43

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Unitization of Geologic Media for the Purpose of Monetizing Geologic Sequestration Credits

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ABSTRACT

The development of carbon credit markets for geologic sequestration will require a framework for accounting injected CO_2 that is based on detailed characterization data, sound engineering design, and an equitable legal and regulatory process. The monetization of CO_2 credits associated with geologic sequestration will require a streamlined process that addresses the technical aspects of a project and also considers the interests of the public and the rights of individuals who may own subsurface mineral and water rights. Such a system has already been established in the oil field unitization process under which the United States petroleum industry currently operates. Oil and gas regulatory agencies in the United States use a process commonly referred to as unitization to organize oil fields into units for the purpose of secondary and tertiary recovery operations. The process by which petroleum fields become unitized may provide a useful model for the selection of appropriate injection target formations and the governing of geologic sequestration projects. Although petroleum reservoirs, saline aquifers, and coal seams generally use different mechanisms for sequestration (for example, dissolution into oil versus dissolution into saline water versus adsorption onto coal),

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the unitization process may be adapted and applied to all types of geologic formations. Application of the unitization process to CO_2 sequestration may result in the establishment of ''geologic sequestration units.''

INTRODUCTION

Concerns about global climate change as a result of high concentrations of greenhouse gases in the atmosphere have led to local, state, national, and international programmatic efforts to significantly reduce anthropogenic greenhouse gas emissions. Carbon dioxide is a greenhouse gas that is emitted in large volumes (billions of tons per year) as a result of anthropogenic activities throughout the world. The reduction of CO_2 emissions to the atmosphere is a primary goal of a variety of programmatic efforts focused on mitigating global climate change at the international, national, state, and local levels. International efforts include the United Nations Framework Convention on Climate Change and the 21 nation-member Carbon Sequestration Leadership Forum. The United States government's Global Climate Change Initiative is focused on developing strategies to reduce emissions at the national level. Examples of state programs include the California Global Warming Solutions Act of 2006 and the Regional Greenhouse Gas Initiative. Although each of these efforts seeks to frame and address the issues associated with climate change in very different ways, all of them recognize the critical function that market-based incentives, particularly the creation and growth of robust carbon credit-trading markets, will play in significantly reducing CO_2 emissions. Due in large part to the efforts of these programs, several carbon credit-trading markets have been created and are currently in operation, including the European Union Emissions Trading Scheme and the Chicago Climate Exchange (CCX). These markets are robust and have exhibited significant growth in recent years. The overall globally aggregated value of carbon credit-trading markets was more than $10 billion in 2005, with some financial analysts predicting a globally aggregated value of between $25 billion and $30 billion in 2006 (Capoor and Ambrosi, 2006).

Current carbon credit markets have developed methodologies for certifying and trading carbon credits generated by a variety of greenhouse gas reduction mechanisms. Activities for which carbon credits can be obtained and monetized include capturing and destroying methane from landfills and livestock operations, replacing the use of fossil fuels with renewable energy resources, and sequestering carbon in terrestrial systems such as forests and soils (United Nations Framework Convention on Climate Change, 2006; CCX, 2007). However, not one of the major carbon markets recognizes, certifies, or trades credits associated with the geologic sequestration of CO_2 (Capoor and Ambrosi, 2006). Because the sequestration capacity of geologic formations in the United States has been estimated to range between 2 billion and 3747 billion tons of CO_2 (Bradshaw et al., 2006), there is tremendous incentive to develop marketable carbon credits for geologic sequestration. Some of the international and national climate change programs, including the Carbon Sequestration Leadership Forum and Global Climate Change Initiative, are working toward the development of protocols and methodologies that will enable geologic sequestration to become a significant part of the global carbon market.

One of the key elements in the Global Climate Change Initiative efforts to encourage large-scale geologic sequestration projects is the establishment of the Regional Carbon Sequestration Partnerships by the U.S. Department of Energy's National Energy Technology Laboratory. The Plains CO_2 Reduction (PCOR) Partnership is one of seven Regional Carbon Sequestration Partnerships created to perform a nationwide assessment of carbon sequestration opportunities. One of the primary functions of the PCOR Partnership, whose region includes nine states and four Canadian provinces, is to facilitate the implementation of geologic sequestration strategies in the region and the development of markets for carbon credits derived from the use of those strategies. Activities of the PCOR Partnership have included reconnaissance-level determinations of the potential sequestration capacity of numerous geologic sinks in the region, including oil fields, coal seams, and deep saline aquifers.

