CO_2 Storage and Sink Enhancements: Developing Comparable Economics

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Abstract

One of the major difficulties in evaluating CO_2 sequestration technologies and practices, both geologic storage of captured CO_2 and storage in biological sinks, is obtaining consistent, transparent, accurate, and comparable economics. This paper reports on a project that compares the economics of major technologies and practices under development for CO_2 sequestration, including captured CO_2 storage options, such as active oil reservoirs, depleted oil and gas reservoirs, deep aquifers, coal beds, and oceans, as well as the enhancement of biological sinks such as forests and croplands. An international group of experts has been assembled to compare on a consistent basis the economics of this diverse array of CO_2 sequestration options. A summary of the results is being prepared along with a spreadsheet model to facilitate economic comparisons. The primary funding source for the project is the Department of Energy (DOE); and the Tennessee Valley Authority (TVA) and the Electric Power Research Institute (EPRI) are providing matching funds. TVA is the prime contractor and the following organizations are subcontractors: EPRI, Parsons Infrastructure and Technology, University of Tennessee, Massachusetts Institute of Technology (MIT), IEA Greenhouse Gas Programme, and SFA Pacific.

Introduction

In order to plan for potential CO_2 mitigation mandates, utilities need better information on CO_2 mitigation options, especially carbon sequestration options that involve non-utility operations. One of the major difficulties in evaluating CO_2 sequestration technologies is obtaining consistent, transparent, accurate, and comparable economics. DOE, EPRI, and TVA are jointly funding an 18-month, $820,000 project, entitled "Economic Evaluation of CO_2 Sequestration Technologies," that will compare on a consistent and logical basis the economics of the major technologies and practices under development for CO_2 sequestration. Concepts to be considered include:

- CO_2 storage in active oil reservoirs, coal beds, depleted oil and gas reservoirs, deep aquifers, and oceans
- Enhanced CO_2 sinks in forests, croplands, and fertilized oceans

Objective

The objective of this project is to evaluate on a common basis the economics of a wide array of CO_2 sequestration options to facilitate utility and policy planning for implementing CO_2 mitigation options.

Project Description

An international group of experts in this area has been assembled to develop the technology/ practice designs and economic premises. TVA will be the prime for this project, responsible for overall completion of the effort. EPRI will organize efforts to select specific sequestration processes to be evaluated for captured CO_2 and will coordinate the efforts of consultants from the MIT, SFA Pacific, and the IEA Greenhouse Gas Programme to develop and refine the framework for the economic evaluations. MIT and Parsons Infrastructure and Technology will develop process designs for captured CO_2 sequestration processes and help TVA develop economic models for comparing technologies and practices. The University of Tennessee Agricultural Policy Research Center, in collaboration with TVA, will evaluate the economics of enhancing CO_2 sequestration in croplands. The IEA Greenhouse Gas Programme will develop the concept design for evaluating the ocean and forest sequestration options.

Economic Framework

Most of the cost comparisons to date have concentrated on CO_2 capture, with the assumption that CO_2 sequestration is a small part of these costs. In addition, these comparisons have used information supplied from studies of specific technologies, and the variability in costs due to variability in assumptions and lack of visibility into assumptions lessens the usefulness of the results. In the case of sequestration, virtually no comparative economic evaluations of processes have been done.

Methodologies for developing economic comparisons are generally available. They range from very detailed ±10 percent for site-specific evaluations, where final decisions are made between options, to very general economics with little insight into the economic premises that were used to develop the economics. The latter is usually a simplification of more detailed economics for very high-level comparisons. In some cases, probability analyses are included to help evaluate risks. This usually adds significantly to the complexity of the model and the time to develop results. The model may use simplified economics to allow probability analysis without making the model too complex to run in a reasonable time.

