CO_2 Source Assessments for the West Coast Regional Sequestration Partnership

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ABSTRACT

The US Department of Energy is sponsoring projects by teams to investigate direct (geological) and in-direct (terrestrial) CO_2 sequestration in seven regions of the United States. The recently formed Regional Partnerships face a number of issues in their assessment of carbon separation, capture and transportation of CO_2 to sites for geological sequestration. This paper discusses early work for the West Coast Regional Partnership to define the region's CO_2 sources, and to begin evaluation of the source characteristics as they apply to the overall geologic sequestration goals.

The technical effort for the Regional Partnership project's Phase 1 is largely concerned with data collection and assessments of the CO_2 sources and sinks. The data for sources, sinks and transportation will be linked, along with other material in a geographic information system (GIS). The planned later phases of work will include the injection of CO_2 for field research to test and deploy elements of the sequestration technology, and to expand the understanding of different geological formations where large quantities of CO_2 may be stored long-term.

The CO_2 source data and issues discussed in the paper represent some of the early project work. The data collection planning involved many of the project participants. The results from the source data collection have the objective to answer questions such as below.

- What kinds of data does the Partnership need to assist decision making?
- What are the existing sources of data and how can they be used for sequestration objectives?
- How will the Partnership screen the data to match limited resources and meet project goals?
- What are the impacts of CO_2 separation and capture technologies on categorizing sources and collecting data?
- Can we collect data that will help evaluate what scenarios are likely for future carbon sequestration in the Region, including the potential to retrofit existing plants for CO_2 control and/or planning new plants with CO_2 control "designed-in"?

Finally, the discussion will present a summary of CO_2 source data collection accomplished for the West Coast Region and the plans for future actions, including suggestions for items that might best be considered from a national perspective to improve consistencies and enhance decision-making across the regions.

Introduction

The focus of the Department of Energy (DOE) regional carbon sequestration program is to assess technical and policy issues of direct (geological) and indirect (terrestrial) sequestration. While terrestrial sequestration concepts are independent from sources of the carbon, stationary or point source data for CO_2 emissions are crucial for geological sequestration options. Each regional partnership will have similar questions about CO_2 sources to answer in Phase I of the project, and hopefully the data on existing sources of CO_2, and the formulation of decision-making processes for how future sources may develop can add significant value to the nation-wide project results.

All the Regions have to answer the broad question, "Where are the significant sources in the region?" The following discussion describes plans for the West Coast Region's team to begin structuring their answer, and presents some of the early data that has been collected for point sources in different industries.

The types of data that the team seeks can be categorized in two types: The first category is relatively fact based, and while obtaining a complete, timely and accurate set of data is labor intensive and costly, there are relatively few issues that require technical or other judgments. The data in this category can largely be summarized as,

- What are the regional sources?
- Where are the sources located?
- How large are the CO_2 emissions?

And related to the third bullet, as much as it is practical, we will seek other data about the major characteristics of the (mixed) gas stream that carries the CO_2.

The second category of data will contain more uncertainty, but are valuable to the decision-making process for future R&D, and eventual large-scale sequestration actions. The main points in this category are,

- When could the industry and their source(s) be ready to control CO_2 emissions?
- How much will it cost to separate and capture the CO_2 and prepare it for sequestration?

These items are only an overview of the scope of the source definition work. There are numerous more detailed questions to be resolved, if not in this phase of work, then later. And with the data that becomes available, the regional team will begin to address the overall issue of how one integrates sources of CO_2 with transportation requirements, sequestration options, and other existing or future regional infrastructure.

Data Requirements

The West Coast team decided early that it would be necessary to screen from among the many sources in the region, and select a practical number for data collection. In some cases (the power generation industry mostly) the quantities of CO_2 are more readily available, and can be used to select the larger and likely more important sources. In other areas, less quantifiable criteria such as seeking a representative set of industries were used to select, or eliminate sources from a detailed examination in Phase I.

In the West Coast Region, the likely industrial sources were defined for data collection:

- Fossil Power Generation
- Petroleum Refining
- Cement and Lime Production
- Steel Manufacturing

- Natural Gas Processing

Other regions will have additional types of sources, and at this early stage of data collection it is possible that one or more of the items above could be eliminated from the West Coast region after preliminary data is collected and evaluated. Exhibit 1 shows National data for CO_2 and the industry specific sources. The overall importance of power generation, and that industry's general propensity for large-scale plants make the plants obvious choices for the more detailed assessments.

