The 'String of Pearls': The Integrated Assessment Cost and Source-Sink Model

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ABSTRACT

This paper describes an analytical model used by the Southwest Regional Partnership on Carbon Sequestration to assess potentially hundreds of CO_2 source and geological sink combinations. The model has been developed over several years, first as an overarching presentation tool, later as an interactive integrated analysis tool, and more recently as a way to summarize the high-level carbon sequestration potential in the region. The model's development is an ongoing project, and includes additional source and sink data throughout the Southwestern U.S. and increasingly standardized cost metrics. Additionally, the model is able to help decision makers (e.g., policy analysts and interested companies) determine where a power plant (or other CO_2 source) could be built given a set of planning decisions based on current power plant locations, sink availability, and existing pipeline infrastructure right-of-ways.

The working results indicate that the cost of capturing carbon dioxide is by far the majority of a project's overall capital cost. For example, a power plant in northern New Mexico has a potential base case capture, transportation and storage-associated cost breakdown of 95%, 2% and 3% of the initial cost estimate, respectively. The analysis also develops overarching results such as regional CO_2 sequestration totals, relative cost issues, a working power plant retirement and replacement sub-module, and a sink lifetime calculator across an initial fifty-year time horizon. The region may support anywhere from several decades to over ten thousand years' worth of sink capacity depending upon the assumptions regarding CO_2 source and sink resources. The model includes new information from the Southwest Regional Partnership as it maintains a pilot project-oriented focus.

INTRODUCTION

The Southwest Regional Partnership (SWP) on Carbon Sequestration is one of several regional partnerships developed by the National Energy Technology Laboratory to assess carbon sequestration in the United States over the coming decades, from the source of CO_2 to the sink. As one of the many thematic committees developed to specialize on each part of a complete carbon sequestration system, the Integrated Assessment Thematic Committee was tasked to develop and implement a framework to allow interested policy makers and individuals the ability to 'understand the story' of Carbon Sequestration in the southwestern United States. The model initially served as an overarching systems view presentation framework, then as a high-level integrated systems cost calculator, and continues to evolve with region-wide calculations for new power plant requirements accounting for both power plant retirements, and potential parasitic energy losses due to carbon sequestration penalties. These model attributes build on the original purpose of the model; to assess potential pilot projects for geological sequestration of carbon dioxide while maintaining a regional view for the southwestern U.S. in a potentially carbon constrained world.

THE INTEGRATED ASSESSMENT MODEL: DEVELOPING THE SYSTEMS FRAMEWORK AND USER OPTIONS

The Integrated Assessment (IA) model was developed in Phase I of a multi-year effort as part of the SWP. The model prototype at the end of Phase I was developed such that it highlighted the salient factors involved with the larger Partnership (Figure 1). In an effort to operationalize this framework, the IA team developed a dynamic simulation systems computer model in Powersim Studio. This allowed for the larger body of Partnership members the ability to see an increasingly complex set of scenarios that address, amongst other items, CO_2 source-to-sink combinations while accounting for their associated infrastructure and economic considerations.

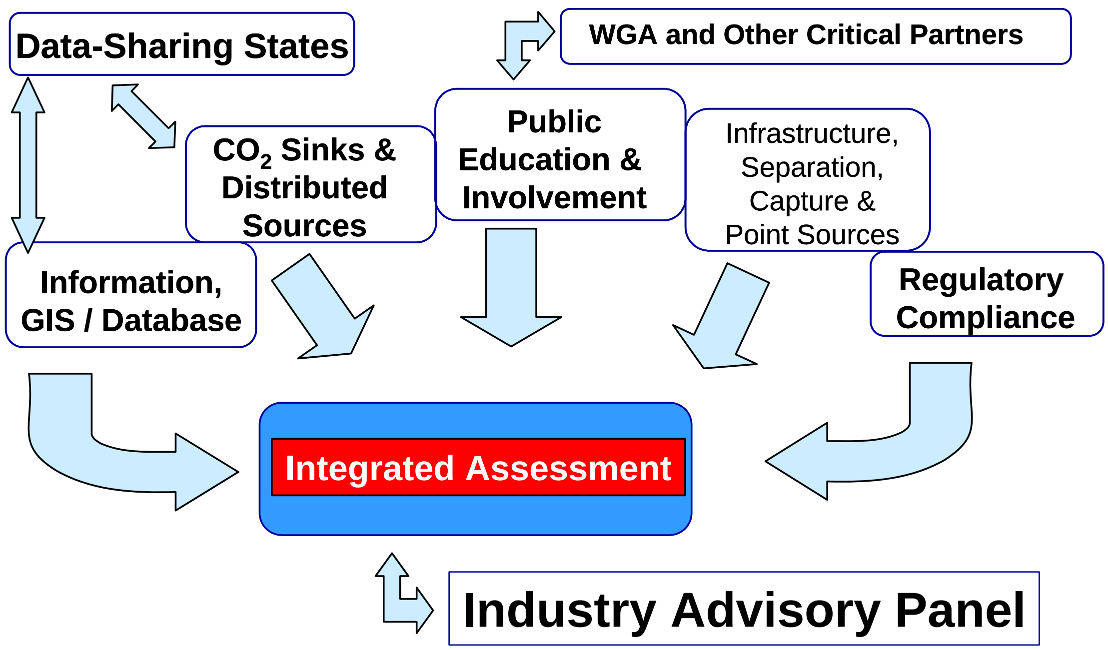


Figure 1. Thematic Committees and Larger Partnership Integration (adapted from McPherson, 2005a).

The model at the end of Phase I was largely a calculator that matched four power plants in New Mexico to seven geological sinks within the partnership region and ranked the combinations from the lowest to the highest cost. This relatively small-scale model allowed the partnership members to understand and appreciate the transparency of the modeling efforts, and provide useful feedback on where the modeling efforts were headed, and to suggest improvements. Figure 2 illustrates the computer model's underlying CO_2 flow and cost structure, and addresses the representative power plants, pipelines and geological storage issues (e.g., how many years will it take until a sink is filled with CO_2 from a power plant of a certain type and size).