The economic evaluations developed for this project will be between the ranges described above and will be typical of prior EPRI economics where a ±25 to 30 percent estimate is made, with the ability to modify values to be relatively site-specific. Material balances are made, equipment lists and pricing are developed, installation costs are estimated and contingencies are estimated for project and process uncertainties. These types of evaluations are intended to be transparent, consistent, and comparable. They will be consistent with the EPRI economics of advanced power generation with CO_2 capture being developed for DOE. Probability analysis will not be included to keep the results consistent with other EPRI studies. At a later date, these economics might be parameterized to be included in the Carnegie-Mellon model being developed under another DOE project.

The economic framework will also include life cycle analysis for the various sequestration options. This means that all greenhouse gas emissions from cradle to grave will be estimated and considered in the analysis. The economic analysis will use spreadsheet models that will be flexible enough to allow a wide variation in the range of parameters to be evaluated and the sensitivity cases to be run.

Conceptual Description

The format of the spreadsheets will be EXCEL workbooks based on work regarding power generation with CO_2 capture and on other economic programs developed at EPRI for economic evaluations of emissions control processes. An input sheet will list all of the variables that can be input and the ranges that produce meaningful results. One or more sheets will contain any formulas for calculating costs and an output sheet for the results. All of the information will be transparent to a user of the spreadsheet. A write-up of the assumptions and basis for the calculations will be developed. The spreadsheet program will not be a production grade suitable for public use, since the costs of developing a version of that level were not included in our proposal. The information available as supporting documents will be sufficient to develop a commercial version at a future time.

Preliminary decisions, regarding values and ways to handle various uncertainties, made at the initial project meeting are summarized below. Members of the project decided that, in some cases, enough information for a final decision was not available and that additional information gathering would be needed to reach a final decision.

<u>Required Amount, Pressure, and Quality of CO_2</u>

We plan to consider a 405.4 MW (net after CO_2 capture) integrated gasification combined cycle (IGCC) plant as the production source of CO_2 (this will be the same as the recent EPRI/DOE advanced power generation economics case 3a) (1). Sensitivity cases for a PC plant and a natural gas-fired system may be considered, if sufficient resources are available. This will be a non-site-specific model using EPRI's central U.S. rates for work done in the captured CO_2 cases. For the sink cases, we will use labor rates appropriate to the concept. For economic purposes, we will assume a 2001 start-date with overnight installation.

For the CO_2 to be transported in a pipeline, composition requirements will be the existing pipeline specification of 2200 psia, -40°F dew point, N_2<300 ppmv, O_2<40 ppmv, and Ar<10 ppmv. The base for pipeline length will be 100 km, with sensitivity cases of 0 and 300 km.

Process Scope

A life cycle analysis of greenhouse gases will be performed for each concept. However, consideration of externalities (damage estimates) will not be included.

Concepts Compared on a CO_2 Avoided Basis

Carbon dioxide capture and storage will be compared with sink enhancement on a CO_2 avoided basis. The cost of CO_2 capture and the quantities of CO_2 emissions avoided by the capture technologies will be obtained from the associated EPRI/DOE economics project[1]. The cost of CO_2 storage will be estimated in this project.

Level of Development

Contingency factors will be used to account for the level of development of the processes. In setting these values, methodology in the EPRI Technical Assessment Guidelines (TAG) will be followed.

Time Period/Economic Discounting

The preliminary decision was to use a 20-year standard evaluation (the length of typical plant evaluations) and one for a longer period (thinking in terms of 100 years). For the longer period, we felt that a bit more investigation of how others handle the longer-term evaluations needed to be done to avoid picking a period that does not make sense.

For discounting costs of CO_2 storage concepts, we will use the same values (discount rate, capital carrying charge, and levelization factor) as the Neville Holt study for the captured CO_2 cases. Appropriate values will also be chosen for the sink concepts. These may be different from the ones used in the captured CO_2 cases since the value of money may be different. For the long-term period, we will add a case where the discounting is done at a zero cost of money. Time preference for CO_2 abatement will also be considered.