Exhibit 1

Summary of U.S. CO_2 Emissions[1] for 2001

	INDUSTRIES	Tg, CO_2 Equivalent
1	Fossil Fuel Combustion	5,615
	• Electricity Generation	2,243
	• Transportation	1,781
	• Industrial	938
	• Others	653
6	Iron and Steel Production	59
7	Cement Manufacture	41
8	Waste Combustion	27
9	Ammonia Manufacture & Urea Application	17
10	Lime Manufacture	13
11	Natural Gas Flaring	5
12	Limestone and Dolomite Use	5
13	Aluminum Production	4

1. US EPA, 2003 Inventory of U.S. Greenhouse Gas Emissions and Sinks. Tg = Teragram

Exhibit 2 shows a preliminary list of 56 data elements. The list contains basically all the items that the team felt would be useful. It is expected that some, if not many of the data elements will not be available for some of the specific plants. Some items can be estimated from data that is available, but other important missing data will have to be pursued in later phases of work. In Phase 1, data collection will focus on larger sources (with considerations given to geographical distribution) and is aimed at helping near-term decisions for Phase II, as well as longer-term issues of large-scale sequestration.

Exhibit 2

Long List of Data Element "Requirements"

1	Plant Type
2	Plant Name
3	Location: City, County, State
4	Elevation
5	Location: Latitude & Longitude
6	Contact: Name, Telephone, Email
7	Ownership and Operator Name, Addresses
8	Seismic Classification Code
9	Design Capacity of Plant
10	Production Capacity of Plant
11	Plant Installation Date
12	Site Area
13	% of Site in use
14	Is Plot Plant Available?
15	Is Simplified Process Flow Sheet Available
16	Number of CO_2 Generating Units or Production Lines
17	Type of Fuel or Feedstock
18	Product and Design Capacity of Unit or Line
19	Production Capacity of Unit or Line
20	Unit or Line Installation Date
21	Pollution Control Technologies
22	Pollution Control Tech. Installation Date
23	Average Annual Production (capacity factor)
24	Fuel/Feedstock Feed Rate
25	Average Fuel Heating Value
26	Flue Gas Flow Rate Lb per Hour
27	CO_2
28	SO_2

29	NO_X
30	O_2
31	H_2O
32	CO
33	Particulates
34	Mercury
35	All Others
36	TOTAL
37	Gas Stream Pressure
38	Gas Stream Temperature
39	Description of pure or high concentration CO_2 streams that become mixed with other streams prior to becoming "stack gas".
40	Actual Annual Plant Emissions, last 3 Years
41	CO_2
42	SO_2
43	NO_X
44	CO
45	Solid Waste Production
46	Solid Waste Disposition
47	Fuel Source
48	Fuel Delivery Mode
49	Water Source
50	Annual Water Consumption
51	Regulated Emission Limits, by Whom
52	SO_2
53	NO_X
54	Particulates
55	Mercury
56	Other

Data Sources

The paper will not attempt to describe the complete process of searching for available data, but there are some sources that are especially useful for the West Coast region, and likely for other regions too. Because CO_2 is not a regulated pollutant, the measurement and recording of emissions varies among States, and among State and Federal agencies. A clear conclusion from even the preliminary data collection is a need for a consistent CO_2 measurement and reporting system (and probably other greenhouse gases).

The next sections summarize the major data sources used for our preliminary data collection. In all the cases, some level of follow-on direct communication will be required with organizations or plants to obtain a more complete picture of the emissions and operational features in the region.

Power Generation

The primary sources of information are the Energy Information Agency (EIA) and the Environmental Protection Agency (EPA). The EIA database contains relevant material about plants and units (a boiler, a combustion turbine, etc.) Data important to the regional sequestration work includes ownership and location, capacity, type of unit, fuels, equipment age, and operating status. The EIA database has a significant amount of other data, including emission control equipment, which will be examined later to augment the plant and company contacts for our region.

The EPA Clean Air Markets organization has a database with emissions, including CO_2. The data is for the plant and lists SO_2 and NO_X as well as CO_2. The plant heat input is also provided. In our region, Alaska was not part of the EPA database, and other States (outside our region) may also be missing, but this was not checked. In some cases it was difficult to match EIA and EPA plants because different names were used, and there does not seem to be a single identification key across the federal agencies.

California has a unique database maintained by the California Air Resources Board (CARB). The database contains valuable plant information that will facilitate contacts, and lists pollutant emissions for organics, CO, NO_X, SO_X, and particulates (PM, PM10, and PM2.5). CO_2 is not part of the CARB data.

