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System-level benefits of extracting and treating saline water from geologic formations during national-scale carbon capture and storage

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ABSTRACT

Despite economic, political, legal, and technical challenges, carbon dioxide (CO_2) capture and storage (CCS) holds promise as a means to substantially reduce anthropogenic atmospheric emissions of carbon dioxide. One of the technical challenges to CCS is an accurate quantification of the potential geologic storage resource. This analysis uses the publically available national-scale, systems-level Water Energy and Carbon Sequestration simulation model (WECSsim©), to show that, depending on assumed boundary conditions, the majority of storage associated with large-scale CCS in the U.S. (on the order of 90–100 GT of total reduced emissions) would occur at a small number of well-located sites with favorable geologic properties. WECSsim, through the use of marginal abatement cost curves, shows that under such a scenario, added costs associated with resident saline water extraction, transport, and treatment (SWETT) are justified by resulting increases in carbon dioxide storage efficiency in the geologic formation. This argument is strengthened when geologic uncertainty is taken into consideration. Like an insurance policy, the enhanced carbon dioxide storage efficiency that comes from SWETT adds well-defined costs to reduce potential economic risks associated with overestimates of the available geologic storage resource.

1. Introduction

Rising carbon dioxide concentrations in the atmosphere due to human industrial activity and land-use change are widely accepted in the scientific community as an important contributor to global climate change (Cook et al., 2013). Both in the United States and globally, combustion of fossil fuels to generate electricity and heat accounted for more than 40% of energy-related anthropogenic carbon dioxide emissions to the atmosphere in 2010 (IEA, 2012) making this sector the single largest source of anthropogenic carbon dioxide emissions. While a long term reduction of atmospheric carbon dioxide emissions would eventually require a transition of the power generation sector toward more carbon dioxide neutral fuels, in the near term, capture of carbon dioxide from coal and gas fired power plants, followed by long-term storage in deep, saline water bearing formations is a technical option with potential to substantially reduce atmospheric carbon dioxide emissions without abandoning valuable existing industrial infrastructure (IPCC, 2005). The technology of compressing and transporting carbon dioxide long distances in pipelines and injecting it into oil-bearing formations is well established, having been used for decades by the petroleum extraction industry in enhanced oil recovery (Jarrell et al., 2002). Capturing the carbon dioxide from power plant emissions, characterizing non-oil bearing formations as potential targets for long-term storage, and ensuring that the carbon dioxide injected underground stays in place are less mature components of CCS that have not been demonstrated simultaneously at large-scale (more than 1 million metric tonnes of post-combustion carbon dioxide injected per year) (NETL, 2012). Most theoretical studies however support large-scale CCS as technically possible, albeit costly (Stauffer et al., 2009; Szulczewski et al., 2012; Eccles et al., 2012). However, in addition to adding costs to fossil-fuel based electricity, CCS would likely create new demands for water and has the potential to create large pressure build up in storage formations. Simultaneous extraction and treatment of saline water from the storage formation may be one way to offset added water demand and reduce pressure build up in the formation. The question addressed by this paper is under what conditions the added cost of SWETT is justified. Marginal abatement cost curves developed by WECSsim, which show how the cost per unit of reduced carbon dioxide emissions to the atmosphere from CCS changes for different levels of cumulative reduction, are used to answer this question. The following sections provide more background on the

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three major challenges to CCS implementation: expense, added water demand, and formation pressurization, and the potential role SWETT might play in each.

1.1. CCS expense

Low concentrations of carbon dioxide in flue gas present a substantial technical and cost challenge to gas separation. Typical post-combustion coal-fired power plant exhaust gas contains on the order of 13% carbon dioxide, 77% nitrogen (N_2), 6% water vapor (H_2O), and 4% oxygen (O_2) along with trace oxides of carbon, nitrogen, and sulfur (Xu et al., 2003), which makes separation of a pure carbon dioxide stream from post-combustion gas a thermodynamically unfavorable endeavor. Adding to the challenge, impurities can lower the density of the stream resulting in a higher pressure drop during pipeline transport and thus added energy costs (Global CCS Institute, 2012). The parasitic energy losses necessary to obtain high purity carbon dioxide from exhaust gas for a 90% carbon dioxide capture rate using the current best proven post-combustion separation technology (amine based) are on the order of 30% of the pre-CCS generation of the power plant (NETL, 2007a).[1] Total amine-based carbon dioxide capture costs including energy use are on the order of $50 to $60 ($2006 United States Dollars (USD)) per tonne of carbon dioxide captured (NETL, 2007a). Compression, transport, and storage add additional costs which, though not trivial, are dwarfed by the energy and capital equipment costs associated with the initial carbon dioxide capture (Kobos et al., 2011a). Altogether, CCS costs are expected to range from around $45 to $65 ($2010 USD) per metric tonne of carbon dioxide stored, which could nearly double the cost of electricity from coal-fired power plants (Kobos et al., 2011b).