CO_2 Leakage Over Time

We assume that, for most of the processes of concern, the CO_2 leakage rate will be low in the time periods we will consider. We will pick a low value (probably <0.1%/year and perform a sensitivity for a higher value). We need to discuss this issue with experts in each of the concept areas to confirm the appropriate low value and to select the higher value.

Monitoring Costs

We will provide a cost allowance for monitoring. This will include a pre-check for suitability of the site; ensuring actual storage; and monitoring for leaks. This will also apply to cropland and forests. We plan to have discussions with experts in the field to finalize this value. We likely will do a sensitivity on this variable between 1 and 10 percent of total costs, if no other information is available.

Transaction Costs—Land, Rights, Etc.

We will provide an allowance for transaction costs. We plan to have discussions with experts in the field to finalize this value. We likely will do a sensitivity on this variable between 1 and 10 percent of total costs, if no other information is available.

Fuel and Electricity Costs

We will use the 2001 Energy Information Agency (EIA) Annual Energy Output (AEO) report to select fuel and electricity costs.

Value of Salable Products

We will use current values for oil and methane. For methane, we will consider either on site use or use requiring transport up to 10 miles.

Results

In mid-December 2000, the members of the project met for two days to finalize the Project Plan. During this meeting, the potential processes and concepts to be evaluated were prioritized, and the concepts were placed into three categories—(1) included, (2) may be included but more information is needed before a final decision can be made, and (3) not included due to the lack of good information at this time. Because one of the most unique aspects of this work is the comparison between storage of captured CO_2 and sink enhancement, project members felt that at least one of each type should be included. The list of concepts and their final status is presented in Table 1.

Table 1. Concepts Status

Included	Not Included
Aquifers	Ocean Fertilization
Oil Reservoirs	Mineralization
Depleted Oil and Gas Reservoirs	
Ocean Storage	
Forests	
Croplands	
Coal Beds	

In the case of ocean fertilization and mineralization, the group felt that at this time there is not enough reasonable information to develop a meaningful concept description and that these processes should not be included until more R&D is performed.

Aquifer Storage

Shown below is the preliminary block diagram for the Aquifer Storage concept. This concept is simple in application. The complexity comes from deciding on the nature of the distribution and number of wells.

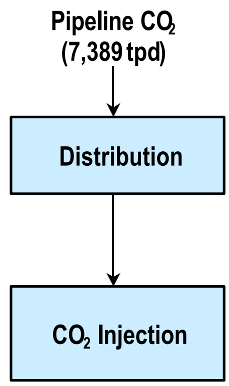

Figure 1. Preliminary Block Diagram for Aquifer Storage Concept

The rationale for including the aquifer concept in the economic evaluation is summarized in Table 2 below. This concept has the largest storage capacity of all the concepts, except the ocean, and is widespread throughout the United States. In addition, it is at commercial scale, although not in the United States. Sufficient data should be available.

Table 2. Rationale for Including Aquifers in the Economic Study

Merits	Potential Challenges	Applicability	Technical Maturity	Data Availability	Industrial Acceptance	Compatibility With Power Systems
• Best potential CO_2 storage capacity of all geological storage options • Retention time predicted to be thousands of years • Offshore aquifers eliminate most safety concerns	• Understanding risk of catastrophic or slow release of CO_2	• Ubiquitous and large, so widespread availability	• Some experience of aquifer storage for chemicals, etc. • Little actual experience for this specific application	• Many studies on this storage option • Specific reservoir characterization is lacking	• Commercial application - CO_2 has been injected into the Utsira formation under the North Sea since August 1996, as part of the Sleipner Vest project • Accepted for materials other than CO_2	• Excellent

Oil Reservoir Storage with Enhanced Oil Recovery (EOR)

Shown below is the preliminary block diagram for the EOR storage concept.