After reviewing the small-scale, initial Phase I 'test case' model in New Mexico, the model's scope was further scaled up to the larger region covered by the SWP to include all of the utility power plants and geological sinks (oil & natural gas formations along with saline aquifers) within the five core states of the SWP (Arizona, Utah, Colorado, New Mexico and Oklahoma).[1]

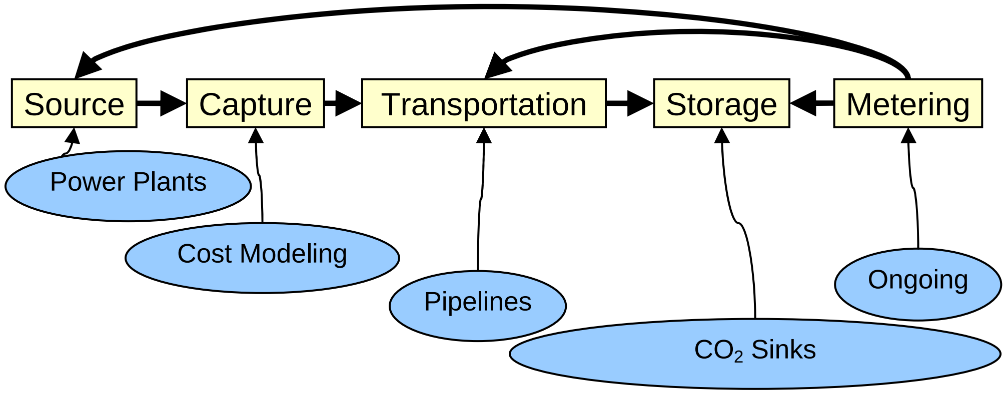


Figure 2. The CO_2 Flow and Cost Structure for the Integrated Assessment Model.

The 'test case' model employed data (CO_2 emissions) for power plants from the 2002 version of the Emissions and Generation Resources Integrated Database (eGRID) (EPA, 2005). Its calculations for CO_2 separation and capture scale and cost metrics were derived from the Integrated Environmental Control Model (IECM) (CMU, 2004).[2] The CO_2 transport and injection equations for CO_2 storage calculations were based on the work of Ogden (2002), Williams (2002) and through industry participation by way of Mike Hirl (Hirl, 2004).[3] The CO_2 geological sinks database was developed by the sinks thematic committee of the SWP; itself managed by the Utah AGRC.[4]

THE 'STRING OF PEARLS' MODEL.

The IA team expanded the initial test case model version beyond the initial few power plants and sinks to include all of New Mexico, and then on to the larger region included in the SWP. The full New Mexico model was the first version to also employ the source-to-sink matching algorithm named the 'String of Pearls' (Kobos et al., 2006). The 'String of Pearls' algorithm calculates the transportation distances based on a great circle distance algorithm from the source of the CO_2 (e.g., power plant) to the closest sink (e.g., geological reservoir) (Stephens, 1998). The 'String of Pearls' module builds on hypothetical pilot project pipelines, power plant locations and potential cost-saving connections with existing CO_2 pipeline infrastructure in the southwestern United States. Figure 3 illustrates the general region that the full 'String of Pearls' model now includes. The sinks database continues to develop, and may include more data from Texas, and additional data detail as the various thematic committees continue to expand and refine their research.[5]

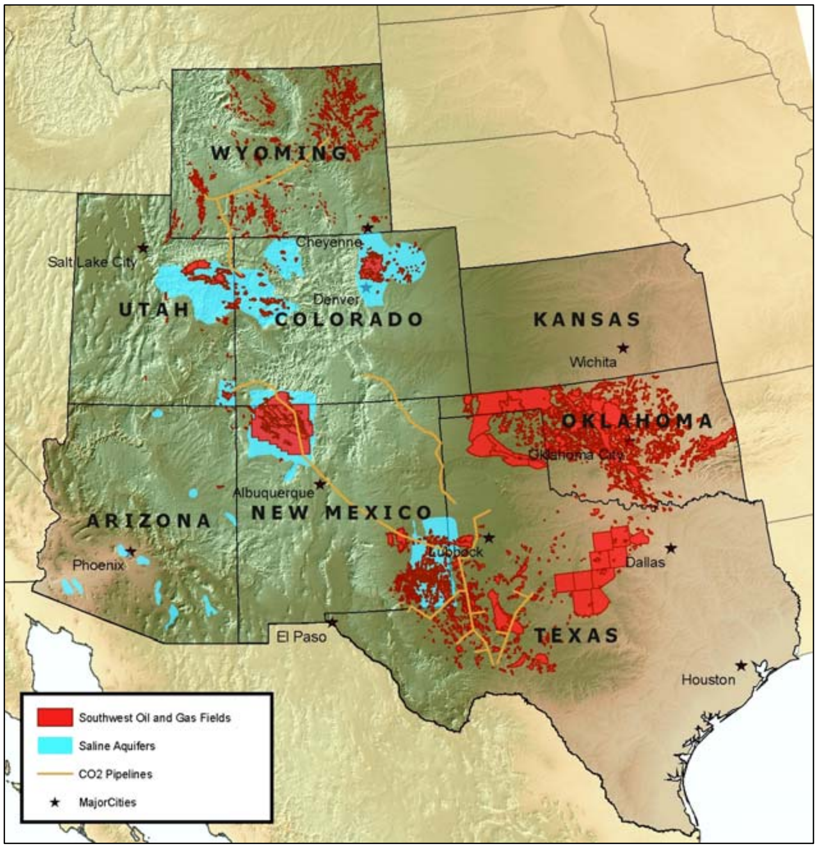


Figure 3. The Southwest Regional Partnership on Carbon Sequestration Regional Boundary (Note: Oil and Gas Fields and Saline Aquifers are shown for illustrative purposes only, the full 'String of Pearls' model includes sinks data for AZ, CO, NM, OK, UT, and the pipelines as of April 2007; Image courtesy of Biediger, 2006).

The model ranks the potential CO_2 sinks (geological formations) according to their geographical location (e.g., latitude and longitude) relative to the selected source of CO_2 (e.g., a power plant amongst the 93 possible existing plants in the SW region). After the model calculates the relative distances between the source and the sink, the model user can sort the sinks according to their distance from the source, their relative size (e.g., million metric tones), and potentially other criteria to address questions such as, '*If we only consider geological sinks that are X distance from the source, and that are of size Y to be sure the sinks are of a suitable size, then how many and which sinks should we consider?*' After down-selecting the source and sink combinations, the model calculates a straight-line pipeline network based on these criteria along with the relevant economic parameters (e.g., pipeline, wellhead, disposal well costs). This allows the interested model users the ability to assess combinations between the 93 power plants, within the 5 core states, and between the 218 geological sinks, and finally in various combinations with the existing pipelines in the region (included by assigning up to 107 geo-coordinate points to bends along the pipelines). Future modeling efforts may include further distance cost refinements to account for additional features.

