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Clean Coal and Carbon Sequestration For Bernie Zak Visitor May 28, 2008

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What is Clean Coal

- Air Emissions
  - SO_2
  - NO_x
  - Particulate
  - Hg
- CO_2 Management
- By-Product Utilization
- Water Use and Discharge
- Plant Efficiency
- Reliability/Availability
- Capital and Product Cost
  - (power and fuels production)

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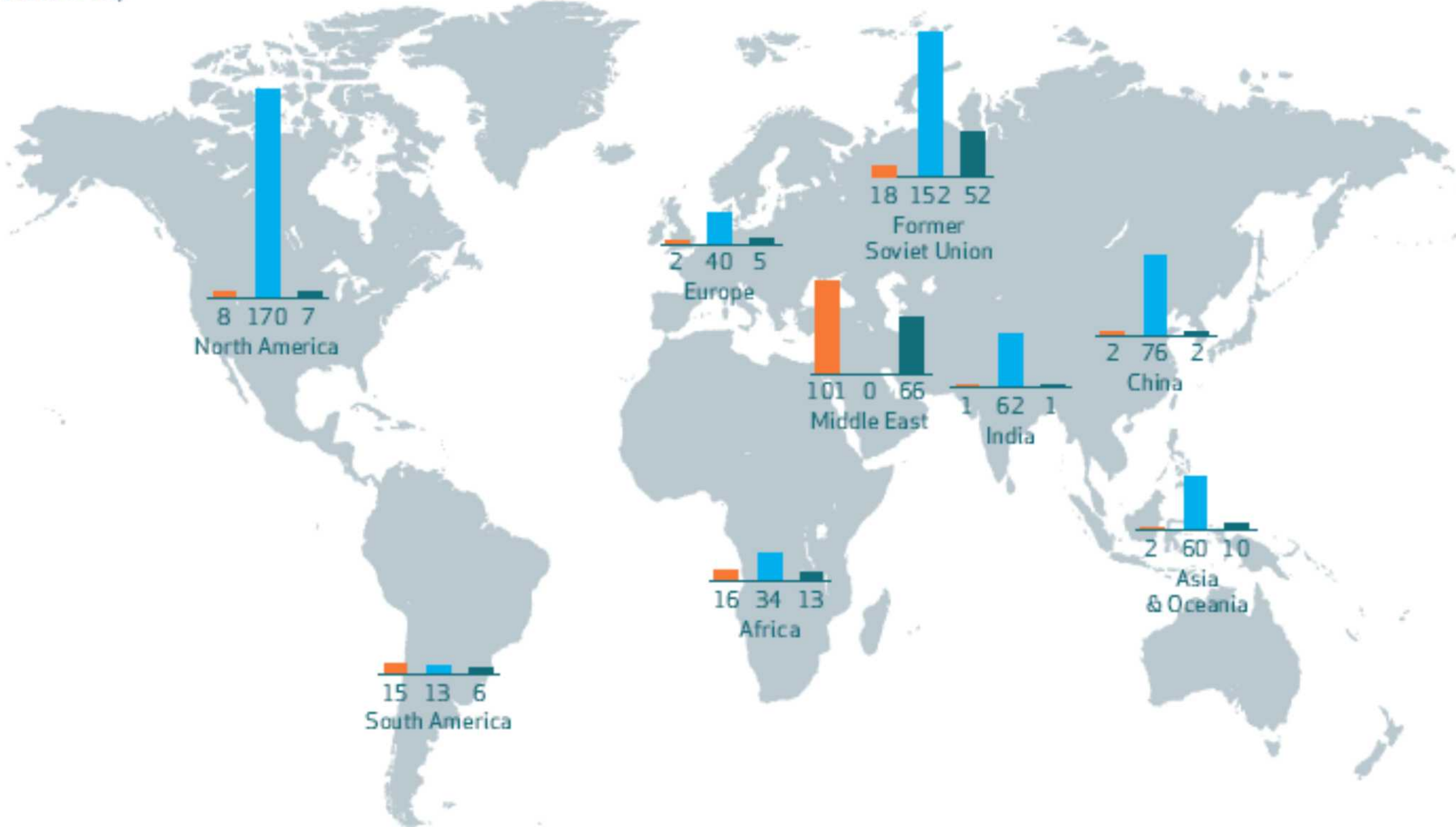
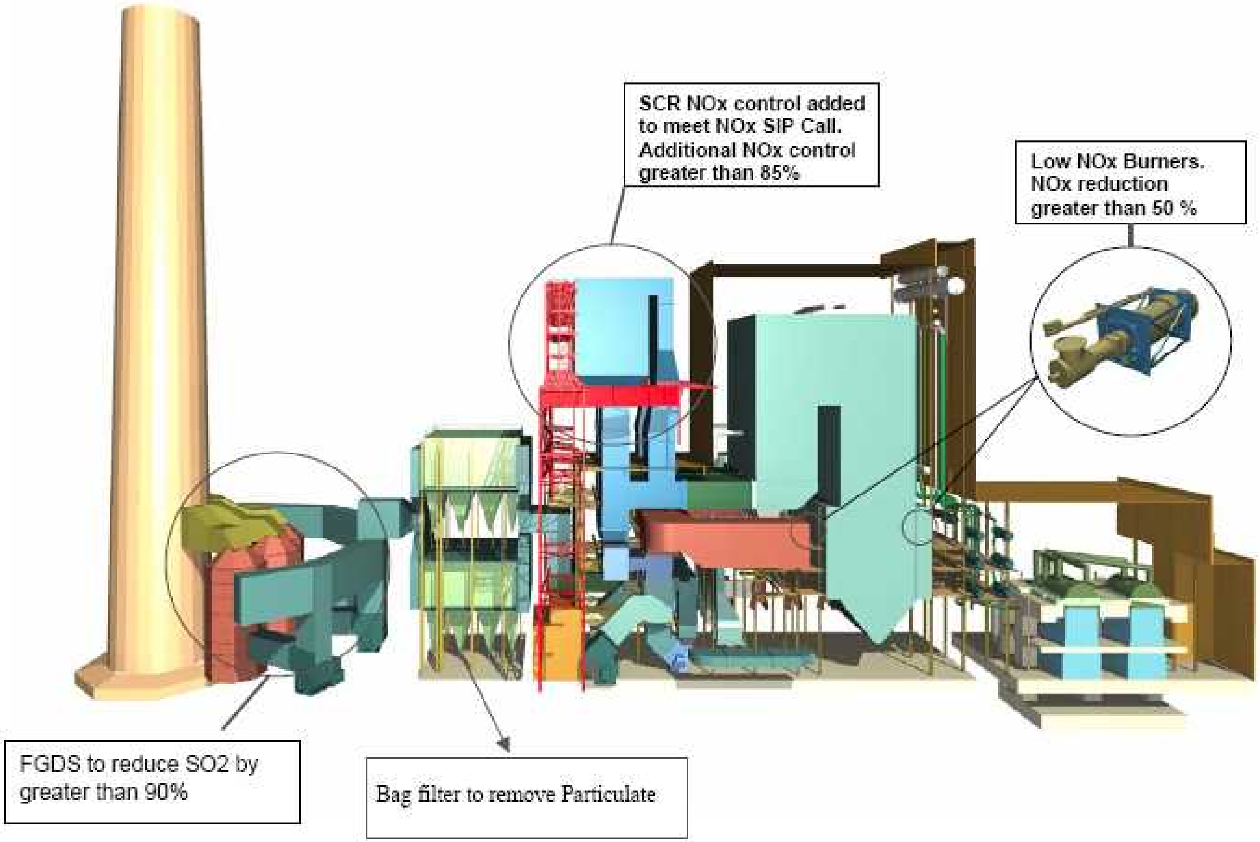
Figure 2: Location of the World's Main Fossil Fuel Reserves (Gigatonnes of oil equivalent)