Over the course of evaluating more than 1900 oil pools, three coalbeds, and two saline aquifer systems throughout the region, it became apparent that although each one of the three types of geologic targets generally uses different mechanisms for sequestration (for example, dissolution into oil versus dissolution into saline water versus adsorption onto coal), they have several properties in common that may dictate the conditions under which large-scale injection of CO_2 can be conducted. For instance, all three types of targets must have competent seals and other trapping mechanisms. From a legal standpoint, each may have privately held mineral rights associated with them. With respect to the establishment and monetization of carbon credits, all three will also require a framework for accounting that is based on detailed characterization data, sound engineering design and operation, and an equitable legal and regulatory process. The development of carbon credit markets for CO_2 sequestered in geologic formations

will require proper accounting of injected CO_2, which will be well served by a streamlined process that takes these conditions and issues into account. Such a system has already been established in the oil field unitization process under which the United States petroleum industry currently operates. Application of an existing unitization process that has been modified to address issues unique to geologic sequestration can facilitate the implementation of geologic sequestration projects and, ultimately, the monetization of credits derived from such projects. Target injection zones that have undergone the scrutiny and due diligence associated with the unitization process may be designated as ''geologic sequestration units.''

APPROACH

The development of markets for carbon credits associated with geologic sequestration will require action from several diverse communities. As with many disciplines and technologies, a broadly recognized framework is needed to facilitate effective communication between the scientific, engineering, regulatory, and legal communities. The establishment of geologic sequestration units by means of a systematic, standardized process based on broadly accepted legal and regulatory practices can provide such a framework, as well as a foundation, for the certification and monetization of geologically derived carbon credits.

The term geologic sequestration unit was chosen to acknowledge the technical, legal, and regulatory process that will be necessary to inject large volumes of CO_2 into areas that may consist of numerous mineral ownership tracts; it was not chosen to represent entire geologic units or formations. Although a geologic sequestration unit will have physical boundaries, those boundaries are not necessarily defined solely on the basis of geologic characteristics (Figure 1). This is similar to the establishment of oil fields, or pools, in most states and is particularly true of unitized oil fields or pools. Typically, the boundaries of oil fields and/or pools are defined in large part by a combination of factors, including geologically based factors such as the known or predicted location of producible oil within a horizon or formation, surface land use factors such as proximity to protected parks and wilderness areas, and in some cases, mineral rights ownership considerations. A geologic sequestration unit would likewise be defined by a combination of parameters, including the location of known zones of porosity and competent seals, surface land use issues, and mineral rights ownership. The approach for creating geologic sequestration units is basically to apply the process by which oil fields become unitized to the formal establishment and recognition of designated areas for geologic CO_2 sequestration projects.

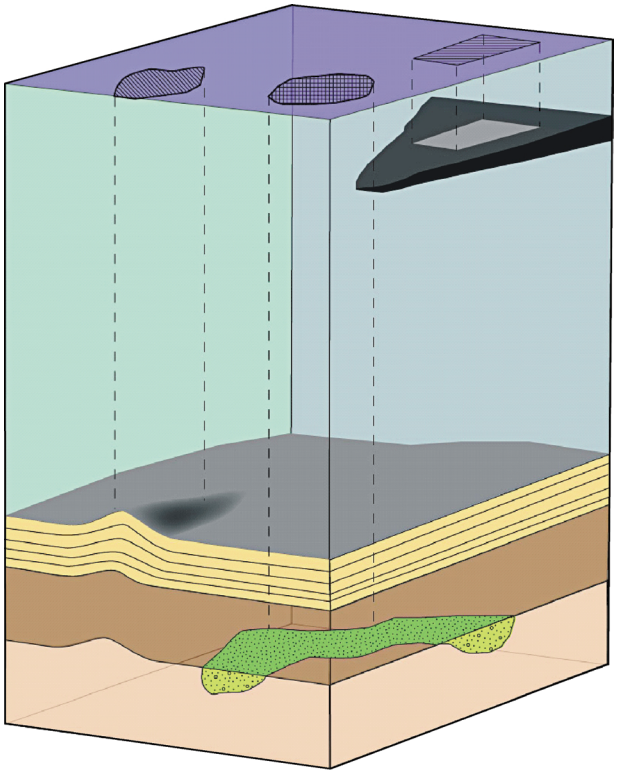

FIGURE 1. Conceptual representation of geologic sequestration units.