The rationale for including the EOR concept in the economic evaluation is summarized in Table 3 below. While this concept has a more limited storage capacity and is not as widespread,

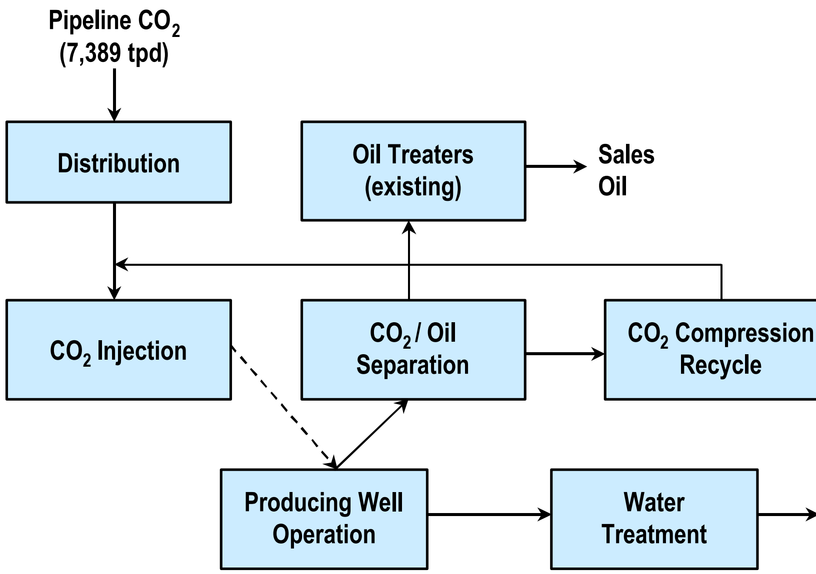

Figure 2. Preliminary Block Diagram for EOR Concept

it is likely to be an early application due to the potential for low-cost storage. It is also commercial in the United States. However, it has not been optimized for maximum CO_2 storage, and its compatibility with power systems is of some concern. Sufficient data should be available.

Table 3. Rationale for Including EOR in the Economic Study

Merits	Potential Challenges	Applicability	Technical Maturity	Data Availability	Industrial Acceptance	Compatibility With Power Systems
• Oil by-product makes option economically attractive • Not considered to involve any undue risks to man or the natural environment • Injection of CO_2 done commercially today	• Could often be cheaper to obtain CO_2 from natural sources • Global storage capacity may be limited (e.g., to 65 Gt C) (2) • For today's blowdown, reservoir operations need to store CO_2 under pressure	• Limited to areas where there are active oil fields	• EOR practiced on a significant scale for last 25 years	• Excellent	• EOR is widely used, in 1998 more than 65 oil fields in the U.S. were being injected with CO_2 • Industry actively investigating the option of using captured CO_2	• Oil operations require continuous supply (versus intermittent) • Issues with fluctuation in the quantity of CO_2 needed over time

Depleted Oil and Gas Reservoir Storage

Shown below is the preliminary block diagram for the Depleted Oil and Gas Reservoir Storage concept.

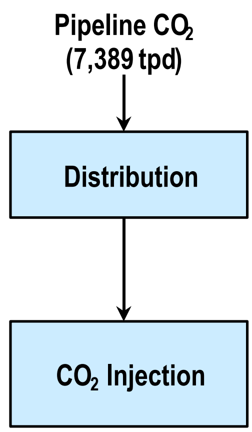

Figure 3. Preliminary Block Diagram for Depleted Oil and Gas Reservoir Storage

The rationale for including the Depleted Oil and Gas Reservoir Storage concept in the economic evaluation is summarized in Table 4 below. This concept is similar to the EOR, except the storage location is simply used for storage without recovery of oil or gas. Since the storage location has a known integrity, it should be relatively straightforward to use. The gas reservoirs may be the easiest since gas should be depleted and the reservoir can just be repressurized. The data should be sufficient, since it is so similar to EOR.