The sample below, Exhibit 3, shows the type of data collected for power generation. EPA emission data is colored light blue, and the other plant and unit information is from the EIA database.

Exhibit 3

ARIZONA Fossil Power Generation

State Company Plant (County)	Unit ID	Generator Nameplate Capacity (megawatts)	Net Summer Capacity (megawatts)	Net Winter Capacity (megawatts)	Unit Type1	Energy Source1 Primary	Year of Commercial Operation	Unit Status1	Further Data Collection
Arizona Electric Pwr Coop		**559.1**	**515**	**515**					
Facility Name	Facility ID (ORISPL)	Year	SO_2 Tons	CO_2 Tons	NO_x Tons	Heat Input (mmBtu)	EPA CLEAN AIR MARKETS DATA		YES
Apache Station	160	2002	5,167.0	3,068,830.5	6,528.4	31,278,625			
Apache Station (Cochise)	GT1	10	10	10	CT	NG	1965	OP	
	GT2	19.8	20	20	GT	DFO	1972	OP	
	GT3	64.9	63	63	GT	DFO	1974	OP	
	ST1	75	72	72	CA	RFO	1965	OP	
	ST2	194.7	175	175	ST	SUB	1979	OP	
	ST3	194.7	175	175	ST	SUB	1979	OP	

Cement and Lime Production

Only minimal data about emissions at cement and lime facilities was found in the preliminary search. Two useful sources of data were the U.S. Geological Survey (USGS) and the Portland Cement Association, which both list plants and information on location and ownership. California's ARB has information for the State on plant locations and criteria pollutants similar to the power plant data. The Oregon Department of Environmental Quality (DEQ) has a database for plants via their permitting process. In addition to ownership and plant contact information the DEQ data includes location by latitude and longitude.

The EPA has published methodologies for calculating CO_2 emissions from cement and other plants, but to-date no EPA data on emissions have been found for the West Coast region.

Natural Gas Processing

Prior to introduction into a pipeline, produced natural gas is typically treated to remove moisture, organic compounds, CO_2, sulfur compounds and other contaminants. While many of the natural gas containments become byproducts and are sold, the reject gas streams may include release of the CO_2 to the atmosphere.

Information about natural gas processing was obtained from the Natural Gas Supply Association's Internet site, and the EIA Natural Gas Navigator Internet site. The EIA site contains production capacities by State. For the West Coast Region, it appears that only Alaska has a significant gas processing capability on the North Slope. Emission data was not found.

Industry partners with plants in the North Slope will be asked to provide information on CO_2 and other emissions.

Information about natural gas processing was not found in the CARB and DEQ databases, but from the Association's and EIA data, only Alaska and California have processing plants that seem significant within our region. Exhibits 4 and 5 show gas-processing data for the U. S. and two States in our region.

Exhibit 4

U.S. Total Natural Gas Plant Processing

Data Series	2001
Natural Gas Processed (Million Cubic Feet)	16,511,427
Total Liquids Extracted (Thousand Barrels)	682,873
Extraction Loss (Million Cubic Feet)	953,984

Exhibit 5

West Coast Region Natural Gas Plant Processing

2002 Data	Alaska	California
Natural Gas Processed (Million Cubic Feet)	2,984,807	258,271
Total Liquids Extracted (Thousand Barrels)	30,334	8,625
Extraction Loss (Million Cubic Feet)	36,149	11,060
Estimated Heat Content of Extraction Loss (Billion Btu)	134,686	36,055

Petroleum Refining

Data about refinery operations was obtained from the EPA, EIA, CARB and Oregon DEQ records. The main data elements relevant to the regional sequestration work are the plant capacities (for early screening decisions) and plant location and contact information. EPA and CARB show criteria pollutant emissions, but there is no information on CO_2. Plants selected for further data collection will need to be contacted and the information about CO_2 and other issues requested.

As an example of the CARB data, Exhibit 6 is shown. As noted, CO_2 data is not collected.

Exhibit 6

CARB Emission Data Example

Data from 2002	**Pollutant**	**Emissions**	**Unit**
	TOG	2084.6	Tons/Yr
	ROG	1461.7	Tons/Yr
	CO	739.8	Tons/Yr
	NOX	2898.3	Tons/Yr

	SOX	1465.8	Tons/Yr
	PM	404.5	Tons/Yr
	PM10	357	Tons/Yr
	PM2.5	346.1	Tons/Yr

Steel Production

Steel production in the region was examined by checking the EPA database. Five plants were located in the West Coast Region and these will be contacted for further information. It may be that some or all the plants are electric furnace processes, and thus mainly indirect producers of CO_2. While pursuing steel production data the exhibit below was found and may be of interest to others that need to estimate CO_2 from steel production.