- Oil
- Coal
- Gas

Source: BP 2007

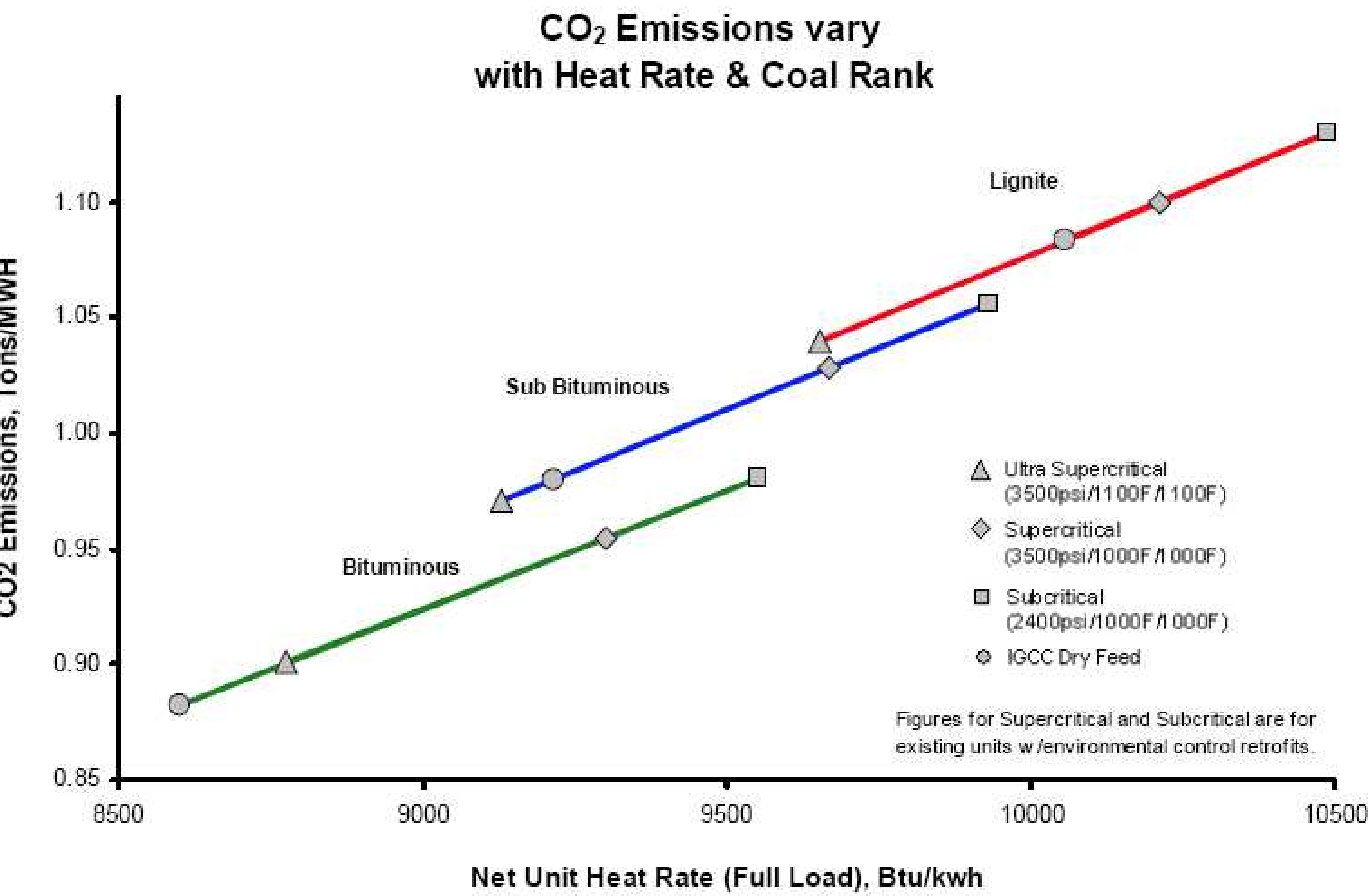


Modern



SCR NOx control added to meet NOx SIP Call. Additional NOx control greater than 85%
Low NOx Burners. NOx reduction greater than 50 %
FGDS to reduce SO2 by greater than 90%
Bag filter to remove Particulate

Efficiency and CO_2 Emissions Comparison



Power Plant Efficiencies by Type

Table 9: Average Efficiency Levels at Pulverised Coal-fired Power Plants

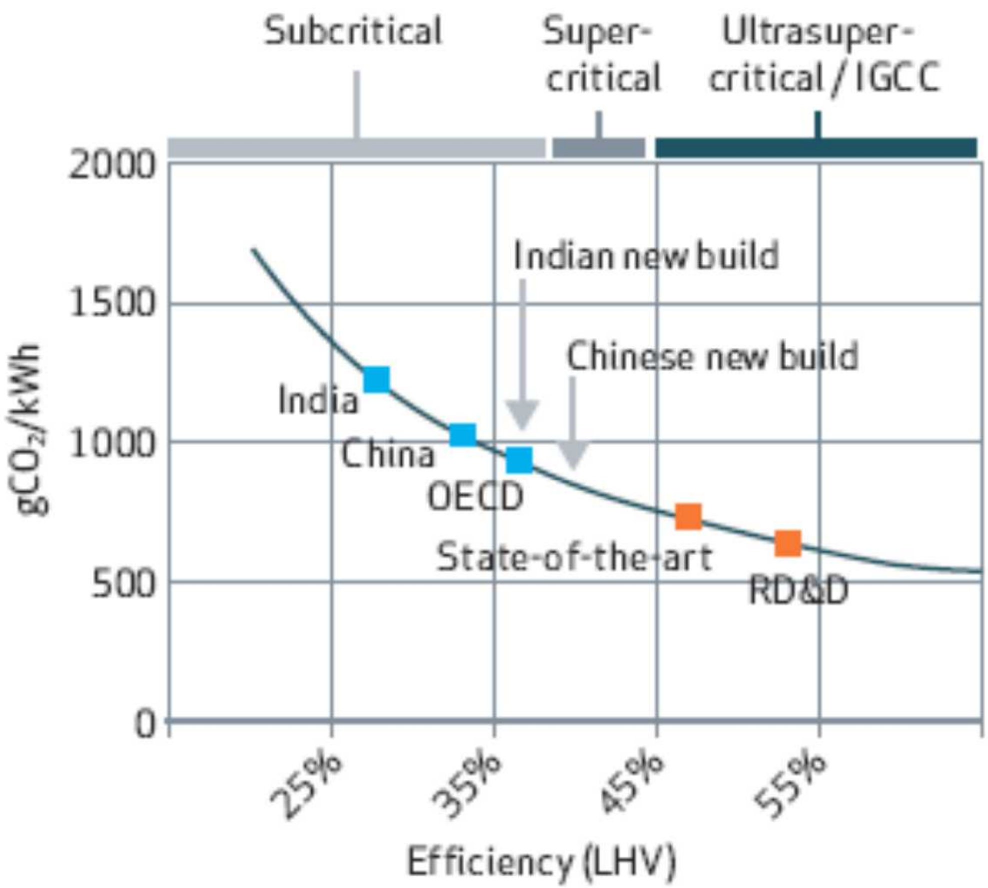
Plant	Low Efficiency	Higher Efficiency	Supercritical	Ultra-supercritical
Average Efficiency Levels:	29%	39%	Up to 46%	50-55%