In modern hydrocarbon production field practices, prior to the initiation of subsurface activities that will affect the fluid distribution and production within an area, mineral ownership tracts may be legally combined to form a larger working area. The process of establishing a geologically and legally defined zone and combining individual ownership tracts within that zone is referred to as unitization, and the working area created by this process is referred to as a unit. The effective result of unitization is mostly threefold; the correlative rights of all mineral owners within the designated area are protected, net revenues are apportioned among all parties with interests in the field, and injection and reservoir management practices are coordinated to improve the efficiency of petroleum extraction (Wiginton, 2006; Libecap, 1994).

We anticipated that a similar unitization process will need to be developed prior to large-scale injection of CO_2 for sequestration in geologic formations. Geologic sequestration unitization will facilitate the monetization of carbon credits by establishing a technical and legal framework by which large-scale CO_2 injection can be implemented at a given location. Under the proposed system, once the physical, legal, and operational boundaries of the geologic sequestration unit have been established by the appropriate governing body, the CO_2 injected into the unit will be legally considered to be in a state of sequestration, and credits will be formally

assigned. The value of the assigned credits will be mostly based on the ability to quantify and verify the amount of CO_2 in a given geologic sequestration unit. Plans for monitoring, mitigation, and verification will be critical components of the final unitization orders. The framework within which the geologic sequestration unit was created will provide all stakeholders, including buyers and sellers of CO_2 credits, with a means by which to access the baseline characterization; monitoring, mitigation, and verification plans; and regulatory instruments necessary to quantify and verify the veracity of the credits.

Unlike oil field unitization, where established methods for the apportionment of revenue shares from the sale of incremental oil are based on estimates of the value of each party's leases and their potential contribution to the unit (Libecap, 1994), review of the literature yielded no established methods for the assignment of carbon credits in geologic sequestration projects between parties. The distribution of credits and/or revenue from the monetization of credits between CO_2 producers, injectors, and the owners of pore-space rights is likely to be negotiated in the conceptual phase of a proposed CO_2 sequestration project. The proposed process for geologic sequestration unitization may or may not be an appropriate forum for those negotiations.

The first step in promulgating a process to establish geologic sequestration units within a given jurisdiction is to identify or establish a government agency or commission that has the power and authority to evaluate and authorize the establishment of geologic sequestration units. In the United States, the authority to establish oil field units is generally held by the agency at the state level that oversees and regulates oil and gas production activities. Oil fields are typically unitized for the purpose of implementing secondary or tertiary enhanced oil recovery projects, which commonly require coordinated injection and production of fluids across a field or part of a field. The oil field unitization rules and methods of the North Dakota Department of Mineral Resources Oil and Gas Division provide an excellent example in the PCOR Partnership region of a decades-old approach that can be modified for the purpose of establishing geologic sequestration units. This chapter focuses primarily on the technical aspects of unitization because they will likely have the broadest applicability to a wide variety of jurisdictions at the state or provincial, national, and international levels.

LIKELY STAKEHOLDERS

Wilson and De Figueiredo (2006) stated that the current case law suggests that, in some instances, both surface and mineral owners may have legitimate claims to injection zones that may be designated as being suitable for geologic sequestration. Other likely stakeholders will include the injectors, owners of the injected CO_2, mineral lessees, neighboring surface and mineral owners, and neighboring mineral lessees (Wilson and De Figueiredo, 2006). This set of stakeholders, with oil production companies typically representing the injectors and the owners of the CO_2, would likely be common to both the oil field unitization process and the proposed geologic sequestration unitization process. Stakeholders who would almost certainly be active participants in the geologic sequestration unitization process include environmental watchdog groups and other not-for-profit nongovernment organizations, power generation companies producing the CO_2, and carbon credit-exchange organizations seeking to facilitate the monetization of credits.

