



**WESTCOAST  
REGIONAL  
CARBON  
SEQUESTRATION  
PARTNERSHIP**  
[westcarb.org](http://westcarb.org)

## WESTCARB Phase I Results Review

### ***Regional CO<sub>2</sub> Source-Sink Matching***


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## Content

- CO<sub>2</sub> Source Analysis
- CO<sub>2</sub> Storage Capacity Estimation
- Transportation Cost Estimation
- Source-Sink Matching



**WEST COAST REGIONAL CARBON SEQUESTRATION PARTNERSHIP 2**



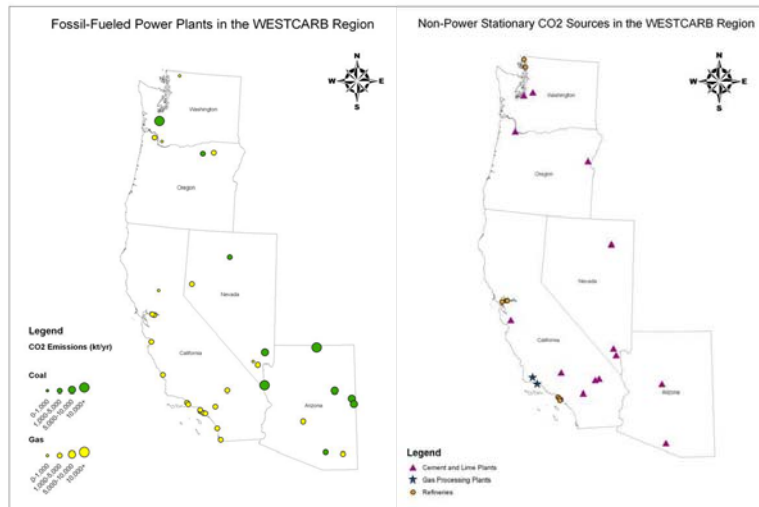
## CO<sub>2</sub> Sources

State	Power Facilities		Refineries		Cement Lime		Gas Processing	
	Facilities	CO2 Emissions (kt/yr)	Facilities	CO2 Emissions (kt/yr)	Facilities	CO2 Emissions (kt/yr)	Facilities	CO2 Emissions (kt/yr)
	#		#		#		#	
AK	6	2,289	3	2,642	0	0	3	0
AZ	9	48,070	0	0	2	1,424	0	0
CA	18	25,070	7	11,312	6	6,016	2	0
NV	5	21,960	0	0	3	0	0	0
OR	4	7,992	0	0	2	597	0	0
WA	3	12,059	3	4,046	3	774	0	0
Total	45	117,439	13	18,000	16	8,811	5	0

- Mainly power generation sources
- No data for gas processing



## CO<sub>2</sub> Sources (cont'd)



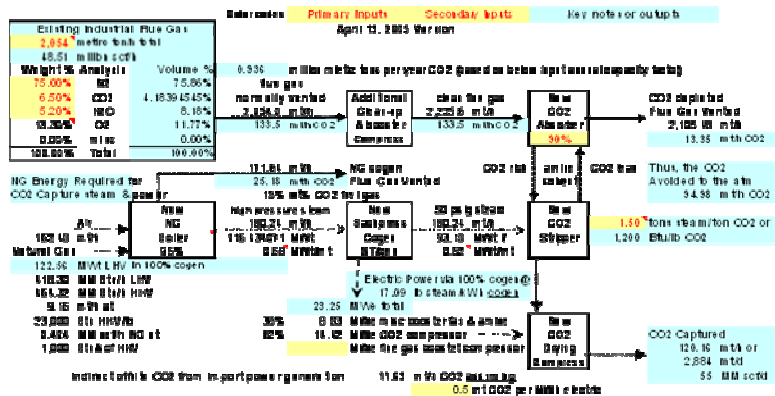
## CO<sub>2</sub> Capture Cost Estimation

- Methodology
  - “Generic CO<sub>2</sub> Capture Retrofit” spreadsheet prepared by SFA Pacific, Inc.
    - Flue gas flow rate (in metric tonnes per hour)
    - Flue gas composition (volume share or weight share of CO<sub>2</sub> in flue gas)
    - Annual load factor
- Assumption
  - Power plants, once installed with capture facility, will operate at 80% of their designed capacities

## CO<sub>2</sub> Capture Cost Estimation (cont'd)

### Generic Industrial CO<sub>2</sub> Capture for Any Large CO<sub>2</sub> Flue Gas Stream

April 2005 working draft by Chris Tombeck at SFA Pacific, Inc.  
Key assumptions in this WCI are an 80% annual capacity factor to make the system power plant for CO<sub>2</sub> capture. This includes the loss of capacity or increased CO<sub>2</sub> emissions of an existing industrial power plant. Also the high demand of low prices on shipping carbon dioxide to the CO<sub>2</sub> storage, based on an 80% capacity factor.