Source: Doosan Babcock

Figure 5: CO_2 Emissions from Coal-fired Power Plants

- Fleet averages
- Single plants

Source: IEA 2006c



Low Emission Levels - Achieved by High Steam Parameters and Flue Gas Cleaning

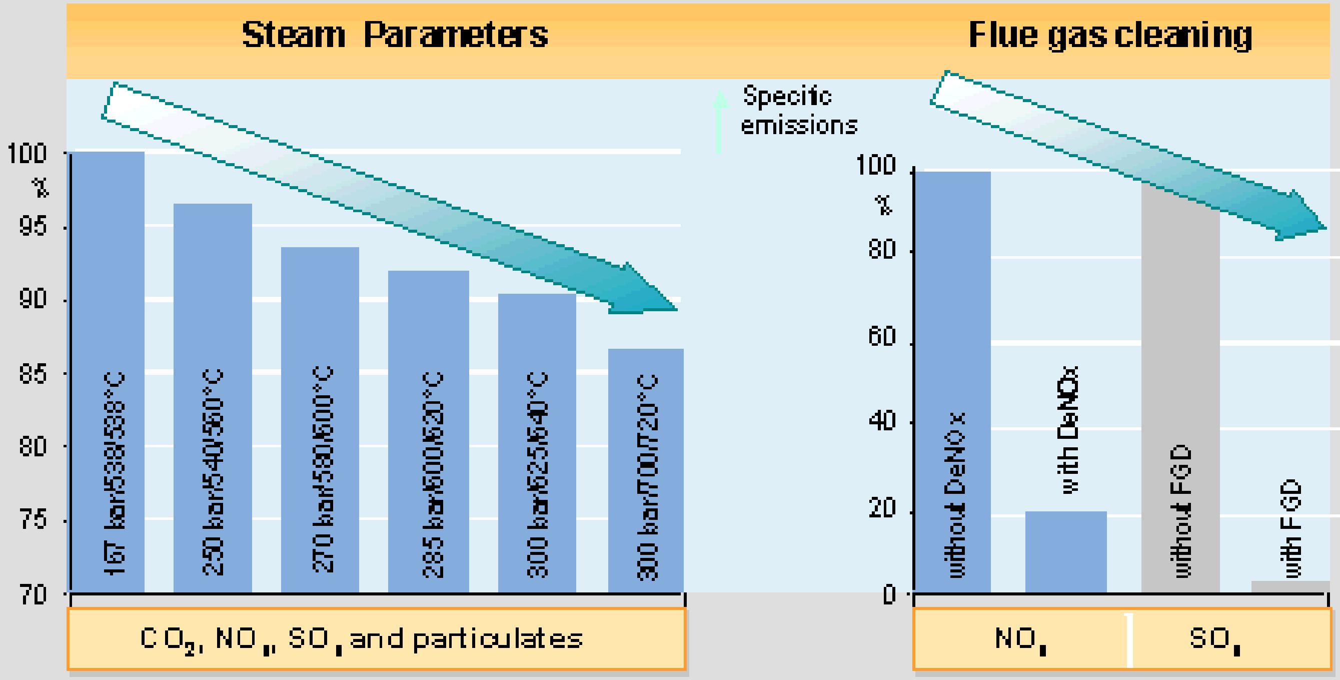
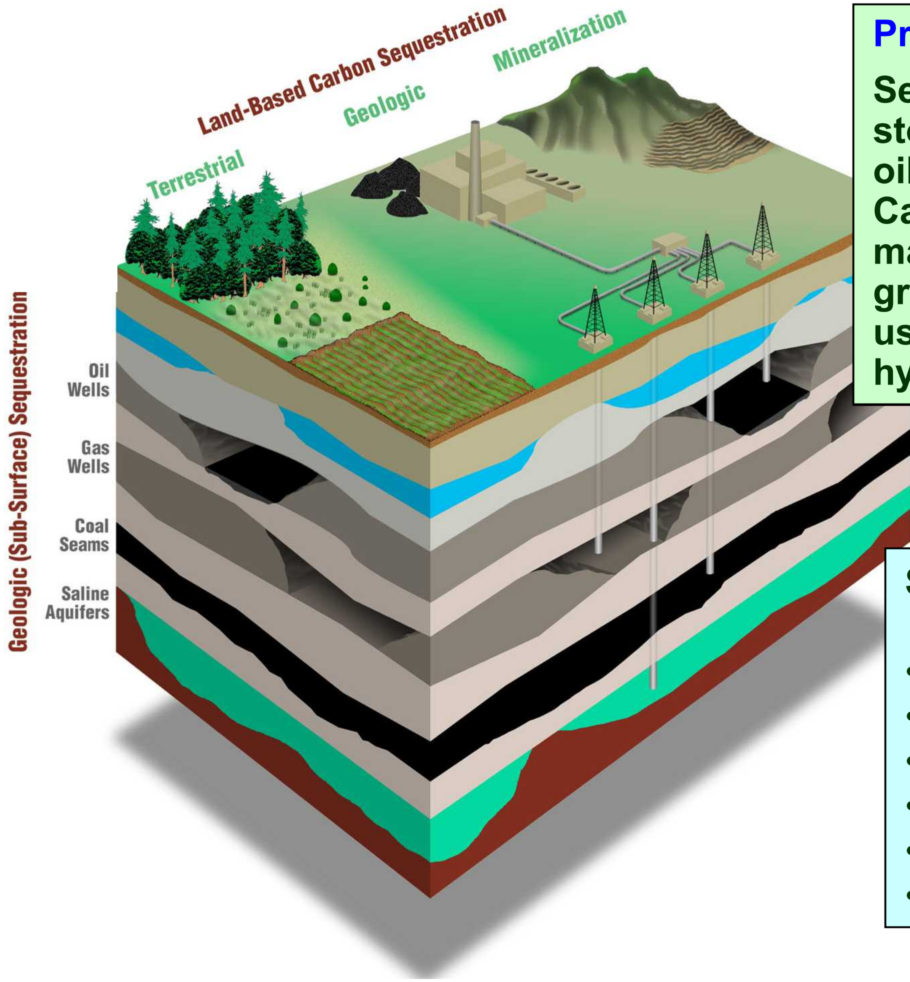