In this Phase II model version, the full 'String of Pearls' dynamic network development algorithm is fully employed amongst the larger dataset. Additionally, the model includes a set of high-level measurement, monitoring and verification (MMV) costs based on the work of Benson et al. (2004) to account for current, and potential future costs for these MMV technologies (currently, the model includes the range of \$0.16 − \$0.31 per tonne of CO_2). The initial 'test case' capture costs derived from the IECM-CS model from Carnegie Mellon University now serve as the basis for a generic regression analysis used to assign general (working) capture costs (\$/tonne and \$/kWh) for the Phase II 'String of Pearls' models. Additional capture and electricity cost metrics will be implemented as the full set of regional partnerships come to a consensus on which metrics and calculation modules to employ.[6]

MODEL USER OPTIONS AND RESULTS.

Over the last several years, the interface options of the 'String of Pearls' model have evolved into two main model modules; the source-to-sink calculator and a regional totals assessment. The source-to-sink calculator continues to include more user options such as percentage capture, cost metrics, and display options for the source-to-sink calculations. The regional totals interface displays region-wide (working) CO_2 capture totals and the associated level of power plant requirements to account for the parasitic energy losses across the 5 core states of the SWP. Figure 4 illustrates the central source-to-sink user options. The model user first selects the source of CO_2 they wish to include in the 'String of Pearls' algorithm. In this particular model run, the San Juan coal plant was selected (light green pull-down option) amongst the 93 existing power plants or even a custom, hypothetical power plant. Next, the coal bed methane and oil and gas formations within the 5 core states were included in the calculations such that only those at least 200 million metric tonnes in size were considered in this particular model run. On the right-hand side of the interface, a *hypothetical* electricity cost and pipeline network are calculated such that the first sink (#51, Basin-Dakota oil/gas formation) fills first, then the model builds to the next closest sink that has at least 200 million metric tonnes of storage capacity (#53, Blanco-Mesaverde oil/gas formation), and so on. The geo-coordinates of the sinks are such that sink 51 is approximately 73 kilometers (km) from the San Juan Power Plant, sink 51 is 12 km from sink 53, and so on.

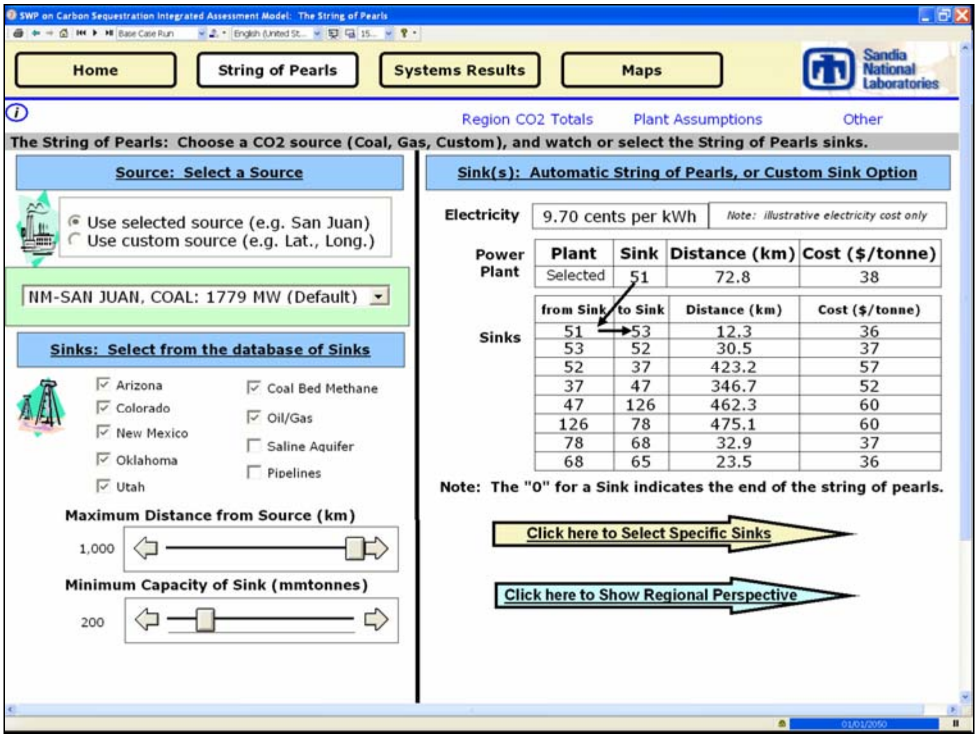


Figure 4. The 'String of Pearls' (SOP) User input Screen.

The corresponding model interface that displays the majority of the String-of-Pearls results is shown in Figure 5. The system results illustrate the high-level stacked cost for the single source (San Juan coal plant) to multiple sinks when considering coal bed methane formations along with oil and gas formations in all 5 of the core states. This scenario was run to illustrate the capture cost (blue) may be by far the majority of the overall costs, followed by either the Wells and MMV or the pipeline costs, depending upon the relative distance from the source to the various sink selections.