Note: Values shown are hypothetical

## CO<sub>2</sub> Capture Cost Estimation (cont'd)

Category	Unit Cost (\$/MWh)	Assumptions	Actual Unit Cost (\$/MWh)	Millions of \$/yr	Notes
Capital Costs	80	10% of total cost	120	3000	
N2 Oxide	\$ 15	15% of total cost	\$13	325	
Energy Storage	\$ 500	50% of total cost	\$420	10500	
Additional Storage	\$ -	0% of total cost	\$0	0	
Process Improvements	\$ 800	80% of total cost	\$672	16800	
CO2 Storage	\$ 25,000	25,000% of total cost	\$21,015	525375	
CO2 Separator	\$ 200,000	200,000% of total cost	\$168,124	4203100	
CO2 Compressor	\$ 1,000	1,000% of total cost	\$841	21025	
<b>Total process costs</b>				<b>587.7</b>	
Design Facilities		10% of process costs		58.8	20-40% typical
Eng. Fees (Design & Startup)		10% of process costs		58.8	10-20% typical
Construction		10% of process costs		58.8	10-20% typical
Working Capital, Labor & Misc.		5% of process costs		29.4	5-10% typical
<b>Total Capital Costs</b>				<b>143.7</b>	
Site specific factor	110%	of total capital cost		158.1	Costs can likely be lower than this amount
<b>Total Capital Costs</b>				<b>143.7</b>	

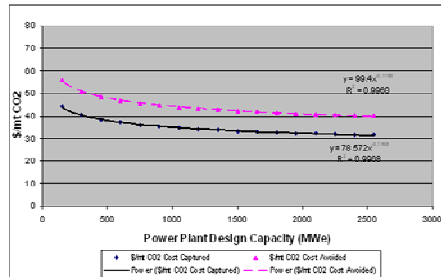
Category	Unit Cost (\$/MWh)	Assumptions	Millions of \$/yr	Net CO <sub>2</sub> Cost (\$/MWh)	Notes
Variable Costs (Energy)	8%	assumed factor	1.5	3.75	Highly sensitive to natural gas cost
Variable Costs (Maintenance)	1.6%	assumed factor	0.4	1.04	10-20% typical
Fixed Costs	\$ 5.00	100% of total cost	12.5	31.25	10-20% typical
Carbon Tax	\$ 10.00	100% of total cost	25.0	64.59	10-20% typical
<b>Total Variable Costs</b>			<b>1.9</b>	<b>4.79</b>	
<b>Total Fixed Costs</b>			<b>12.5</b>	<b>31.25</b>	
<b>Total CO<sub>2</sub> Costs</b>			<b>14.4</b>	<b>36.04</b>	

Note: Total net cost is the sum of variable and fixed costs. Net cost is the energy equivalent of the CO<sub>2</sub> capture stream of power.

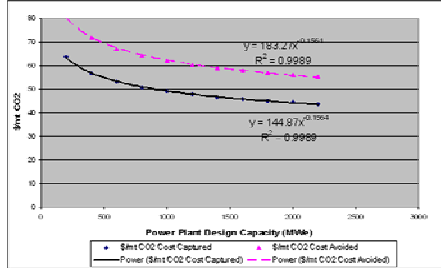
Note: Values shown are hypothetical

## CO<sub>2</sub> Capture Cost Estimation (cont'd)

Coal



Natural Gas



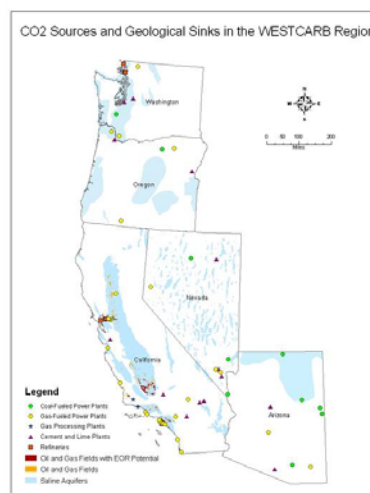
- Nat Gas @ \$5/MBtu
- No Carbon Tax

## CO<sub>2</sub> Storage Capacity Estimation

- Oil & Gas
- Saline Reservoirs



## Geological Sinks



## Storage Capacity

- For any hydrocarbon field, the CO<sub>2</sub> storage capacity is the underground volume of oil and gas that have been produced
  - Conservative but consistent method
- The storage capacity of saline reservoirs depends on the available pore volume and the CO<sub>2</sub> storage efficiency in fully water-saturated reservoirs