Exhibit 7

Steel Manufacturing CO_2 Emissions

CO_2 Emissions Per Metric Ton of Liquid Steel	
Process	Kg/ton
Ore/pellet/coke/blast furnace/BOF	2,010
Ore/pellet/Midrex plant/EAF	1,874
Ore/pellet/Corex plant/BOF	3,089
50-percent ore/rotary hearth and scrap/EAF	1,872
40-percent ore/iron carbide and scrap/EAF	982
Ore/iron carbide/carbide-to-steel process	1,089
Scrap/EAF	641
Note: Assumes coal-generated electricity used for oxygen generation and all other electricity.	
Source: Gordon Geiger	

BOF: Basic Oxygen Furnace, EAF: Electric Arc Furnace

Data Application and Decision-Making

While it is too early in the data collection process to predict with confidence the quantities and types of data that can be found for some of the CO_2 sources, it is not too early to formulate plans to use the data for sequestration evaluations, including the assessment of possible Phase II projects and future large-scale carbon sequestration concepts for the region.

The West Coast partnership seeks, at a minimum, the knowledge of where major CO_2 sources are sited, the amounts and types of emissions, the sources' geographical relationship to other existing infrastructure, and surrounding demographics. Closely related to the source data is the need for performance and economic information about processes to collect, transport and dispose of the CO_2. Data selection depends heavily on engineering judgments with the recognition that the database will require refinement and additions as work proceeds beyond Phase 1.

Other Data

To complement the carbon source data, the partnership has access to published and in-house performance and cost data for CO_2 capture and separation technologies. This information will be used to help estimate the potential for carbon sequestration over time, and for several scenarios of variable conditions. The two main CO_2 capture "decisions" are (1) the feasibility of retrofits to existing sources, or (2) replacement of existing facilities (over time) with new facilities designed for carbon capture and sequestration.

Unless the carbon source is adjacent the sequestration site, a pipeline will be required for transportation of the CO_2. The partnership is collecting GIS data on existing pipelines and right-of-ways, and will examine potential new routes as the major carbon sources and sinks are identified. Within the scope of the project the transport data can only include summary level information, and will be used to make broad estimates of feasibility for different routes to connect sources and sinks.

Finally, the major portion of the partnership's work is directed at collection and creation of geological data for potential sequestration sites such as oil and gas fields, deep saline deposits, and other formations. The sequestration formations are most important to the project's work, and Phase I will begin to define geological characteristics that will impact the placement of the CO_2, and retention of the gas for very long durations (hundreds and thousands of years).

Preparations for Phase II

The immediate decision for the partnership will be to decide about the potential for a Phase II carbon sequestration demonstration or test program, and where to locate it. As presently understood, Phase II will require a relatively small quantity of CO_2, so the source and processes for capture are not major decision factors. For example, the Phase II CO_2 could be produced with commercial processes and sent by truck or rail to the sequestration test site. If the source is a nearby industrial site (a refinery for example), there might be a small diameter pipeline installed to move the compressed gas. Ideally the project would include CO_2 capture and sequestration at an actual source, depending on available budget.

To better understand and evaluate the broad impacts of carbon emissions and sequestration beyond Phase II, the partnership will estimate the quantities of CO_2 that can be reasonably expected to sequestered during a selected future time frame. This is where the decisions get really complicated.