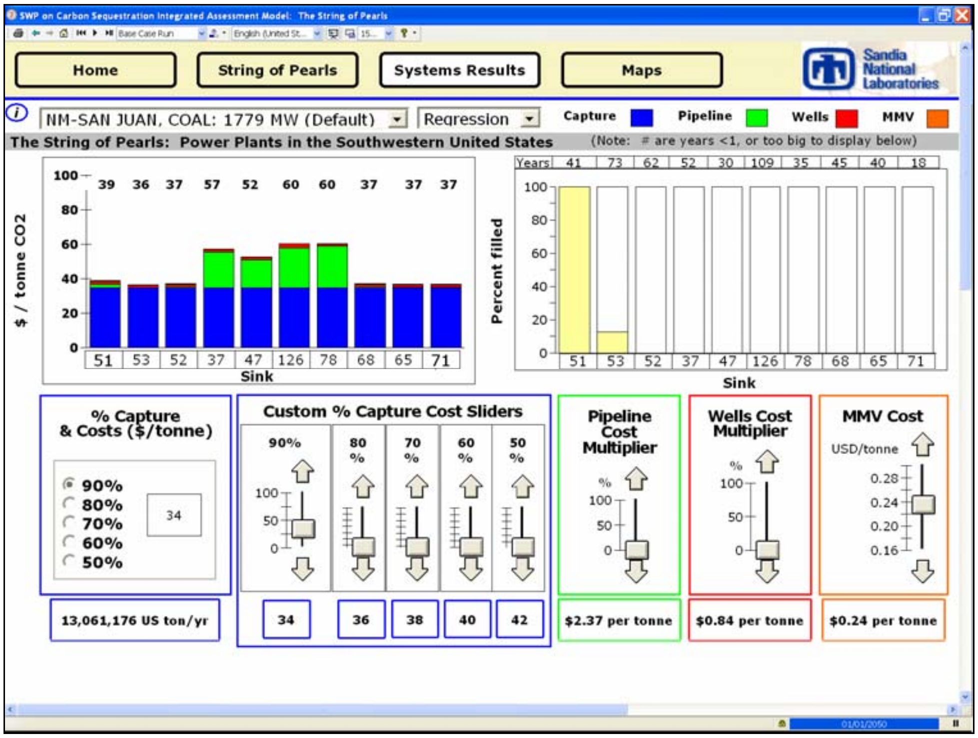


Figure 5. The Systems Results Interface for the 'String of Pearls' Model Module (illustrates the source-to-sink stacked cost bar graphs (upper left), the years of sink fill capacity across the initial 50 year time horizon (upper right), and the user options on capture percentage, capture cost, pipelines, well costs, and monitoring, measurement and verification (MMV) costs (bottom).

Figure 6 illustrates the New Mexico-specific sinks, among many, that the model can include according to their type (coal bed methane, oil/gas, saline aquifers), size, geographic location (e.g., state) or distance from the source. If a pilot project were to include only very specific sinks across one or multiple states, the user can select only those sinks of interest, and run the 'String of Pearls' model to determine the overall system's attributes.

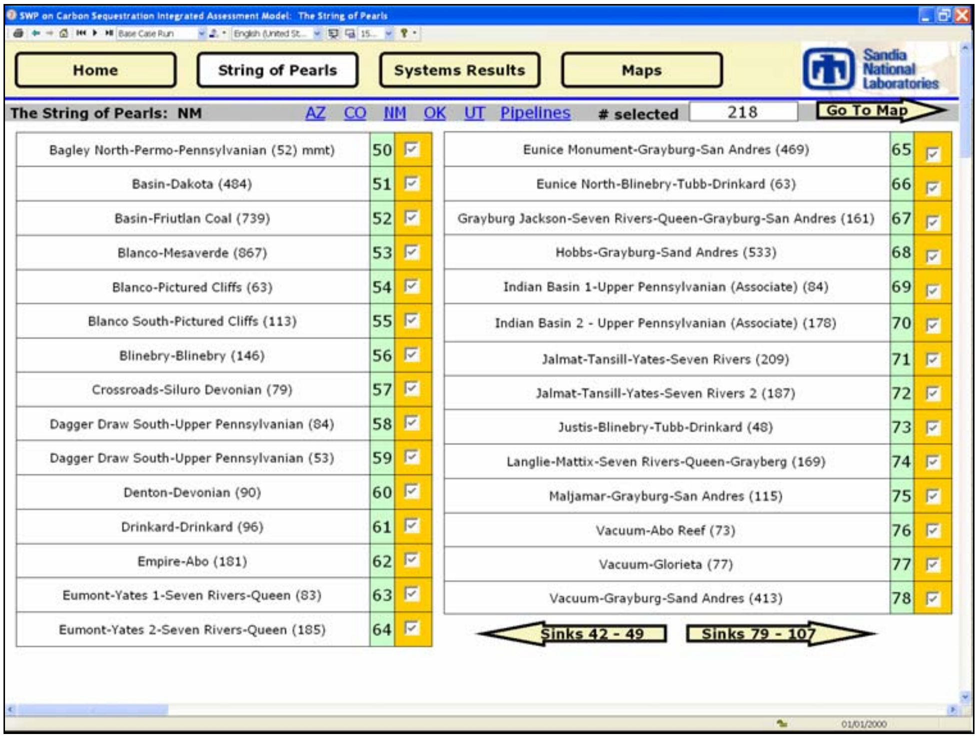


Figure 6. The New Mexico Geologic Formations (CO_2 sinks) Page.

THE REGIONAL CONTEXT: SUMMARIES AND PUTTING THE TOTALS INTO CONTEXT

The five core states included within the Southwest Regional Partnership (SWP) on Carbon Sequestration constitute a modest amount of the total U.S. carbon dioxide emissions. As illustrated in Figure 7, the power plants within the SWP represented roughly 8% of the national total carbon dioxide emissions in 2000.

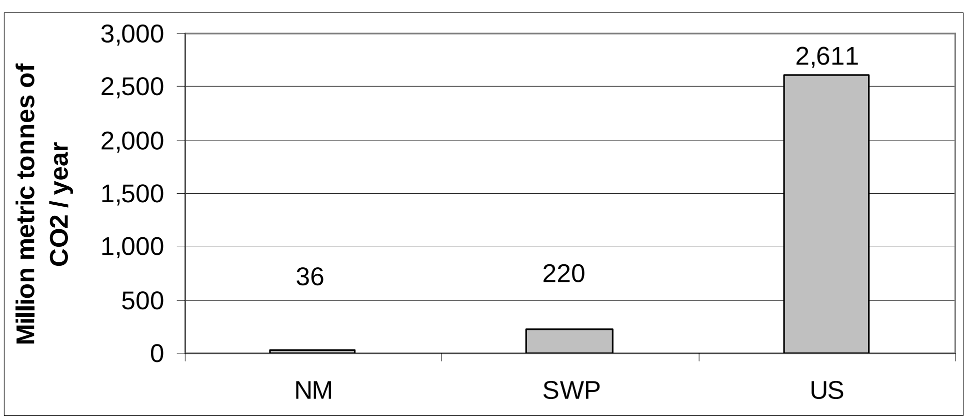


Figure 7. New Mexico, Regional and National Carbon Dioxide Emissions Totals in 2000 (Note: Stationary Power Plants only, the Southwest Regional Partnership (SWP) is the sum of the emissions from Arizona, Colorado, New Mexico, Oklahoma and Utah, (EPA, 2005)).