Table 4. Rationale for Including Depleted Oil and Gas Reservoirs in the Economic Study

Merits	Potential Challenges	Applicability	Technical Maturity	Data Availability	Industrial Acceptance	Compatibility With Power Systems
• Global storage capacity as much as 140 Gt C for disused gas fields and 40 Gt C for disused oil fields (3) • Reservoirs have proven containment over geological time frames • Knowledge about reservoir already exists	• Today very few reservoirs depleted • Understanding risk of catastrophic or slow release of CO_2	• Limited to areas where there are disused oil and gas reservoirs	• Uses similar technology to EOR	• Good	• No commercial scheme involving such fields as yet exists • May be liability issues	• May need multiple reservoirs for large power plants

Coal Bed Storage

Shown below is a preliminary block diagram for the Coal Bed Storage concept.

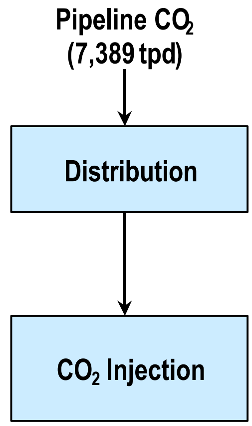

Figure 4. Preliminary Block Diagram for Coal Bed Storage Concept

The rationale for including the Coal Bed Storage concept in the economic evaluation is summarized in Table 5 below. While the data is limited, CH_4 by-product production credits and significant coal deposits make a good argument for inclusion. Data availability is limited.

Table 5. Rationale for Including Coal Bed Storage in the Economic Study

Merits	Potential Challenges	Applicability	Technical Maturity	Data Availability	Industrial Acceptance	Compatibility With Power Systems
• CH_4 by-product makes option economically attractive • CO_2 strongly sequestered by adsorption on coal matrix • Worldwide large coal deposits means potentially large CO_2 storage capacity	• Enhanced gas recovery (EGR) methods for coal bed CH_4 exploitation require further refinement	• Unclear as to how many types of coal formations will be practical to use for coal bed CH_4 production	• Injection of CO_2 into coal beds already used to enhance CH_4 recovery, although process is still at an early stage of development	• Limited	• Well accepted	• Could be used to develop a zero greenhouse gas emissions power plant fueled by coalbed CH_4, where waste CO_2 produced by plant is injected into coalbed CH_4 reservoirs to produce more CH_4

Ocean Storage

Shown below is a preliminary block diagram for the Ocean Storage concept.

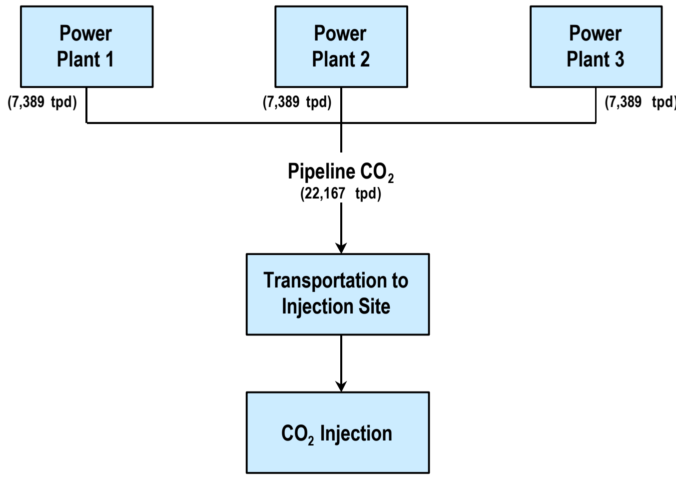

Figure 5. Preliminary Block Diagram for Ocean Storage Concept

The rationale for including the Ocean Storage concept in the economic evaluation is summarized in Table 6 below. The ocean has the largest storage capacity of any of the concepts, and much work has been done to study ways to store CO_2 in the ocean. Sufficient data should be available.