THE OIL FIELD UNITIZATION PROCESS IN NORTH DAKOTA

The North Dakota Department of Mineral Resources Oil and Gas Division regulates the drilling and production of oil and gas in North Dakota. The mission of the agency is to encourage and promote the development, production, and use of oil and gas in such a manner as will prevent waste, maximize economic recovery, and fully protect the correlative rights of all owners. The ultimate mandate of the agency is that North Dakota landowners, royalty owners, producers, and the general public realize the greatest possible good from these vital natural resources. To that end, the establishment of oil field units is commonly considered to be an appropriate means of realizing the goals of the North Dakota Department of Mineral Resources Oil and Gas Division. In order for an oil field to be unitized in North Dakota, the North Dakota Department of Mineral Resources Oil and Gas Division must find that the following have been demonstrated by the petitioner:

1) The unitized management, operation, and further development of the field are reasonably necessary to effectively and substantially increase the ultimate recovery of oil.
2) One or more of said unitized methods of operation are feasible, will prevent waste, and will, with reasonable probability, result in the increased recovery of substantially more oil than would otherwise be recovered.
3) The estimated additional cost, if any, of conducting such operations will not exceed the value of the additional oil and gas so recovered.
4) Such unitization is for the common good and will result in the general advantage of the owners of the oil and gas rights.

If all of these are demonstrated, then the North Dakota Department of Mineral Resources Oil and Gas Division can move to create the unit and provide for the unitization, all upon such terms and conditions as may be shown by the evidence to be fair, reasonable, and equitable and which are necessary to protect, safeguard, and adjust the respective rights and obligations of the several persons affected. The petition must set forth a description of the proposed unit area with a map, must allege the existence of the facts required to be found by the commission, and must have attached thereto a proposed plan of unitization applicable to such proposed unit area (North Dakota Century Code, 2005).

The evidence and facts referred to in the North Dakota state law (North Dakota Century Code, 2005), although not specified in the law itself, by matter of practice include detailed geologic and engineering reports on the field or fields being considered for unitization. The North Dakota Department of Mineral Resources Oil and Gas Division requires such reports as part of the unitization process. The technical reports of successful unit applications generally provide data on the geology of the reservoir, including lithological descriptions and maps showing the structure of the reservoir formation and its productive intervals, interval thickness, and porosity and permeability. Some geologic reports include key supplemental information such as core descriptions and analyses, geophysical data, and geochemical data. Engineering reports provide in-depth discussions of reservoir properties, fluid properties, reservoir performance and pressure history, oil-in-place calculations, reserves, unitization parameters, pressure maintenance, and economic evaluation of the proposed unitization plan. The body of evidence presented to the North Dakota Department of Mineral Resources Oil and Gas Division by those seeking to unitize an oil field will also include predictions, commonly based on substantial modeling exercises, of the incremental fluid production and, if applicable, the effects of the injection and production activities on neighboring reservoirs that may occur as a result of the implementation of the unitization plan. Those who petition the North Dakota Department of Mineral Resources Oil and Gas Division must submit a unitization plan that contains fair, reasonable, and equitable provisions for several aspects of oil recovery. Some of those provisions that may be applicable to the establishment of geologic sequestration units include the following:

1) The efficient unitized management of the further development and operation of the unit area. This includes the designation of a unit operator by the owners of a simple majority of the working interest in the unit area.
2) The creation of an operating committee to have general overall management and control of the unit and the conduct of its business and affairs and the operations carried on by it.
3) The time when and conditions under which and the method by which the unit must or may be dissolved and its affairs wound up.

The use of public hearings is the primary mechanism in the decision-making process for considering the unitization of oil fields in North Dakota. Each petition for unitization must go through a series of public hearings at which the testimony of the petitioners, expert witnesses, and other stakeholders is heard by the North Dakota Department of Mineral Resources Oil and Gas Division. Notification of the schedule for public hearings is given to all potentially affected parties (landowners, royalty owners, operators, etc.) via mailed invitations, whereas the public at large is notified through notices in local newspapers (North Dakota Century Code, 2005).