Figure 1

Carbon Sequestration



Problem Description:

Sequestration is the capture and storage of CO_2 from the combustion of oil, natural gas, coal and biomass. Carbon sequestration could play a major role in the reduction of greenhouse gases through increased use of clean coal, natural gas and hydrogen

Sequestration Capacity:
Herzog (MIT)

- **Oceans 1000s Gt,**
- **Deep saline aquifers 100s to 1000s Gt**
- **Depleted oil and gas reservoirs 100s Gt**
- **Coal Seams 10s to 100s Gt**
- **Terrestrial (e.g., trees and soils) 10s Gt**
- **Reuse <1Gt/yr.**

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Full Scale Projects

- Demonstrated on a full scale by the Alberta Energy Board in the 1980's at the Sunshine and Boundary Dam PC plants
- Combined Cycle Natural Gas Plants for Power and CO2 for Enhanced Oil Recovery, Scotland and North Africa, inititiated by BP

Major Issues for Sequestration

- Parasitic Losses
  - 10 existing PC (pulverized coal) coal plants with sequestration added will need 4 additional plants installed
  - 10 existing Natural Gas plants with sequestration added will need 2 additional plants installed
- How will sequestration be regulated?
- Can projected sequestration capacities be achieved?
- Can separation and capture costs be reduced by a factor of 10?

General Map of Sources and Pipelines

- *electrical power plants*
- *cement & other plants*
- *urban centers*
- *non-point sources (agriculture, automobiles, etc.)*

Total regional point source emissions ~10^8 t/yr.