Table 6. Rationale for Including Ocean Storage in the Economic Study

Merits	Potential Challenges	Applicability	Technical Maturity	Data Availability	Industrial Acceptance	Compatibility With Power Systems
• Largest potential sink for CO_2, storage capacity estimated to be upwards of 1000 Gt C (4) • Leaks do not pose safety issues	• Could have a negative impact on local marine environment • Significant legal and jurisdictional issues to be overcome • Negatively perceived by non governmental organizations (NGOs) • Retention time, on the order of hundreds of years, less than for underground storage	• Best suited to countries situated adjacent to ocean trenches and that do not have access to suitable underground reservoirs, for example Japan • Populated areas are near coastlines	• Much experience from offshore exploration/ production is applicable	• Modest	• Not well perceived compared to geological storage options • Field experiment to take place off the coast of Hawaii in 2001, this should help to reduce some of the uncertainties	• Excellent for plants situated on coastline

Forest Sink Enhancement

Shown below is a preliminary block diagram for the Forest Sink Enhancement concept.

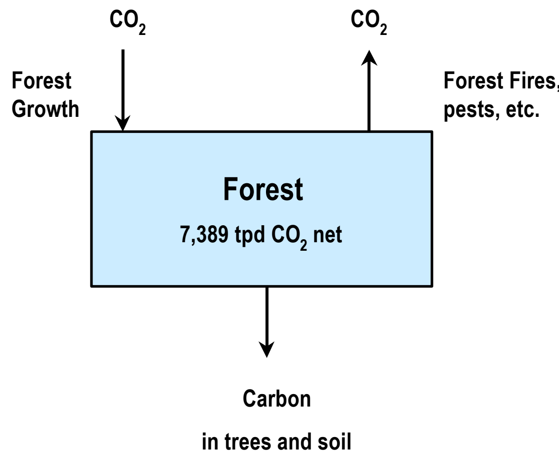

Figure 6. Preliminary Block Diagram for Forest Storage Concept

The rationale for including the Forest Sink Enhancement concept in the economic evaluation is summarized in Table 7 below. Forests are generally considered the lowest-cost storage option, and a great deal of work has been done on them. This is the basic sink comparison to be made with the captured storage concept. A number of concerns still remain, and matching the economics will be difficult. Sufficient data should be available.

Table 7. Rationale for Including Forest Sinks in the Economic Study

Merits	Potential Challenges	Applicability	Technical Maturity	Data Availability	Industrial Acceptance	Compatibility with power systems
• Low cost • Significant forest available • Provides funding and employment in rural areas and developing countries. • Preservation of biodiversity	• Monitoring and verification of carbon storage • Opportunities for fraud • "Leakage" minimization • Short-term storage • Risks of forest loss through fires, pests and social factors	• Particularly applicable to areas of low population with few other land use options • Changes to albedo may make forests less effective in high latitudes • Global capacity limited and costs increase substantially as less favorable sites are used	• Forestry is technically mature • Land owners and farmers need to be educated on merits of forestry for carbon storage • Monitoring and verification services offered but further developments would be beneficial to increase accuracy and reduce costs	• Good • Current projects small and may not be representative of large schemes • Current large-scale projects are mainly deforestation avoidance	• Still being debated at the COP 6 meeting • Considered the easy, low-cost option • Some companies already buying forestry carbon credits • Still concerns over "leakage" and risks	• Applicable to all power systems since there is no direct link to the power plant

Cropland Sink Enhancement

Shown below is a preliminary block diagram for the Cropland Sink Enhancement concept. The cropland concept involves enhancing soil carbon sequestration by switching from conventional- to conservation-tillage systems and improving residue management. Conservation-tillage systems use less intensive tillage, often no tillage, and leave at least 30 percent of the crop residues on the soil surface. Conservation-tillage systems also sometimes include a winter cover crop that remains on the soil surface to reduce soil erosion. The winter cover crop is not harvested and adds additional crop residue to soil organic matter.

General parameters for estimating the net cost of switching to conservation-tillage systems are presented in the block diagram below. The net cost of switching to conservation-tillage systems is the added cost of tillage-system inputs, plus or minus the change in revenue from changes in crop yield.