1.2. Added water demands associated with CCS

Added power demands to make-up for parasitic losses result in added water demands associated with thermoelectric make-up power (MUP). The magnitude of this demand depends on the power plant technology and the cooling technology utilized to generate the MUP. Roach et al. (2010) show that added water extraction demands associated with national-scale CCS on the 2005 U.S. fleet of existing coal-fired power plants would increase total thermoelectric withdrawal by almost 15% if MUP was generated using the same technology for power generation and cooling as in the original plants. If instead, all MUP came from IGCC plants cooled by towers, the added water demands would add only 1% to national thermoelectric withdrawals, a substantial amount of which could be offset by extracting saline water from the storage formation for treatment and use. Klise et al. (2013) show that if MUP came from NGCC plants cooled by towers, the added water demand could be offset completely in most cases by water extracted from the storage formation and treated for use in the MUP plant. The importance of added water demands will depend largely on regional water availability. However, if projected increases in power demands are realized, water constraints to power plant development are likely even in the absence of CCS related demands (Tidwell et al., submitted for publication). Thus, it is likely that added water demands would be an important issue associated with large-scale CCS implementation in much of the U.S.

[1] Pre-combustion and oxy-combustion are higher efficiency options, but pre-combustion can only be utilized on relatively uncommon integrated gas combined cycle (IGCC) plants, and oxy-combustion requires large volumes of pure oxygen, with associated energy costs for generation (NETL, 2007b).

1.3. Pressurization of the storage formation during CCS

Injecting large volumes of carbon dioxide into the subsurface introduces many unknowns and risks associated with pressurizing the storage formation. Unrelieved high pressure has the potential to induce seismic activity in the storage formation and create weaknesses in protective cap rocks (Birkholzer et al., 2012; Morris et al., 2011). Even without seismicity concerns, high pressure injection creates gradients in flow potentials that may drive carbon dioxide and saline pore-water, or combinations of the two through new or existing weaknesses in protective cap rocks, including abandoned wells, into adjoining or overlying formations (Little and Jackson, 2010). Unrelieved pressurization of formations also reduces the efficiency with which carbon dioxide can be stored (Bergmo et al., 2011; Heath et al., 2014).

1.4. Saline water extraction, transport, and treatment (SWETT) as a partial solution

One option to address pressure build up in the formation is 'active reservoir management' (Buscheck et al., 2012) in which native saline water is extracted from one area of the storage formation while carbon dioxide is injected into another area. This approach can be used both to prevent unwanted pressure build up and increase carbon dioxide storage efficiency (the percent of pore volume in the storage formation occupied by carbon dioxide) dramatically. Heath et al. (2014), using two dimensional homogeneous closed-boundary simulations, show that saline water extraction can improve carbon dioxide storage efficiency by almost two orders of magnitude. In three dimensional heterogeneous simulations, Buscheck et al. (2012) use saline water extraction to actively 'steer' the carbon dioxide injection plume to enhance storage efficiency in the formation. When active reservoir management is combined with treatment of the extracted saline water for beneficial re-use, some portion of the added water demands associated with CCS can also be offset (Klise et al., 2013). Therefore, two of the three big challenges for large-scale CCS (added water demands and pressurization of the formation) can be addressed using simultaneous extraction and treatment of native saline water in the storage formation. SWETT adds costs to CCS, but where the added benefits outweigh these additional costs, SWETT may play an important role in CCS.

2. Methods

The Water, Energy, and Carbon Sequestration simulation model (WECSsim) is a national-scale systems level model that combines a national database of coal and gas fired power plants with a national database of deep saline formations as potential carbon dioxide storage targets and sources for extracted saline water. The power plant database in WECSsim is based on the 2005 U.S. coal and gas power plant fleet as represented in the eGRID2007 database (EPA, 2007), augmented with plant specific information on water withdrawal and consumption from Averyt et al. (2013). The geological database is based on the 2008 NatCarb database (NETL, 2008b), modified and augmented to include information on formation depth, thickness, porosity, permeability, and native water salinity for 325 separate formations as described in Klise et al. (2013). The model user can select a power plant and a carbon dioxide capture percentage, and WECSsim will determine the lowest cost formation for carbon dioxide storage, and the impact of CCS on the levelized cost of energy (LCOE) from the plant. This calculation depends on many assumptions related to the power plant, the level of carbon dioxide capture, the MUP technology utilized, the storage target, and the potential extraction and treatment of native saline water. The WECSsim