## Transportation Cost Estimation

- Pipeline Design Capacity
- Pipeline Diameter
- Obstacle Layers for CO<sub>2</sub> Transportation
- Pipeline Cost



## Pipeline Design Capacity

- For refineries and cement and lime plants, pipeline design capacity equals the 2002 CO<sub>2</sub> emission multiplied by a default capture efficiency (90%)
- For power plants, the designed pipeline capacity is calculated as following:

$$VC_{CO_2} = \frac{VE_{CO_2}^{2002}}{OE^{2002}} * CE_0$$

where

- $VC_{CO_2}$  = Annual captured CO<sub>2</sub> flow (ton)
- $VE_{CO_2}^{2002}$  = 2002 annual CO<sub>2</sub> emission (ton)
- $OE^{2002}$  = 2002 plant operating factor
- $CE_0$  = Default CO<sub>2</sub> capture efficiency (90%)



## Pipeline Diameter Calculation

- Assumes that standard pipelines in the gas industry will be used in CO<sub>2</sub> transportation. The pipeline diameter increases in 4 inch increments (after 4, 6, and 8 inches).

Pipeline Diameter (inch)	CO <sub>2</sub> Flow Rate (Mt/yr)	
	lower bound	upper bound
4		0.19
6	0.19	0.54
8	0.54	1.13
12	1.13	3.25
16	3.25	6.86
20	6.86	12.26
24	12.26	19.69
30	19.69	35.16
36	35.16	56.46



## Crossing Cost Factor

**Estimated Relative Crossing Cost Factor**

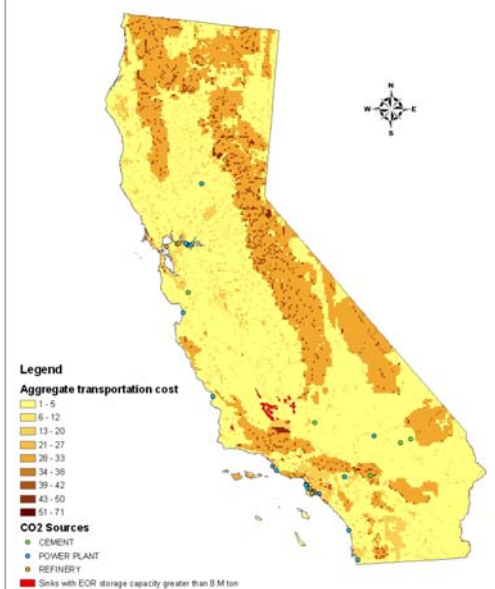
Construction Condition	Cost Factor
Base Case	1
Slope	
10-20%	0.1
20-30%	0.4
>30%	0.8
Protected Area	
Populated Place	15
Wetland	15
National Park	30
State Park	15
Crossing	
Waterway Crossing	10
Railroad Crossing	3
Highway Crossing	3



## Aggregate Crossing Cost Factor Calculation Example

**Aggregate Crossing Cost Factor = 1 (base case)**  
 + Slope factor  
 + Populated area\*15  
 + Wetland\*15  
 + National Park\*30  
 + State Park\*15  
 + Waterway\*10  
 + Railroad\*3  
 + Highway\*3

Aggregate Transportation Cost (Ratio to the Base Case)



## Transportation Cost Calculation

- Base Case Construction Cost
  - The base case pipeline construction cost is estimated to be \$12,000/in/km
- Crossing Cost
  - The obstacle crossing cost is calculated as the product of the relative weight and the base case construction cost for an 8 inch pipeline, but is assumed to be the same for pipelines of any diameter
- Operation and Management Cost
  - The O&M cost is estimated to be \$3,100/km per year, independent of pipeline diameter



## Source-Sink Matching

- Distance-Based Source-Sink Matching
- California Study
  - Full-Cost
  - Optimized Transportation
  - Storage Cost
    - For EOR Uses, EOR Credit
    - For Saline Reservoir Uses, Costs Developed by DOE/EPRI/TVA