The Southwest region, however, also represents a substantial opportunity for carbon sequestration in geological formations. For example, based on the recent summaries from NETL, the SWP oil and gas formations represent 26% of the oil and gas sink capacity across all of the Partnerships; a sizable share given the relatively lower population densities, regional history of oil and gas production, and the fact that many CO_2 transportation pipelines have been in operation in the region for many years (NETL, 2007).

In the face of a potentially carbon constrained world, electricity exports across state lines pose an interesting policy challenge. If electricity is generated in one state, but serves the demand load in another, the issue of who pays for the added costs associated with carbon sequestration technology will come into question. For additional context, Arizona, Colorado, New Mexico, Oklahoma and Utah, for example, export roughly 63, 11, 73, 32 and 65 percent of their electricity to regions beyond their state's boundaries (EIA, 2004).[7] Figures 8 and 9 illustrate the megawatts installed in the Southwestern states along with their associated CO_2 emissions.

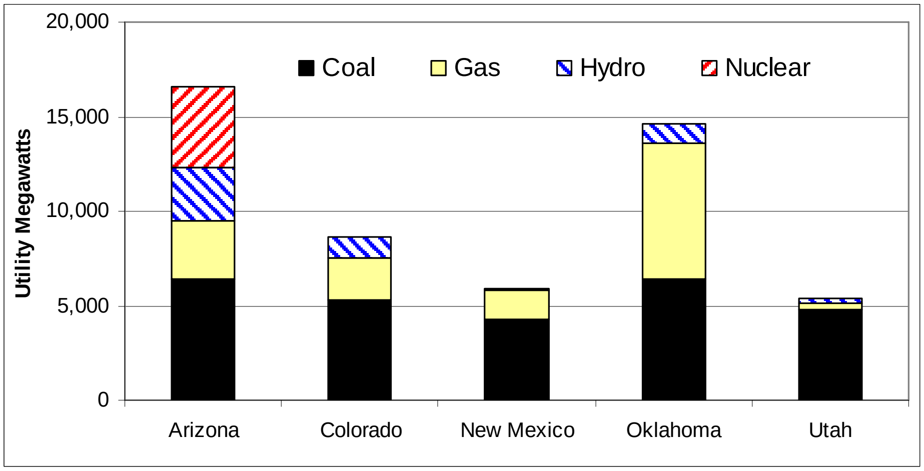


Figure 11. Installed, Utility-based Installed Megawatts for the Five Core States in the Southwestern U.S. in 2000 (Note: Oil-based and other fuels represented 2% or less of the total installed MW) (EPA, 2005).

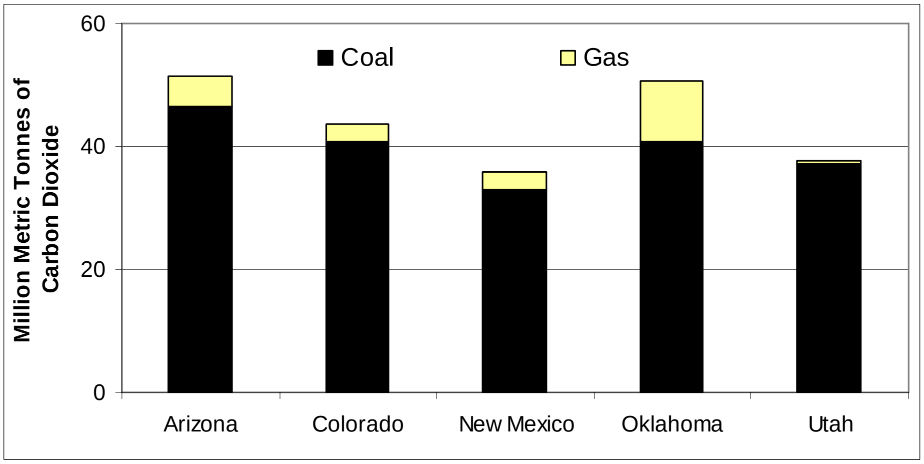


Figure 12. Carbon Dioxide Emissions (Million tonnes) from Utilities from the Five Core States in the SWP in 2000 (Note: Oil-based and other fuels represented 2% or less of the total CO_2 emissions; EPA, 2005).

The sources and sinks database will continue to develop as more (or fewer) sources are considered for the Integrated Assessment model, and as the new eGRID database becomes more widely adopted across the regional partnerships (EPA, 2007).

NEW MODEL CAPABILITIES: PROTOTYPE USER OPTIONS AND THE DIRECTION OF THE INTEGRATED ASSESSMENT MODELING

In the second half of Phase II (2007), the Integrated Assessment team continues to collect CO_2 sinks data for Texas, other states, and potentially other pilot projects as the overall SWP looks to address several key issues. These include assessing what types of sinks should or should not be included in the analysis based on their size, location, depth, and within certain regulatory constraints. In effort to begin 'telling the regional story' of carbon sequestration for the SWP, a second set of model components were developed to complement the original 'String of Pearls' source-to-sink model framework. Figures 13, 14 and 15 illustrates the *working* display interface for the carbon capture regional summary. In short, they show how many total installed megawatts the SW region will need over the coming decades in the face of power plant retirements, build time delays for new plants, and potential carbon sequestration energy requirements due to the parasitic losses associated with amine-based systems. This is still a prototype model module such that the numbers are purely illustrative, and will continue to be refined as new and better information becomes available. These modeling efforts are driving towards a common way to illustrate three main points; (1) power plant retirement and replacement dynamics up to 2050, (2) how parasitic energy losses will affect how much and what type of capacity may be installed in the future to meet electricity demand (or other services requiring power that produces CO_2), and (3) using this type of modeling framework allows the interested model user the ability to truly explore scenario-based-discovery by adjusting the assumptions employed by the Integrated Assessment to test for system sensitivities and various source-to-sink combinations.