General parameters for estimating the additional CO_2 sequestered in soil organic matter are also presented in the block diagram. These parameters are (1) the increase in crop residue carbon added to soil organic matter, (2) the reduced rate of soil organic matter decomposition to CO_2, and (3) the reduced soil erosion and the associated reduction of CO_2 emitted from eroded soil.

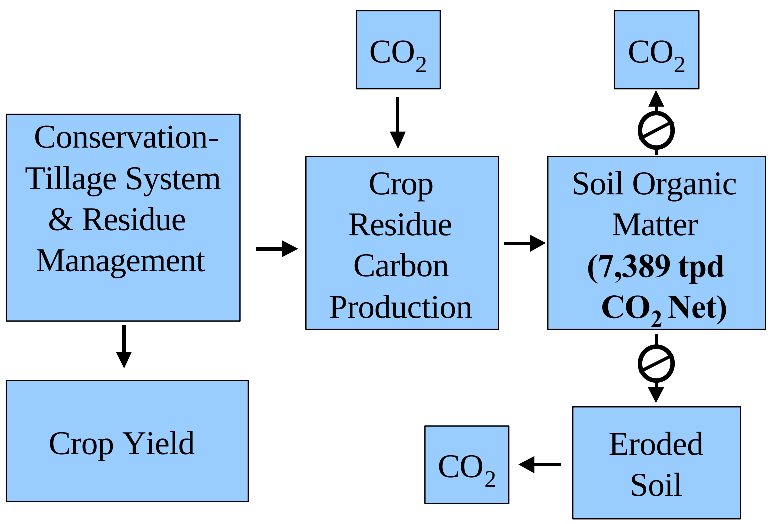

Figure 7. Preliminary Block Diagram for Cropland Sink Concept

The rationale for including the Cropland Sink Enhancement concept in the economic evaluation is summarized in Table 8 below. The cropland component of this project will estimate added costs of converting from conventional-tillage systems to conservation-tillage systems that sequester additional carbon in soil organic matter. Increased adoption of conservation-tillage systems and improved residue management accounts for about one-half of the potential for reducing greenhouse (GHG) emissions from U.S. croplands (5). The remaining one-half of the potential for reducing GHG emissions from U.S. croplands is highly fragmented and beyond the scope and resources of this project.

In conventional-tillage systems, soil is plowed or otherwise thoroughly tilled and all of the crop residues are mixed with soil. In contrast, conservation-tillage systems involve less intensive tillage (often no tillage), leave 30 percent or more of the crop residues on the soil surface, and sequester additional carbon in soil organic matter that otherwise would be emitted to the atmosphere as CO_2. In addition to sequestering more carbon, conservation-tillage systems also have lower emissions associated with production and use of tillage-system inputs, dramatically reduce soil erosion and CO_2 emissions from eroded soil, improve soil quality, and conserve soil water by reducing water runoff and evaporation from the soil.

Table 8. Rationale for Including Cropland Sinks in the Economic Study

Merits	Potential Challenges	Applicability	Technical Maturity	Data Availability	Industrial Acceptance	Compatibility With Power Systems
• Relatively low projected cost/ton of CO_2 • Collateral benefits of conservation tillage—improved soil quality, reduced soil erosion, improved water-use efficiency, improved crop productivity where well adapted	• Possible need for periodic use of conventional tillage to maintain crop productivity, resulting in partial loss of sequestered CO_2 • Possible reversion to conventional tillage due to changes in land ownership • Resistance to including biological sinks in GHG polices • Poorly developed infrastructure for CO2 credits and markets • Good base for infrastructure	• Excellent in well-drained soils, water deficient cropping systems, and highly erosive soils • Moderately good in most other cropping systems	• Conservation tillage systems under development since early 1970s • ~35% adoption achieved to date in U.S. • Technology ready for rapid adoption, given additional economic incentives	• Good for costs of tillage systems • Moderately good for CO_2 sequestration rates • Lacking for equilibrium levels of sequestered carbon and time to equilibrium • Good for CO_2 emissions factors associated with tillage-system inputs	• Generally good farmer acceptance because of collateral benefits • Somewhat greater economic risk to farmers • May require moderate adoption incentives to achieve rapid additional adoption	• Good compatibility via combining farm-level CO_2 sequestration credits into bundles of sufficient size to match power project needs