APPLICATION OF THE NORTH DAKOTA OIL FIELD UNITIZATION PROCESS TO THE DEVELOPMENT OF GEOLOGIC SEQUESTRATION UNITS

Many of the aspects of the oil field unitization process used by the North Dakota Department of Mineral Resources Oil and Gas Division may be applied to a similar process to establish geologic sequestration units. In fact, much of the North Dakota oil field unitization process for secondary and tertiary enhanced oil recovery projects may be modified to provide the backbone structure of a unitization process for large-scale geologic sequestration projects. In its mission statement, the ultimate mandate of the North Dakota Department of Mineral Resources Oil and Gas Division is that North Dakota landowners, royalty owners, producers, and the general public realize the greatest possible good from the state's oil and gas resources. With this as a guide for the sequestration of CO_2, key elements of a mission statement for the agency responsible for the oversight and regulation of CO_2 sequestration activities and, therefore, establishment of geologic sequestration units may include the prevention of CO_2 leakage outside of target injection zones, the maximization of economical CO_2 sequestration, and the full protection of the correlative rights of all potentially affected owners and stakeholders.

Once a sufficient amount of geologic and engineering background data has been assembled, an application to classify a target injection zone as a geologic

sequestration unit may be prepared. In order for a target injection zone to be classified as a geologic sequestration unit, the regulating agency should find that the following have been demonstrated by the petitioner:

1) The unitization of the field is reasonably necessary to effectively and substantially maximize the injection of CO_2 and minimize impacts to potable groundwater resources.
2) The said sequestration method of operation is feasible and will, with reasonable probability, result in the net reduction of CO_2 emissions relative to the CO_2 source.
3) The estimated costs of sequestration and measurement, monitoring, and verification activities are economically viable such that long-term operation and monitoring can be anticipated with reasonable probability.
4) Such unitization is for the common good and will result in the protection of correlative rights of potentially affected owners and the health and safety of the general public and the environment.

As with the oil field unitization process in North Dakota, the geologic sequestration unitization process should require detailed geologic and engineering reports on the specific oil field, saline aquifer target zone, or coal seam being considered for classification as a geologic sequestration unit. The reports should describe in detail the technical and legal justifications for the proposed boundaries and operational parameters of the proposed unit, with significant emphasis being placed on demonstrating a low probability of contamination of groundwater resources. The technical reports of qualifying unit applications should provide a discussion and interpretation of readily available data on the geology of the injection target zone and the primary sealing formation above the target zone, including lithological descriptions and maps of key parameters. Supplemental information such as core descriptions and analyses, geophysical data, and geochemical data should be presented where available. The location and status of all existing and previously existing wellbores in the proposed geologic sequestration unit and its surrounding vicinity must be presented and described with respect to their potential to act as conduits for CO_2 migration out of the unit. Engineering reports providing in-depth discussions of reservoir properties, seal properties, formation fluid properties, and injectivity should be provided. For oil fields being considered for sequestration unitization, reservoir performance, pressure history, and oil-in-place data should be included as well. The results of modeling exercises conducted to predict the fate and movement of the injected CO_2 within the proposed geologic sequestration unit will also be a critical component of a geologic sequestration unit application.

Although oil field unitization rules regarding unit management, operations, and timing issues may be applicable to the geologic sequestration unit process, key provisions that are not included in the North Dakota Department of Mineral Resources Oil and Gas Division rules but which would likely be required as part of a unitization plan for geologic CO_2 sequestration may include the following:

1) The enumeration of methods and technologies that will be used to periodically conduct measurement, monitoring, and verification activities to ensure the effective, long-term sequestration of CO_2 within the geologic sequestration unit. This should include a schedule for conducting measurement, monitoring, and verification activities.
2) The establishment of baseline geologic, hydrogeochemical, and hydrodynamic characteristics of the injection target zone, primary and secondary sealing formations, and regional geologic settings. These are critical to construct a valid framework upon which sequestration can be verified and the long-term fate of injected CO_2 can be predicted.

As with the oil field unitization process in North Dakota, the use of public hearings, including the participation of the geologic sequestration unit operators, expert witnesses, and other stakeholders, should be a significant part of the decision-making process for considering the establishment of geologic sequestration units. Public hearings enable all potentially affected parties the opportunity to express their views regarding the establishment of the proposed geologic sequestration unit.