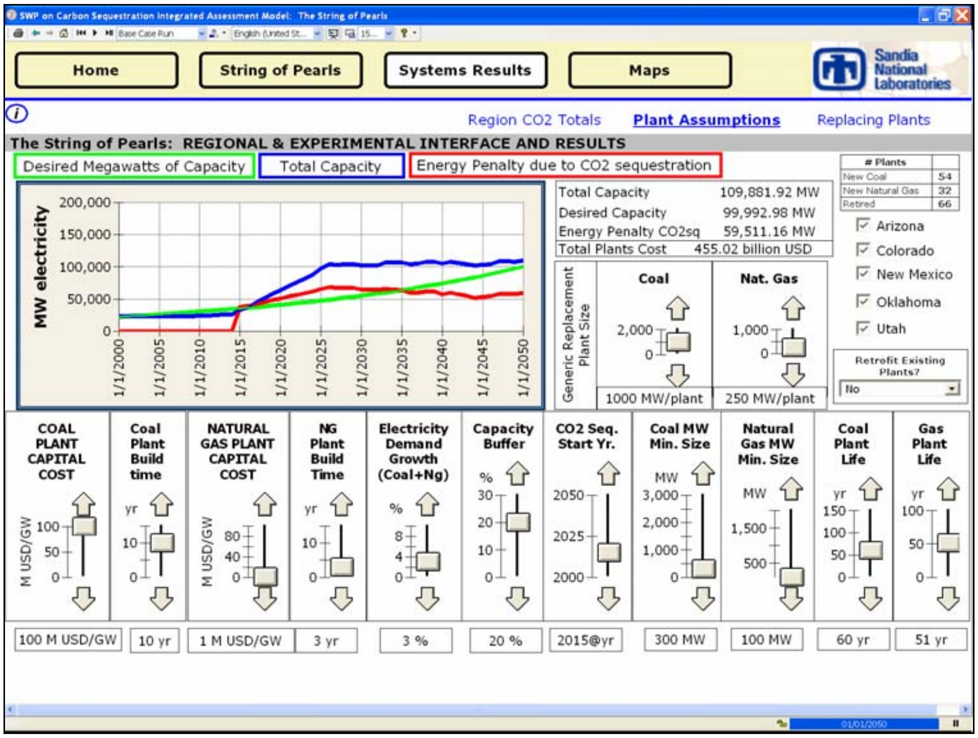


Figure 13. Prototype Total Installed Megawatts Regional Summary for the SWP under an Aggressive, Hypothetical Scenario. (Note: Annual 3% growth rate in capacity (green line), the total energy requirements due to carbon sequestration (red line), and the total installed megawatts for the region (blue line)).

Figure 13 illustrates that under these assumptions, up to 66 power plants may retire by 2050, 54 new coal-based power plants may have to come online, and up to 32 natural gas plants will have to come online as well. The 'new' power plants, however, are purely an illustrative calculation based on new plants replacing retired ones, and in this particular model run, those required to make up for the parasitic energy losses due to carbon sequestration starting in 2015.

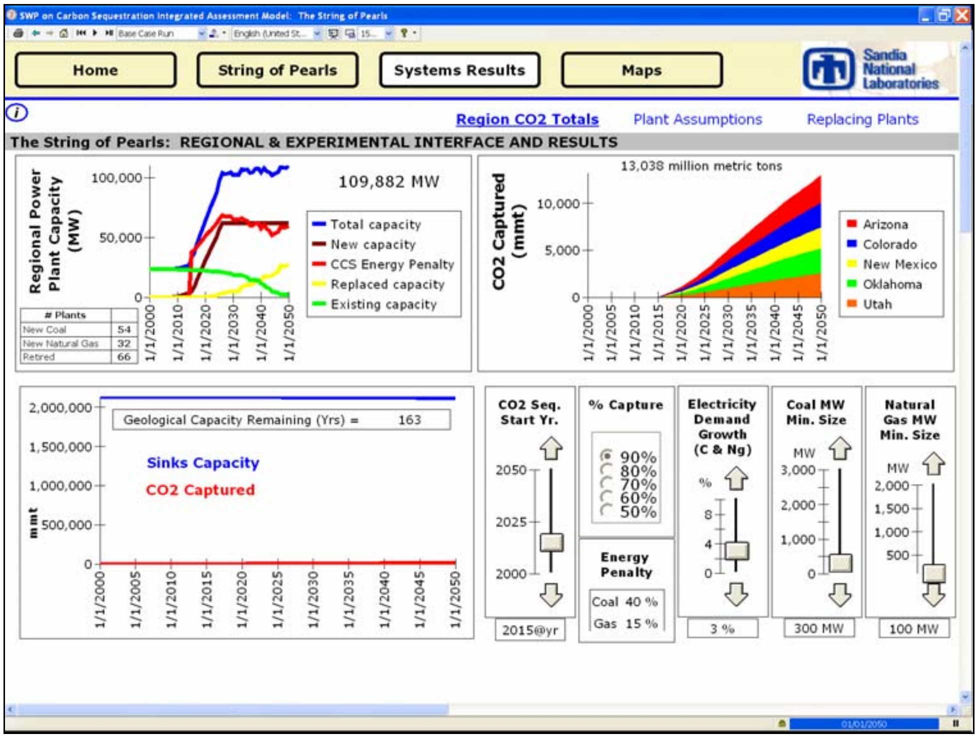


Figure 14. Prototype Power Plant, Carbon Capture and Sink Lifetime Summary for the SWP.