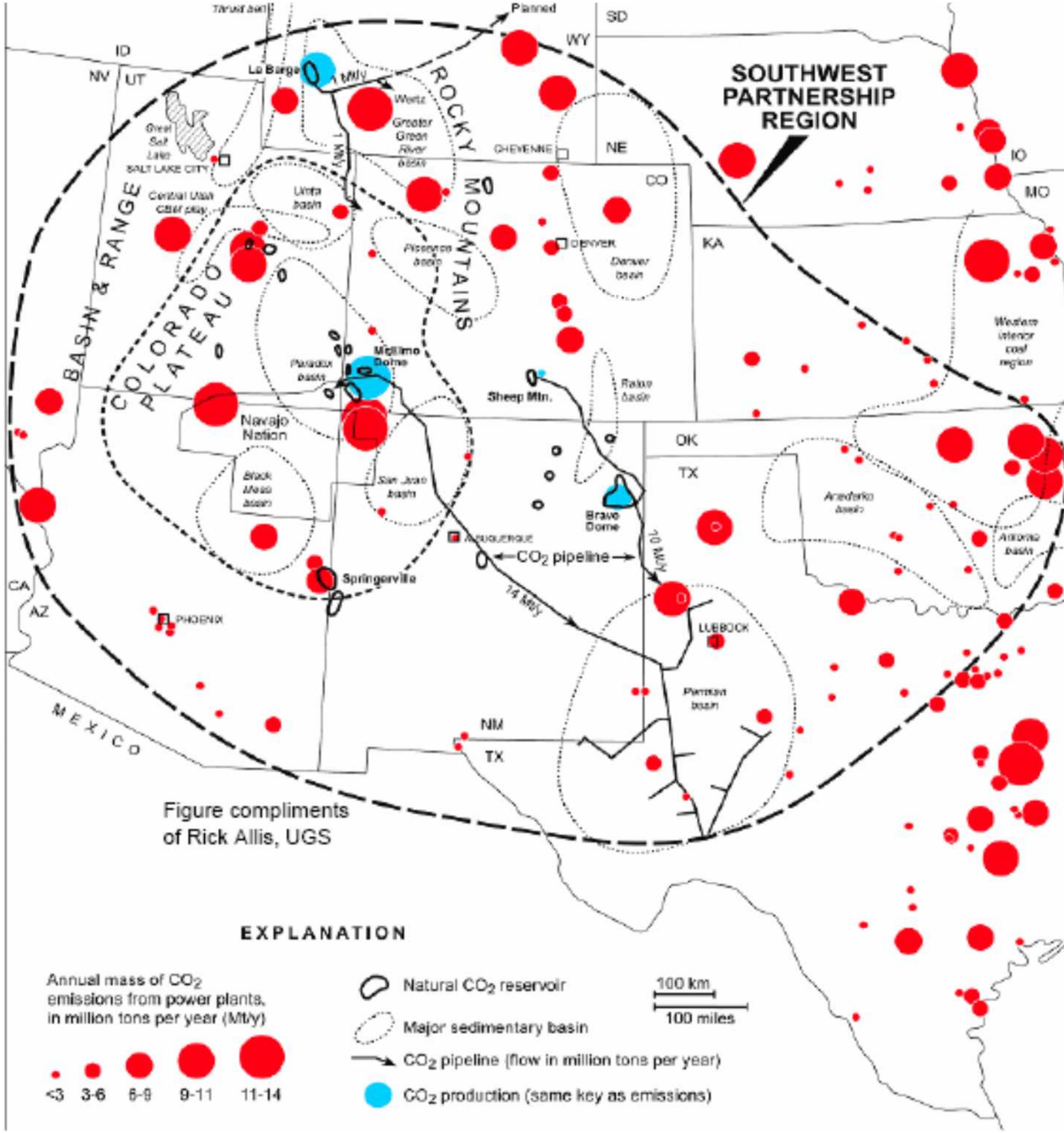


Figure compliments of Rick Allis, UGS

Carbon Sequestration Technologies Will Add Costs to Fossil Fuels But Are Feasible

