, technical, or economic issues may preclude or obviate portions of this end-state, which would be fine – the goal is a component framework that can highlight needs or gaps rather than a permanent document.

- All new large point sources (e.g., coal plants) constructed after 2020 would have CCS.
- Pipelines would deliver CO_2 from point sources to optimal storage resources.
- All existing large commercial pure CO_2 streams (e.g., ethanol plants, fertilizer plants, refineries, gas processing plants) would be captured and stored geologically by 2020.
- Large EOR projects will be the first to purchase and consume large low-cost (near pure) CO_2 streams
- All sites would be "safe and effective" based on sound science and monitoring rubrics.
- There is no substantial, prolonged leakage from a pre-existing orphaned or abandoned well or a new well.
- Large-scale demonstration projects would be financed and insured through robust, market-driven mechanisms.
- Major projects would be insured against risk

This end-state does not contain incendiary positions (e.g., a minimal carbon tax of $50); as such, most stakeholders can agree on these points. Just through definition, however, key questions emerge that allows one to consider specific technology and policy issues as well as pathways towards achieving these goals. As an illustration, the first bullet about large point sources is helpful. Three simple aspects are of a large plant are discussed: well count, water displacement, and regulatory footprint. In the question of well count, for a given 1000 MW coal plant equivalent, tens to hundreds of wells will be required over a 50 year plant lifetime just to handle the volumes [5].

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This raises questions regarding site certification and decertification that might not otherwise be asked. In the question of brine displacement, sufficiently large volumes will be injected that large brine plumes may emerge far from the actual injection site. This raises important questions both technical (how can one monitor and attribute brine to a regional displacement field?) and regulatory (are sets of companies or the state to be held liable for far-field brine contamination?). Finally, emissions from a 1000 MW plant will produce 2 billion barrels of CO_2 over 50 years. At some point, it is likely to cross state and national boundaries, creating challenges in attribution, monitoring, regulation, and liability. Similar kinds of technical, financial, legal, and insurance concerns are readily identified once an end-state is defined.

What follows are a set of discussion points derived from the delineated end state. While these points are not necessarily unanticipated in other ways, the end-state definition helps to focus on the key questions and issues.

National, basin scale geological assessments

In general, future coal plants will be built near coal basins [6], and individual large plants will require large storage capacity and injectivity [7]. In North America, new plant design, permitting, licensing and construction typically require 7-12 years [8]. To meet the first goal of the end-state analysis (CCS for all new plants after 2020), it would be prudent to have detailed geological sink information before the design and permitting process begins. Conservatively, this would mean detailed information on a basin to sub-basin scale for an entire market before 2010. At a minimum, information on injectivity, capacity, and effectiveness would be required to obtain plant financing and insurance.

Thus, to achieve the first and central goal of the end-state characterization requires detailed storage maps at a national level [9]. By analogy to the GEODISC project, collecting and organizing this information is likely to take a minimum of 3 years [10], and may take more if the key data are not immediately available or organized. This suggests that in North America, national level geological assessments should begin no later than 2007 to facilitate that goal. To achieve this end-state, it may be worthwhile for decision makers to consider whether the existing programs or assessment are likely to provide this information in sufficient richness and accessibility.

Pipeline routing and optimization

Within North America, all existing CO_2 pipelines run from low-cost sources of CO_2 (e.g., CO_2 domes, gas processing plants) to EOR operations (figure 1a). As CCS evolves, it is likely that the market will seek to offset the cost of storage through EOR early on. As such, one can posit an evolution of local pipelines running from early low-cost sources (e.g., fertilizer plants, refineries) to local EOR opportunities (figure 1b). This market incentive will generally help accelerate CCS deployment, and some have considered these pipelines as the initial backbone for CCS deployment.

However, already the existing CO_2 pipelines are running at capacity. Even in locations with abundant CO_2 supply and demand, pipelines built many years earlier cannot carry enough CO_2 to market. This suggests that these pipelines will not ever be able to carry the larger load of industrial CCS. This could be resolved in different ways. For example, states or provinces might provide incentives to build pipelines with spare capacity. Alternatively, a much larger and more complicated network could emerge (figure 1c). If rights-of-way or pipeline permitting become an issues and multiple new lines are needed to handle the capacity, the network might become a chokepoint to deployment that limits the ability of CCS to penetrate eager markets and increase the risk of leakage or public backlash. By delineating the end state, different stakeholders can begin to grapple with the future deployment they prefer and how best to execute it.