Although the unitization process is designed to take into consideration the concerns of interested individuals, it should also include a mechanism that enables the regulatory agency to act according to the best interests of a majority of the stakeholders. With respect to oil field unitization, every major oil-producing state, with the exception of Texas, has adopted a compulsory unitization statute (Wiginton, 2006). This authority allows a supermajority of mineral rights owners in conjunction with the appropriate agency to force an objecting minority to allow the project to move forward. The ability to impose compulsory unitization is very important and should be a component of the geologic sequestration unitization process because it is commonly impossible to achieve 100% approval over a large enough geographic area to ensure project success. The application of compulsory unitization in some cases will not likely be without controversy, particularly with respect to perceptions of unfairness that might be held by stakeholders such as nongovernment organizations and/or minority mineral rights owners in the area under consideration. However, the use of neutral experts in compulsory unitization proceedings is one way to

minimize or mitigate many objections that may arise. Wiginton (2006) described in detail how the use of impartial independent experts has been successfully applied to address issues of perceived procedural unfairness in several court decisions that are relevant to the oil field unitization process and which would likely be applicable to geologic sequestration unitization as well.

CHALLENGES AND LIMITS TO THE UNITIZATION APPROACH

The process of formally organizing a geologic sequestration unit according to the oil field unitization model is not without challenges and limits. For example, the proposed approach does not address issues of pore-space value or liability associated with the injection and storage of large volumes of CO_2 over extended periods of time. The pore-space value and liability issues will have to be addressed primarily through the legal system, either through the application of relevant case law or through the legislative process.

With regard to pore-space value, examinations of American and Canadian case law related to hazardous waste injection and natural gas storage have been used to provide an insight on the issue of pore-space value and ownership and suggest that such issues are mostly unresolved in many jurisdictions (Wilson and De Figueiredo, 2006). The Interstate Oil and Gas Compact Commission (IOGCC) has recommended that states and provinces consider the potential need for new legislation to clarify and address pore-space ownership issues and that such legislation use existing natural gas storage and enhanced oil recovery statutes as guides for new laws (IOGCC, 2005). Hazardous waste injection and natural gas storage laws have been considered as potential models for protecting correlative rights that may be associated with the injection of CO_2 into geologic formations (IOGCC, 2005; Wilson and De Figueiredo, 2006).

Liability issues associated with large-scale geologic sequestration of CO_2 are unique among projects covered by underground injection control laws in that the duration of effective sequestration will be measured in terms of centuries and, possibly, millennia (Wilson et al., 2003). Furthermore, current public and private mechanisms that would govern the liability associated with geologic sequestration have been found to be inadequate for addressing the issue (De Figueiredo, 2007). Rogers (2006) suggested that the government can alleviate some of the uncertainty associated with liability through legislative actions that limit or eliminate the liability for unforeseeable environmental damage, provided that regulatory processes are properly followed and negligence is not committed. It has also been proposed that a government institution could assume long-term liability for CO_2 sequestered in geologic formations (De Figueiredo, 2007).

The extremely long-term nature of CO_2 sequestration in geologic media also presents unique financial challenges that are not currently addressed by the oil field unitization approach. Whereas the injection of CO_2 for enhanced oil recovery has a well-understood and predictable financial return from the sale of incrementally produced oil (Jarrell et al., 2002) that can be used as a means of paying for CO_2 plume monitoring and the mitigation of leaks, potential financial returns from credits associated with geologic sequestration are presently uncertain and unpredictable and may not be adequate to cover the costs of monitoring, mitigation, and verification activities. Rogers (2006) suggested that the government can alleviate some of the uncertainty associated with monitoring and mitigation by offering financial incentives such as tax breaks or credits. The bonds posted by the responsible parties (for example, those conducting the injection and/or those gaining marketable credits) prior to injection can be used to establish a CO_2 damages fund to cover future expenses associated with liability and risk management.

Further challenges may be associated with the participation of stakeholders who may be relatively new to the concept of a unitization process for the management of subsurface geologic systems. It is critical that the process be as open and transparent as possible and the requirements for baseline characterization and modeling be rigorous to ensure that any and all questions and concerns posed by stakeholders can be effectively and quickly addressed.