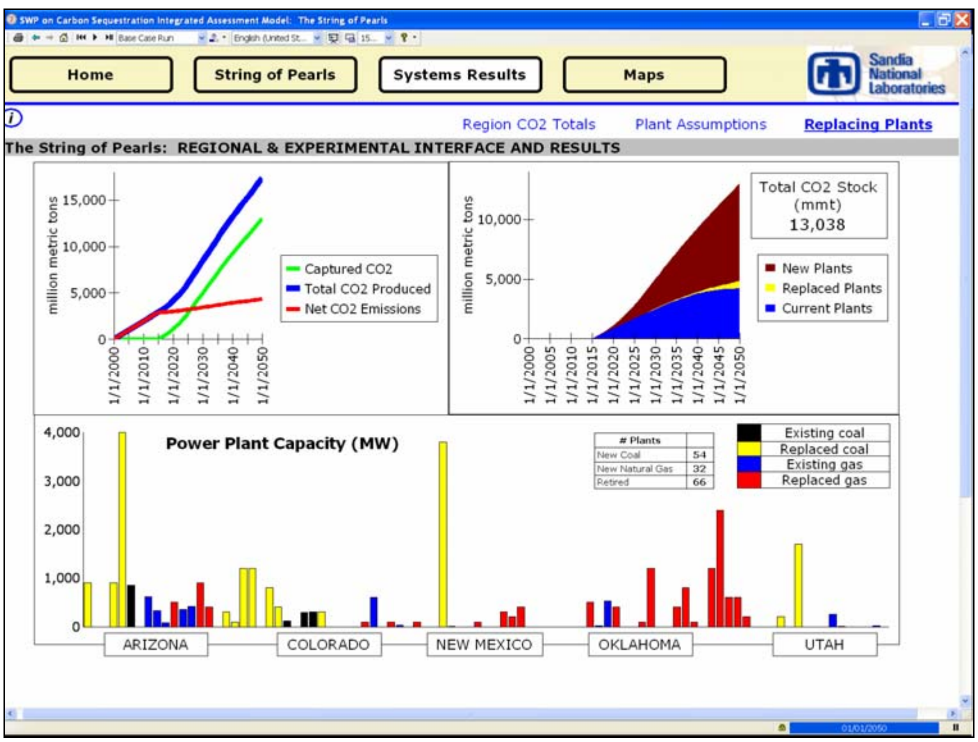
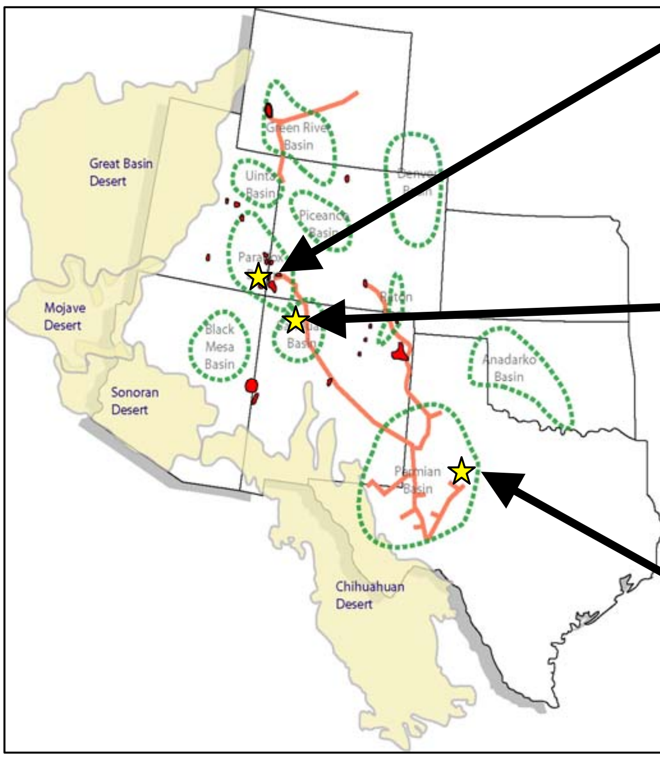


Figure 15. Prototype Power Plant Retirement, Replacement and Carbon Capture Interface.

DISCUSSION

The Integrated Assessment modeling efforts during Phase I (~2004 – 2005) focused largely on oil and gas reservoirs within the state of New Mexico. In Phase II (~2006 – 2007), the efforts included more region-wide source-to-sink matching, and select pilot projects. Additionally, during Phase II (and beyond) the SWP will be engaged in select pilot projects to more adequately assess specific geological sink characteristics, as well as potentially a few measurement, monitoring and verification strategies (led by Julianna Fessenden at Los Alamos National Laboratories). The pilot projects are close to existing CO_2 transportation infrastructure (orange lines) as well as spread across multiple geological basins (Figure 16).



<u>Paradox Basin, Utah</u>:
combined EOR and deep saline aquifer sequestration pilot test, up to 150,000 tons per year for 2 years
(Jim Rutledge)

<u>San Juan Basin, NM</u>:
combined ECBM and terrestrial sequestration pilot test, estimated 75,000 tons per year for 1 year
(Scott Reeves, Joel Brown)

<u>Permian Basin, TX</u>:
combined EOR and sequestration pilot test at SACROC & Claytonville, over 150,000 tons per year for over 2 years
(Mark Holtz)

Figure 16. Planned Carbon Sequestration Demonstration Options in Phase II (and beyond) with their respective main project leaders (adapted from McPherson (2005a, 2005b)).

When the pilot projects begin to yield additional information, the Integrated Assessment will include them to help round out the carbon sequestration story as part of the SWP. With these three components; (1) the full 'String of Pearls' Integrated Assessment model, (2) the regional assessment summary model module, and (3) lessons learned from specific projects, planners will be able to assess the technologies, economics and associated issues with the evolving analysis.

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REFERENCES

Benson, S.M., Hoversten, M., Gasperikova, E. and M. Haines. (2004). Monitoring Protocols and Life-Cycle Costs for Geologic Storage of Carbon Dioxide. GHGT7, Vancouver, Canada.

Biediger, Barry. (2006). The Southwest Regional Partnership on Carbon Sequestration, The Sinks Database, Personal Communication, Images reproduced with the permission of Biediger of the Utah Automated Geographic Reference Center (AGRC), June 22, 2006.

Carnegie Mellon University (CMU). (2004). The Integrated Environmental Control Model (IECM). IECM, Update version 4.0.4.1, September.

Drennen, T.E., Baker, A.B., Jones, S.A., Kamery, W.J., Lutz, A.E., Rosthal, J.E. (2004). The Hydrogen Futures Simulation Model (H2Sim) Technical Description. SAND2004-4937. October.

Environmental Protection Agency (EPA). (2005). Emissions & Generation Resource Integrated Database (eGRID), eGRID2002, Version 2.01. Year 2000 Data, 27, June 2005. http://www.epa.gov/cleanenergy/egrid/index.htm

Environmental Protection Agency (EPA). (2007). Emissions & Generation Resource Integrated Database (eGRID), eGRID2006, Version 2.0. Year 2004 Data, 16, April 2007. http://www.epa.gov/cleanenergy/egrid/index.htm

Energy Information Administration (EIA). (2004). Individual State Data. 19, March, 2004. http://www.eia.doe.gov/emeu/states/_states.html

Hirl, M. (2004). CO_2 Sequestration Integrated Model Workshop, Personal Communication, April 20.