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Groundwater resources

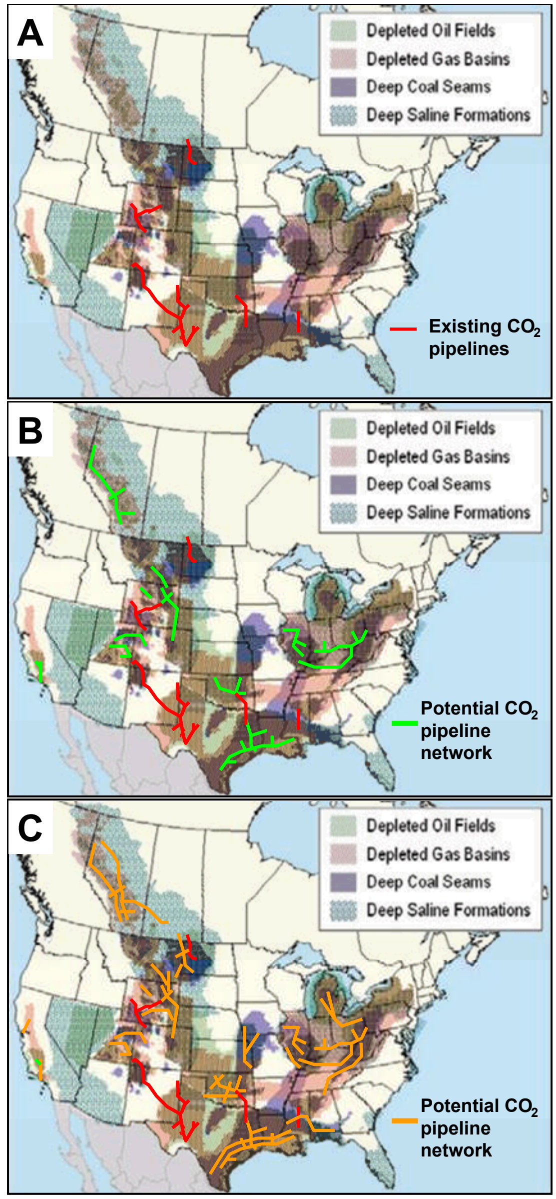

Figure 1: CO_2 pipeline networks in North America (A) Current distribution of pipelines. (B) Hypothetical 2025 network evolved around early CO2-EOR opportunities and low-cost CO2. (C) Hypothetical 2025 network of pipelines built to service single large projects. Basemap from Dooley et al 2004

The Clean Water Act and Underground Injection Control programs of the US EPA regulate and protect drinking water, so how CCS might affect drinking water merits consideration [11]. As mentioned earlier, one Gt C annual abatement (~3.6 Gt CO_2) will require injection of roughly 60 million barrels of supercritical CO_2 each day. However, data from deep saline formations can be quite limited, and the data that exists requires substantial interpolation [12].

Groundwater protection flows naturally from two end-state components: injection of all new plant builds after 2020 and "safe and effective" storage. Initially, large-scale injections must displace water from saline formations. Many large injections may displace substantial water volumes into shallow positions. This could displace water evenly, with little or no effect on local water quality. However, gradients in head and salinity can cause variations in pathway [12], which might result in saline intrusions from depth, causing substantial cost and concerns. Such plumes could cross state lines, and attribution would be extremely difficult. Coming to terms with potential water displacement effects may prompt detailed hydrological studies and models to better manage this concern.

Small amounts of CO_2 leakage may still constitute safe and effective storage, provided that groundwater quality is not negatively affected. Very small amounts may also be difficult to detect through conventional monitoring means. However, it has been seen that small amounts of CO_2 may mobilize metals from formation minerals [13]. Conceivably, trace organic constituents might also mobilize and concentrate. It is not currently clear if small amounts of CO_2 might mobilize harmful materials common setting; however, some targeted experiments might resolve key aspects of these issues.

How long is long enough?

One of the chief unresolved concerns of many stakeholders is "How long is long enough?" This question takes two forms: what defines permanence [14], and what constitutes due diligence? In the case of the second question, investors, operators, insurers, and regulators have a stake in knowing when a CO_2 injection can cease to be monitored and a site officially decertified or abandoned.

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Regarding this question, the last four components of the end-state description are of interest: all sites insured, market mechanisms for large-scale deployment, storage must be safe and effective, and no harmful leakage from wells. The first two suggest an upper maximum of 30 years; this is the longest duration of any insurance policy post-dating commercial operation. The second two can be used to focus studies on post-injection processes. Because post injection pressure wanes from injection pressure and reactive chemistry buffers, geological risk subsides over time – identifying and quantifying that time constant has special merit. Because wells present special risks, and it is not clear whether that risk subsides with time [15], understanding and quantifying this risk becomes a clear research priority. Similarly, technology development might be fruitfully spent investigating well closure and abandonment approaches and materials. This understanding would provide clarity to the minimal duration suggested by science, which can inform the decision-making process.

Discussion

An important finding of end-state analysis must be scientific and technical gaps. Once identified, a reasonable timeframe for their resolution should emerge (e.g., national geological capacity assessments before 2010). Once defined, it is possible to converge on an end state for CO_2 deployment that is highly desirable, which might resolve tensions between stakeholders with different goals (e.g., industry and environmental interests). In the case of groundwater quality, not all aspects need be tackled at once. However, two examples of potential high concern and impact are presented relative to the end-state definition. To achieve the end state, accelerated study of large hydrological system architecture and CO_2 effects on shallow aquifers may suffice in the near term. Both of those studies would benefit from data collected during capacity assessments, suggesting both a higher priority and a need for data sharing and exchange. This illustrates the potential benefits to decision makers in working with experts and key stakeholders to construct an acceptable end-state vision.

Finally, specific performance goals may be added to flesh out an end-state for North America. For example, an unacceptable rate of leakage may be defined (e.g., 1% annual injected volume) or performance for new EOR recovery may be considered (e.g., 60% minimal recovery from CO2-EOR projects). The statement of these goals prompts inquiry as to the basis for the goals and the ability of the current system to deliver them and can provide insight into the needs and desires for all stakeholders to provide consensus to decision makers.

Conclusions

Definition and delineation of a CCS end state is useful to plan the allocation of resources in the near term, to identify and close gaps that prevent deployment, and to highlight technical, political, and social issues of importance to stakeholders. This analysis identifies three points discussed:

1. National, basin-scale geological assessments continue to present a key gap to current deployment that requires aggressive short term resolution.
2. Pipeline networks may emerge as an important bottleneck for deployment. Market mechanisms alone are unlikely to create the needed infrastructure, so some sort of policy or regulatory incentive may be needed.
3. Groundwater resources may emerge as a persistent concern. Currently, CCS research into groundwater protection is not commensurate to the potential threat.

The right road lies under your tongue – just ask it

--Chinese proverb

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