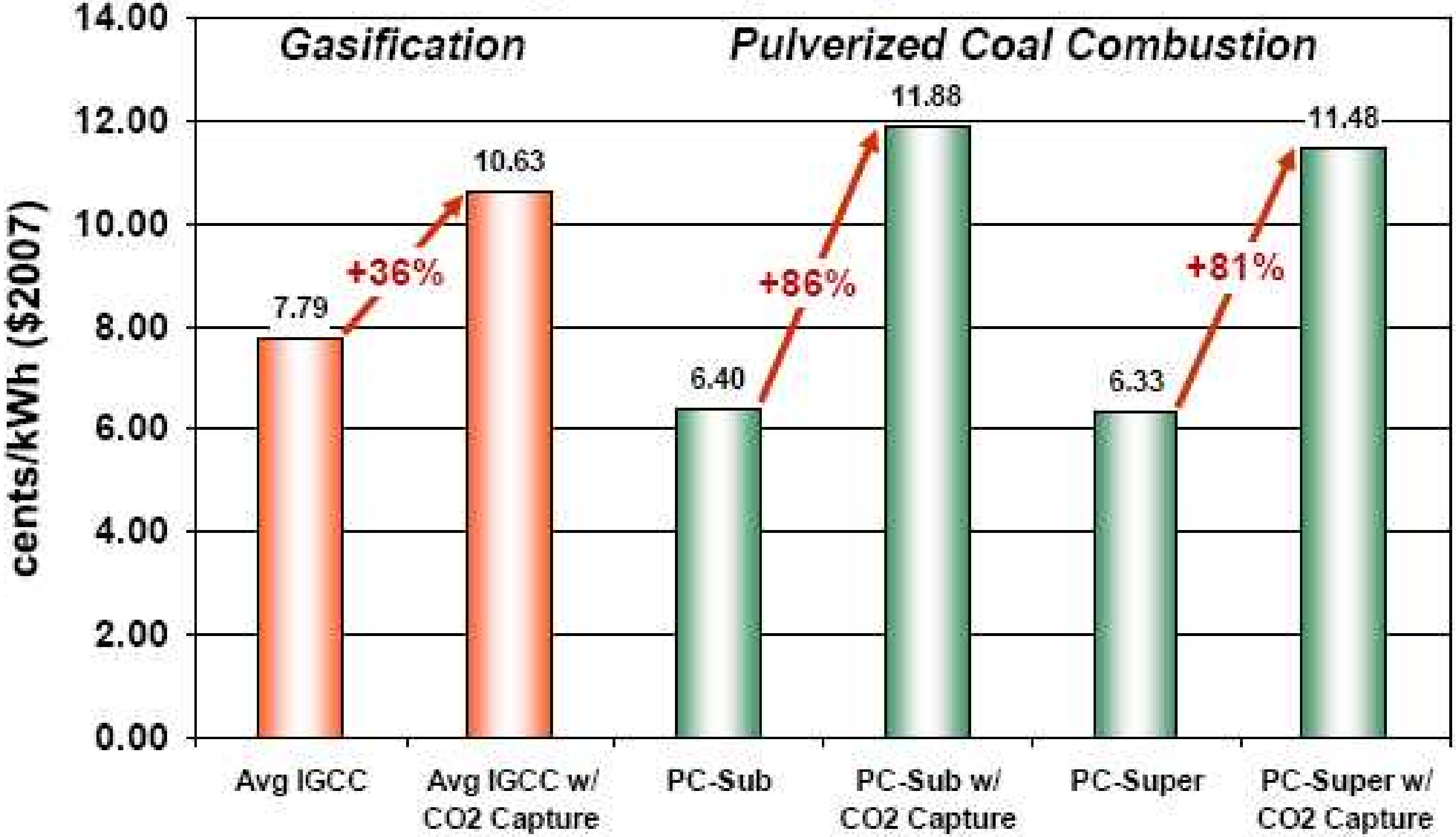
Electricity Cost Without/With Carbon Sequestration

Power Plant Systems	Natural Gas Combined Cycle (US$/kWh)	Pulverized Coal (US$/kWh)	Integrated Gasification Combined Cycle (US$/kWh)
Without Capture (Reference Plant)	.03 - .05	.04 -.05	.04 -.06
With Capture and Geological Storage	.04 - .08	.06 - .10	.05 - .09
With Capture and EOR	.04 - .07	.05 - .08	.04 - .07

Source: IPCC Special Report on Carbon Dioxide Capture and Storage, Summary for Policymakers, September 25th 2005. Table S. 3.

Capturing CO_2 with Today's Technology is Expensive

Cost of Electricity Comparison



January 2007 Dollars, Coal cost $1.80/10^6 Btu

DOE/NETL Report: "Cost and Performance Baseline for Fossil Energy Plants", May 2007

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Supply Side Options Available for IRP

Options	Option Size MW	Capital Costs $/kW	Includes a 10% Process Contingency	Capacity Factor %	2008 Fuel Price $/mmBtu	Heatrate Btu/kWhr	Levelized Capital $/MWhr	2008 O&M $/MWhr	2008 Fuel $/MWhr	Total** $/MWhr
COAL										
Pulverized Coal	200	2,065	no	85%	2.20	8,990	33	8	20	61
IGCC***	200	3,387	yes	85%	2.20	8,221	55	12	18	85
Pulverized Coal (with CO_2 removal)	200	3,240	no	85%	2.20	10,939	52	10	24	86
IGCC*** (with CO_2 removal)	200	4,172	yes	85%	2.20	10,830	67	14	24	105
NATURAL GAS (all combustion turbines technologies are derated for an elevation of 4,500 feet)										
Aeroderivative	40	1,014	no	15%	7.00	9,800	88	15	69	171
Combustion Turbine	81	963	no	15%	7.00	9,336	83	10	65	158
Combustion Turbine	150	563	no	15%	7.00	10,297	49	10	72	132
Combined Cycle (1x1)	240	1,002	no	40%	7.00	7,114	34	7	50	91
Combined Cycle (2x1)	480	936	no	40%	7.00	7,175	32	7	50	90
OTHER										
Nuclear	200	2,958	yes	85%	0.48	10,510	48	18	5	71
Wind	100	1,933	no	33%		N/A	77	9		86
Solar - Parabolic Trough (solar only)	100	3,990	yes	23%		N/A	191	28		219
Solar - Photovoltaic (two axis tracking)	50	5,000	no	25%		N/A	221	8		229
Biomass	25	3,251	no	85%	2.00	13,864	53	22	28	102
Geothermal *****	24	2,340	no	85%		29,050	39	7	0	46
STORAGE										
Compressed Air Energy	100	1,320	yes	30%	7.00	4,500	61	12	32	104

Costs are derived from EPRI TAG which have been modified to fit PNM financial assumptions and site conditions. Not included are site specific owners costs such as water acquisition, site development, transmission infrastructure upgrades, community outreach costs and fuel infrastructure which may vary sigificantly depending upon site location. O&M estimates are derived from Cummins & Barnard Cost Estimates Study for combustion turbine technologies.