Kobos, P.H., D.J. Borns, L.A. Malczynski and O.H. Paananen. (2005a). Southwest Regional Partnership on Carbon Sequestration: A Test Case Model in the San Juan Basin. Poster Presentation at the Fourth Annual Carbon Capture and Sequestration Conference, Alexandria, VA, May 2 – 5.

Kobos, P.H., D.J. Borns and L.A. Malczynski. (2005b). The Southwest Regional Partnership on Carbon Sequestration: Employing the Integrated Assessment Model for Systems Insight. Proceedings of the 25th Annual N. American Conference of the USAEE/IAEE, September 19 – 21, 2005, Denver, CO.

Kobos, P.H., L.A. Malczynski and D.J. Borns. (2006a). Southwest Regional Partnership on Carbon Sequestration: The ‘String of Pearls’ Integrated Assessment Model. Proceedings of the 5th Annual Carbon Capture and Sequestration Conference, Alexandria, VA, May 8 – 11.

Kobos, P.H., L.A. Malczynski and D.J. Borns. (2006b). Employing the ‘String of Pearls’ Integrated Assessment Model: A Carbon Sequestration Systems Analysis Tool. Proceedings of the 26th USAEE/IAEE North American Conference, Ann Arbor, MI, September 24 – 27, 2006.

McCoy S.T. and E.S. Rubin. (2007). An Engineering-Economic Model of Pipeline Transport of CO_2 with Application to Carbon Capture and Storage. Manuscript submitted to Energy Conservation & Management.

McPherson, B. (2005a). Phase I Project Overview, DE-PS26-O3NT41983, October 12, NETL Regional Carbon, Sequestration Partnerships Review Meeting Pittsburgh, Pennsylvania.

McPherson, B. (2005b). U.S. Department of Energy Solicitation DE-PS26-05NT42255, Technical Narrative March 15.

Meyer, H. (2006). Personal Communication, utilized The Integrated Environmental Control Model (IECM), As of February 2.

National Energy Technology Laboratory (NETL). (2007). National Perspectives, http://www.netl.doe.gov/publications/carbon_seq/atlas/National%20Perspectives.pdf As of April 25, 2007.

Ogden, J.M. (2002). Modeling Infrastructure For a Fossil Hydrogen Energy System with CO_2 Sequestration. Sixth Greenhouse Gas Control Technologies Conference, Kyoto, Japan, September 30 – October 4.

Paananen, O. (2004). A Framework for Assessing Carbon Storage in the Southwestern United States. Presentation at the Third Annual Conference on Carbon Sequestration, Alexandria, VA, May 3 – 6.

Rao, A.B. and E. Rubin. (2002). A Technical, Economic, and Environmental Assessment of Amine-Based CO_2 Capture Technology for Power Pant Greenhouse Gas Control. Environ. Sci. Technol. 36, pp. 4467-4475.

Rao, A.B., Rubin, E.S., Keith, D.W. and M.G. Morgan. (2006). Evaluation of potential cost reductions from improved amine-based CO_2 capture systems. Energy Policy, Volume 34, Issue 18, December, pp. 3765-3772.

Stephens, R. (1998). Ready-To-Run Visual Basic Algorithms, Second Edition. John Wiley & Sons.

Williams, R.H. (2002). Toward Zero Emissions for Transportation Using Fossil Fuels. In VII Biennial Asilomar Conference on Transportation, Energy, and Environmental Policy: Washington, D.C. - forthcoming, and Prepared for Managing Transitions in the Transportation Sector: How fast and how far? VII Biannual Conference on Transportation, Energy & Environmental Policy, Monterey, CA. 11-14, September, 2001, final draft revised 7.15.2002.

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[1] The complete power plant (CO_2 source) and geological sinks data is included for the states of Arizona, Utah, Colorado, New Mexico and Oklahoma. Portions of Texas, Wyoming, Kansas and Nevada may be included in the IA model as the regional partnerships continue to develop the sinks database.

[2] The Gas Technology Institute (GTI) used the IECM to calculate the CO_2 capture costs for several power plants as part of their Phase I participation in the SWP. Additional capture cost updates are being developed amongst all of the regional partnership, and other information may be included from Rao and Rubin (2002) and Rao et al., (2006).

[3] Based on the Ogden (2002) model of CO_2 disposal costs for CO_2 sequestration, Williams (2002) develops the general framework where the cost of CO_2 disposal is a function of the cost of the pipeline transmission (CPT) + the cost of disposal wells (CDW) + the cost of surface piping near the disposal wells (CSP); where CPT($/t$CO_2$) = CPT_0*($Quantity_n$/$Quantity_0$)^-0.53 * (length of $pipeline_n$/length of $pipeline_0$)1.24; Cost per well ($/well)=$1.0 million + ($1.25 million/km)*[depth(km)]; CSP=0.138*(Quantity-104.17)^0.253. The calculations developed for the IA also draw on the work of Drennen et al. (2004) and the work of Kobos et al. (2005a, 2005b). Future work on the transportation metrics may draw from the work of McCoy and Rubin (2007).

[4] Barry Biediger of the Utah AGRC has been central to the SWP. His ability to maintain and manage the core SWP sinks data allowed the Integrated Assessment model to further expand to the larger SWP region. It was decided to include all of the data unless missing data prevented further analysis (e.g., sink's depth from the surface) or size constraints limited their usefulness for larger-scale sequestration (those sinks with less than 10 million metric tonnes in size, which equates to less than one year's worth of storage for a large coal-fired power plant).

[5] The Integrated Assessment Committee included the relative size of the TX sinks within the pipelines capacity option. Future efforts may include the geo-coordinates of the down-selected geological sinks in the SACROC region.

[6] Additional information regarding previous model versions can be found in a series of conference papers for the interested reader (Kobos et al., (2005a,b); Kobos et al., (2006a,b).

[7] Colorado imported approximately 4% of its electricity in 2000 (EIA, 2005). The new eGRID database will likely present new information for the SWP to include in its analyses as the regional assessment continues to evolve.