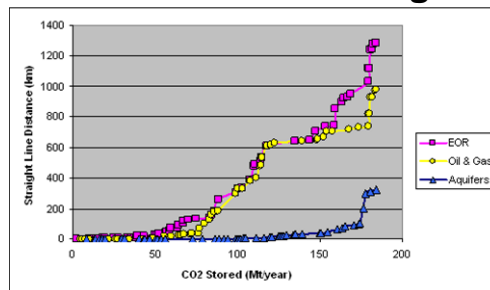
## Distance Based Source-Sink Matching

- For all sinks and sources in region
- Straight line matching
- Sink capacity constraint is not considered
- Gives a sense of minimum transport costs where the geological information is not sufficient to do a full cost evaluation

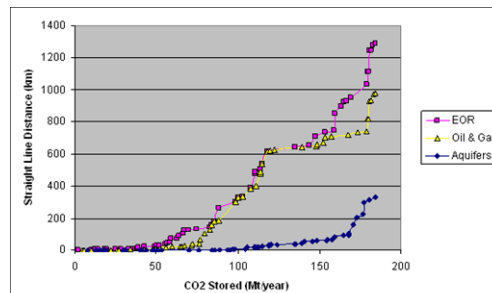


## Distance Based Source-Sink Matching (cont'd)

*With  
Nevada  
reservoirs*



*Without  
Nevada  
reservoirs*



## California Study

- For sinks and sources in California only
- Least-cost path matching
- Sink capacity constraint is considered
- Transportation obstacle layers are applied
- A cost allocation iteration is used for source-sink matching



## Fields Classification

- Oil fields are classified into five categories
  - Fields with miscible CO<sub>2</sub>-EOR potential (depth >3000 feet, API>25)
  - Fields with immiscible CO<sub>2</sub>-EOR potential (depth >3000 feet, 17.5<API<25)
  - Fields with CO<sub>2</sub> storage potential but no EOR potential (depth >3000 feet, API<17.5)
  - Fields without CO<sub>2</sub> storage (depth <3000 feet)
  - Fields undetermined (depth or API missing)
- Gas fields are classified into three categories
  - Fields with CO<sub>2</sub> storage potential (depth >3000 feet)
  - Fields without CO<sub>2</sub> storage potential (depth <3000 feet)
  - Fields undetermined (depth missing)



## CO<sub>2</sub> Sinks with EOR Potential

- Miscible Application of CO<sub>2</sub>-EOR
  - Number of Fields: 124
  - Total Storage Capacity: 3284 Mtons (preliminary estimate)
- Immiscible Application of CO<sub>2</sub>-EOR
  - Number of Fields: 20
  - Total Storage Capacity: 176 Mtons (preliminary estimate)



## Sources and Sinks in Matching

- 32 Sources
- 55 Sinks with EOR storage capacity greater than 8 million tons



## Work Flow

- Standard Iteration
  - Doing cost allocation with the sink layer
  - Get the least cost paths for each source to the corresponding sink
  - Calculate the aggregate in-flow CO<sub>2</sub> for each sink, comparing with its storage capacity
  - If none of the sinks is overflowed – **DONE!** Exit the iteration.



## Work Flow (cont'd)

- If a sink is overflowed, exclude sources based on their distances to the sink, until remaining CO<sub>2</sub> in-flow is less than the storage capacity. Further sources will be excluded earlier.
- Set the new source layer as all excluded sources in the above step
- Set the new sink layer as all the sinks with remaining storage capacity
- Start next iteration with the new source layer and new sink layer

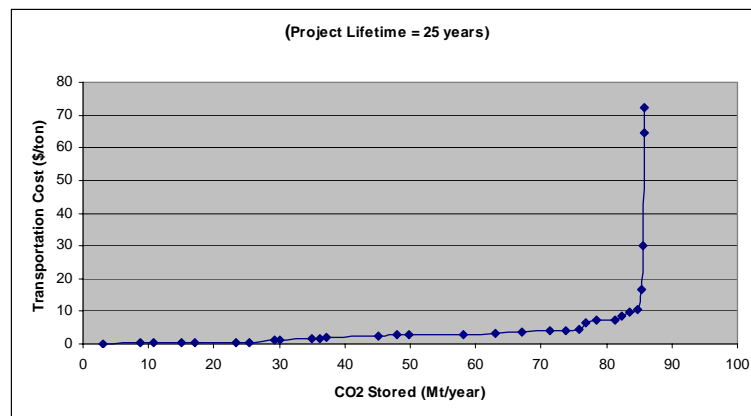


## Application

- First of 8 Iterations



## Marginal Transportation Cost by Annual CO<sub>2</sub> Storage Rate in California EOR Oil Fields



## Supply Curves for Capture and Geologic Storage Assume Present-Day Conditions

California Marginal Cost by CO<sub>2</sub> Storage Rate