Future Activities

The schedule for the project is shown below in Figure 7. The project will run through the end of April in 2002. The spreadsheet development will run concurrently with the data collection effort, since the framework can be built and then populated with the information from the data collection effort.

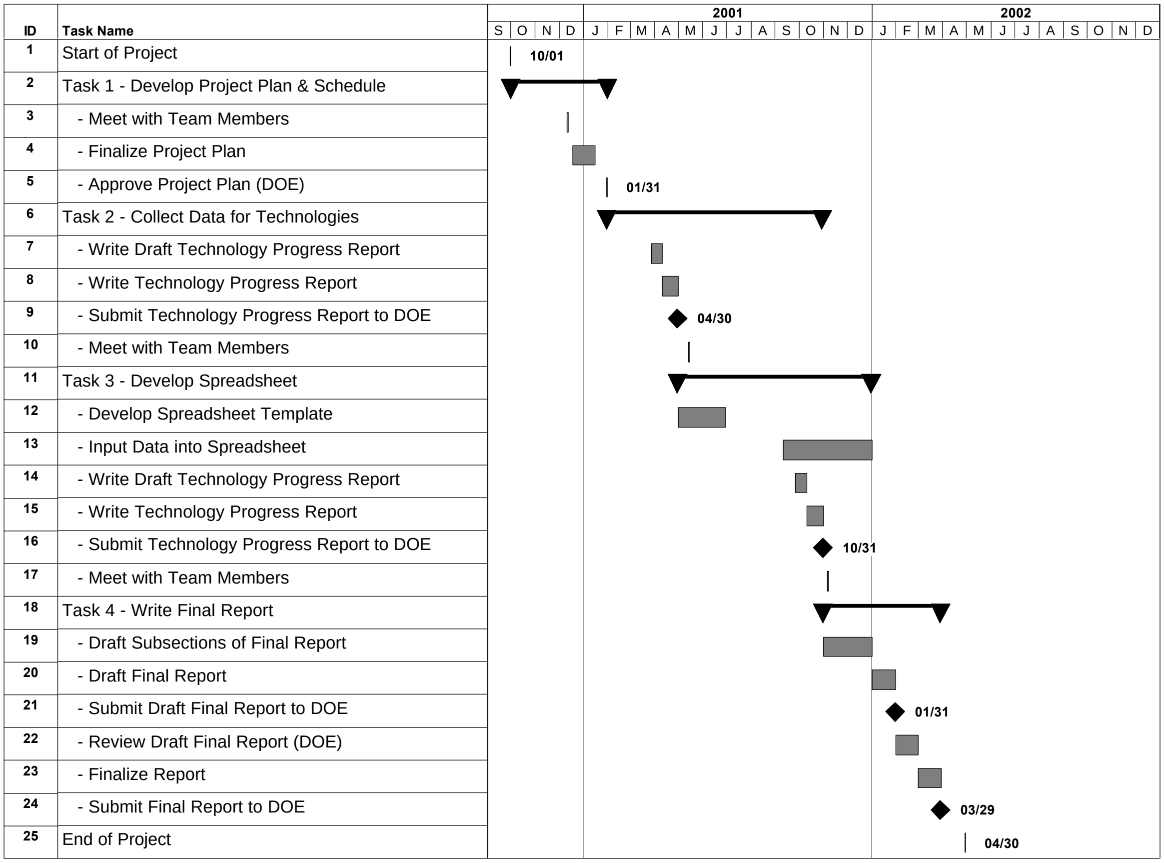

Figure 7. Project Schedule

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