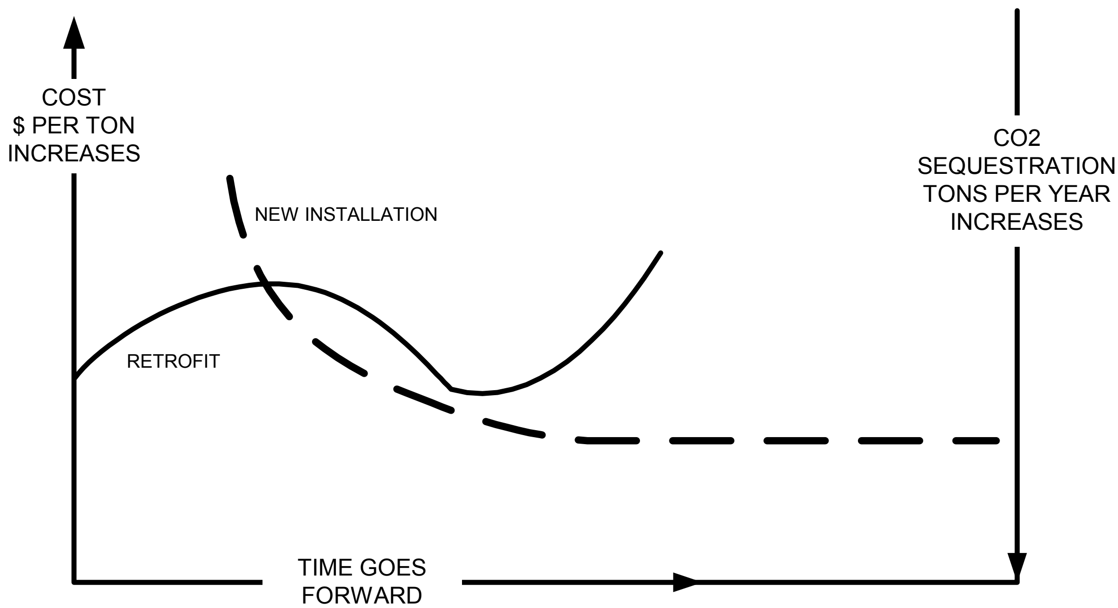
First there is the technical – economic – political – social quandary of retrofitting existing sources to capture the CO_2 and pipeline it to the sequestration site, or replacing the existing sources with facilities designed to include capture and preparation of the CO_2 for a pipeline. The current technologies for retrofit are expensive and significantly reduce a plant's capability to produce – for a power generation example, retrofitting an amine CO_2 collection system and compression for the pipeline can cut the unit generating capacity by 20 to 30%, or more. And in many plants it will be extremely difficult to physically install the new equipment within the existing plant footprint. Conversely, while the new plant installation opens more options for location and the use of more efficient processes, the capital costs are much larger and the effort to permit new installations, no matter what their benefits, may prove preventive.

What one might expect to see is illustrated in Exhibit 8. The retrofit cases (solid line) begin early; the costs increase as "low hanging fruit" is picked (if any for retrofit) and more difficult plants are retrofit. At some point, the retrofit technology cost and performance will improve as technology advances, but then costs rise again as smaller and more costly units are retrofit.

The new installations (dotted line) begin later because the technologies must be developed and proven. The costs are initially high, but decrease relatively quickly and level off as the technology becomes widely commercial. While Exhibit 8 may help explain a conceptual thought process, at some point the partnerships are going to have to examine real cases.