Although many challenges must be addressed before geologic sequestration unitization processes can be established, the fact that hundreds of millions of tons of CO_2 have been safely injected into unitized oil fields as part of tertiary oil recovery operations in Texas, New Mexico, and Canada (Jarrell et al., 2002; Wilson et al., 2003) provides support to the validity of applying the oil field unitization model to establishing geologic sequestration units.

CONCLUSIONS

The implementation of formal geologic sequestration unitization processes at the state government level would facilitate the establishment of geologic sequestration units in petroleum reservoirs, saline aquifers, and coal seams. Areas to be established as geologic sequestration units will be those that have been proven to provide effective storage and have known fluid migration properties. Unit boundaries have already been established for hundreds of oil fields as part of the field operational and regulatory processes. The establishment

of a geologic sequestration unit within a geologic setting that does not produce hydrocarbons, such as a saline aquifer, will still require the same detailed documentation that demonstrates to the appropriate regulatory agency that the operator of the project (1) adequately understands the geology and hydrodynamics of the proposed geologic sequestration unit and (2) has an appropriate measurement, monitoring, and verification plan in place to keep track of the injected CO_2.

Most oil and gas reservoirs will likely have an advantage over saline aquifers and coal seams when it comes to selecting potential geologic sequestration unit locations. Specifically, an oil or gas reservoir is a geologic feature that is characterized by a reservoir rock with porosity and permeability sufficient to allow for the movement of fluids and is competently sealed above by impermeable rock. These universal characteristics of oil reservoirs help to expedite the unitization process for oil fields, whether it be for enhanced oil recovery or CO_2 sequestration projects. The oil field unitization process also has the built-in advantage of being based on a wealth of data from many wells in relatively close proximity to each other. These data include well logs that provide detailed porosity and permeability values for the entire field and years (commonly decades) of formation fluid production and reservoir pressure historical data. The high economic return commonly associated with oil fields also results in the collection of expensive rock core, geomechanical, geophysical, and geochemical analyses data for many fields. All of these diverse data sets are then typically brought together to develop highly accurate and precise hydrodynamic models for most of the oil fields that may be considered for unitization. Unfortunately, most target zones within saline aquifers and many coal seams are not nearly as well characterized as the typical oil field. Many of the data sets routinely associated with oil field unitization will not exist for most saline aquifers and coal seams that may be proposed as geologic sequestration units. That being said, the general approach outlined for the establishment of geologic sequestration units can still be applied to target zones within saline aquifers and coal seams, although a significant amount of field-based geologic, hydrogeologic, and hydrogeochemical characterization should be conducted prior to considering large-scale CO_2 injection in areas where such data are sparse.

If unitized oil fields are used as a model, geologic sequestration units could vary in size from as small as a few acres to as large as hundreds of square miles. The size of a geologic sequestration unit will be directly dependent on the geologic and hydrodynamic characteristics of the area being considered as a target for CO_2 injection. Like oil field units, a geologic sequestration unit should only be established across an area where those characteristics have been demonstrated to be thoroughly documented and well understood. With this in mind, it will not likely be possible to declare entire regional formations or aquifer systems to be single geologic sequestration units. Geologic formations and aquifer systems are typically too heterogeneous and lacking in characterization data to adequately model large regions to the precision required for unitization. Instead, identifying localized areas within a formation or aquifer system that have specific characteristics, particularly with respect to competent seals, that allow for the secure long-term storage of CO_2 will be necessary.

An effective, well-organized geologic sequestration unitization process can benefit stakeholders in many ways. The transparency of the process would afford all stakeholders with the opportunity to voice their concerns and, potentially, affect the operational parameters and boundaries of the proposed unit. Those with mineral or pore-space ownership interests in the proposed unit would have an impartial, government-regulated mechanism by which their interests can be protected, with the potential for those interests to yield financial rewards from a new revenue source. The owners, buyers, and brokers of geologically associated carbon credits would benefit from the frames of reference that would be created by the public presentation of baseline geologic and engineering characterization data that would be part of the geologic sequestration unitization process. All of these aspects of the geologic sequestration unitization process would lend stability and credibility to the initiation and long-term operation of large-scale CO_2 sequestration projects in a variety of geologic media. The establishment of geologic sequestration units would provide a framework for carbon credit accounting that facilitates credit monetization by instilling a confidence in the long-term validity of those credits that is based on sound technical and legal principles.

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