Exhibit 8

Retrofit versus New Design

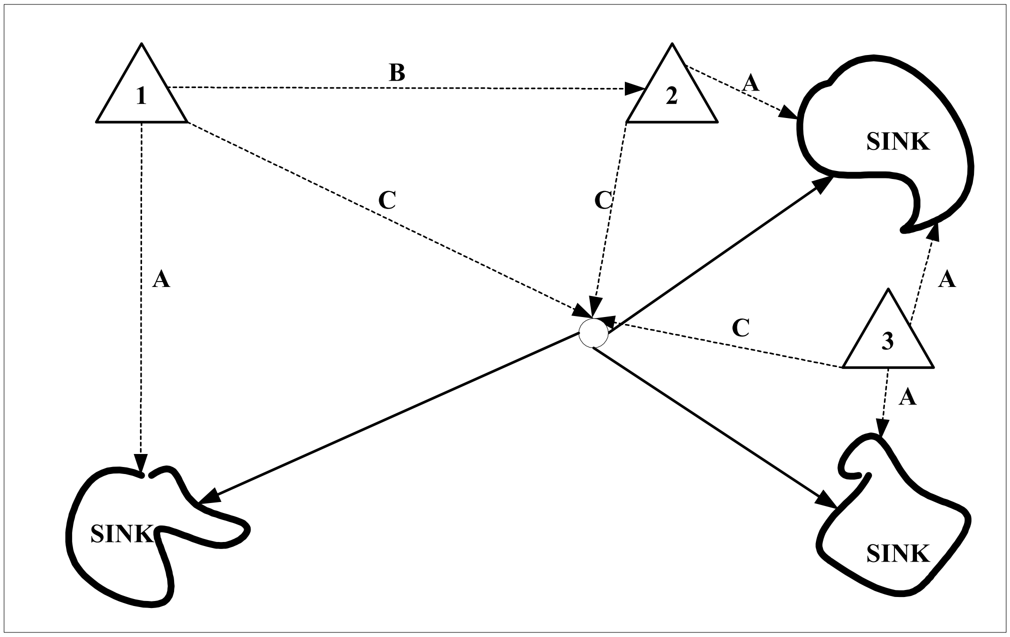


The timing issues also impact how we match CO_2 sources with carbon sequestration sinks. Take the simple example shown in Exhibit 9. There are three labeled sequestration sinks and three numbered sources. Lines show possible pipeline routes: "A" denotes the most direct line from a source to a sink. The line labeled "B" illustrates the potential route where sources 1 and 2 are combined before completing the transport to the sink. By combining sources the pipeline and right-of-way could be less expensive; in some cases combining sources may be the only way to justify a pipeline, or provide sufficient CO_2 for sequestration operations, especially if enhanced oil/gas recovery is planned.

The routes labeled "C" show a case where the three sources are combined a one point, and illustrated by the solid lines, could go to any of the sinks, or possibly some CO_2 could go to more than one sink. As the reader can envision, there are other combination possible too, and this example is only for a small set of sources and sinks.

Exhibit 9

Matching Sources and Sequestration Sinks

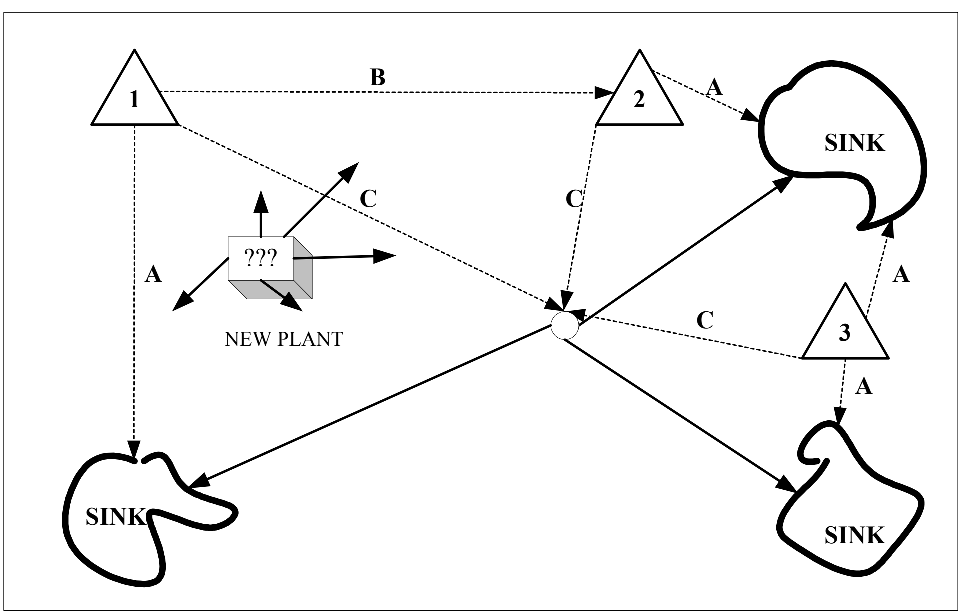


The "static" case in Exhibit 9 is complicated further as one looks in more detail at physical geography, existing infrastructure and the rules, regulations and politics that will impact each match of source and sink.

The static case becomes "dynamic" in Exhibit 10 when a new source of CO_2 is added (shown as a box). The questions that arise add another layer to the problem: Do we site the new plant adjacent to the sink (which may not be the best location for other reasons)? Should the site be selected so that existing sources can combine with the new plant for better sequestration economics? And for each of those decisions it is necessary to choose which sink, and/or which combination.

Exhibit 10

"Dynamic" Matching Scenarios



We said the decisions get complicated.

The West Coast team will examine these types of issues by developing a set of scenarios where we can roughly estimate economic and other impacts. The project scope precludes a vigorous examination of the options; so much of the evaluation will use the teams' engineering and business judgments. The judgmental nature of the preliminary decisions will benefit greatly from the number of project participants, their diverse backgrounds and ability to draw from resources at their home organizations. Hopefully, a more complete and structured procedure for evaluating options can be constructed in later phases of work, possibly for use by all the partnerships at a national level to evaluate sequestration across all the regions.

The West Coast Partnership's participants look forward to evaluation of the data, and proceeding onward to later phases of this important area of research and development.