***Levelized costs for solar includes 10% federal ITC, 6% state ITC, 5 years accelerated depreciation, 1st year state PTC; for wind total costs include 1st year federal PTC;*

****IGCC costs have been modified to account for elevation effects at 4,500 feet.*

***** Options with carbon removal do not include sequestration, estimated to be $10/MWh adder*

****** Represents maximum potential, smaller projects may be feasible*

DRAFT - Updated 1/15/08

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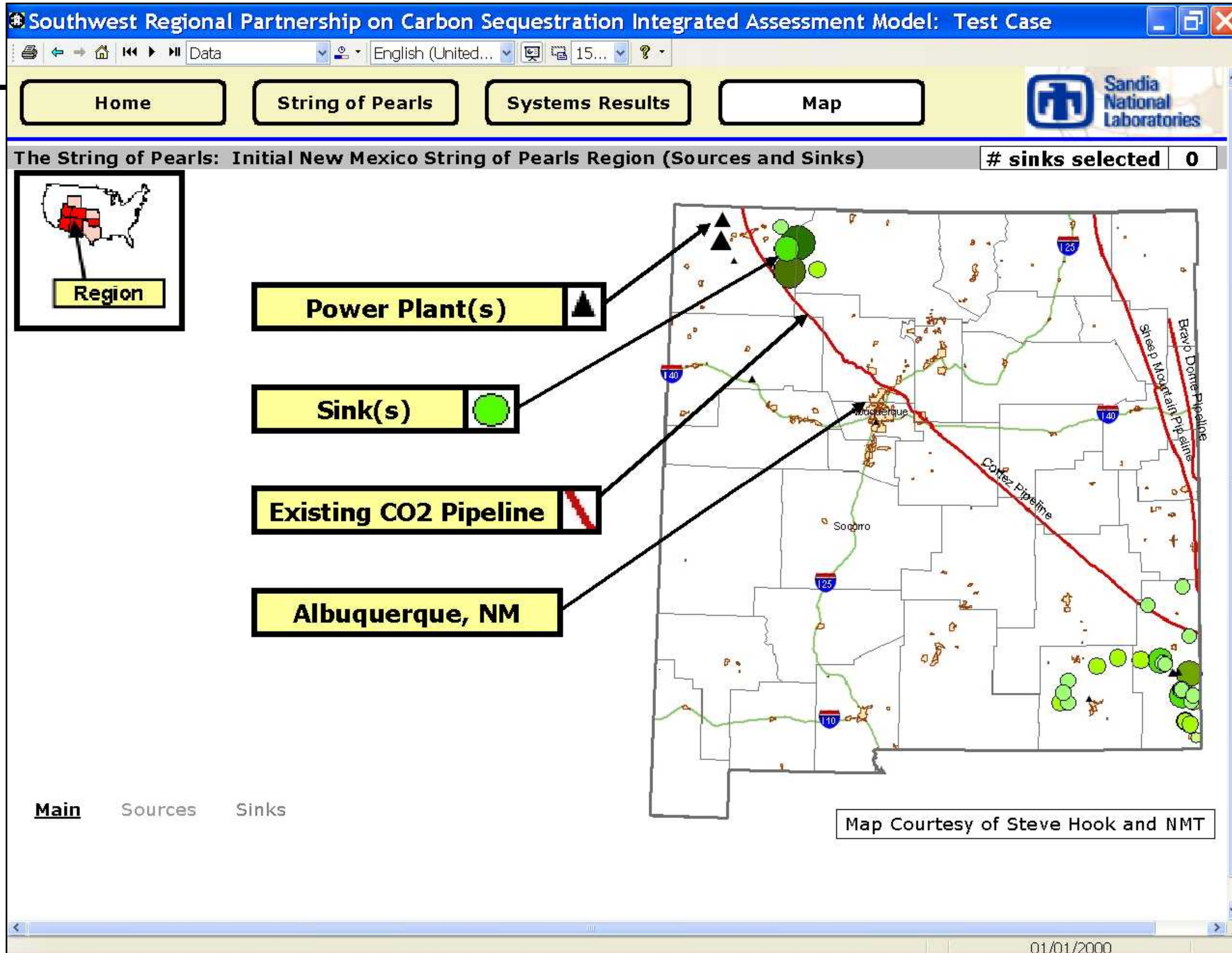
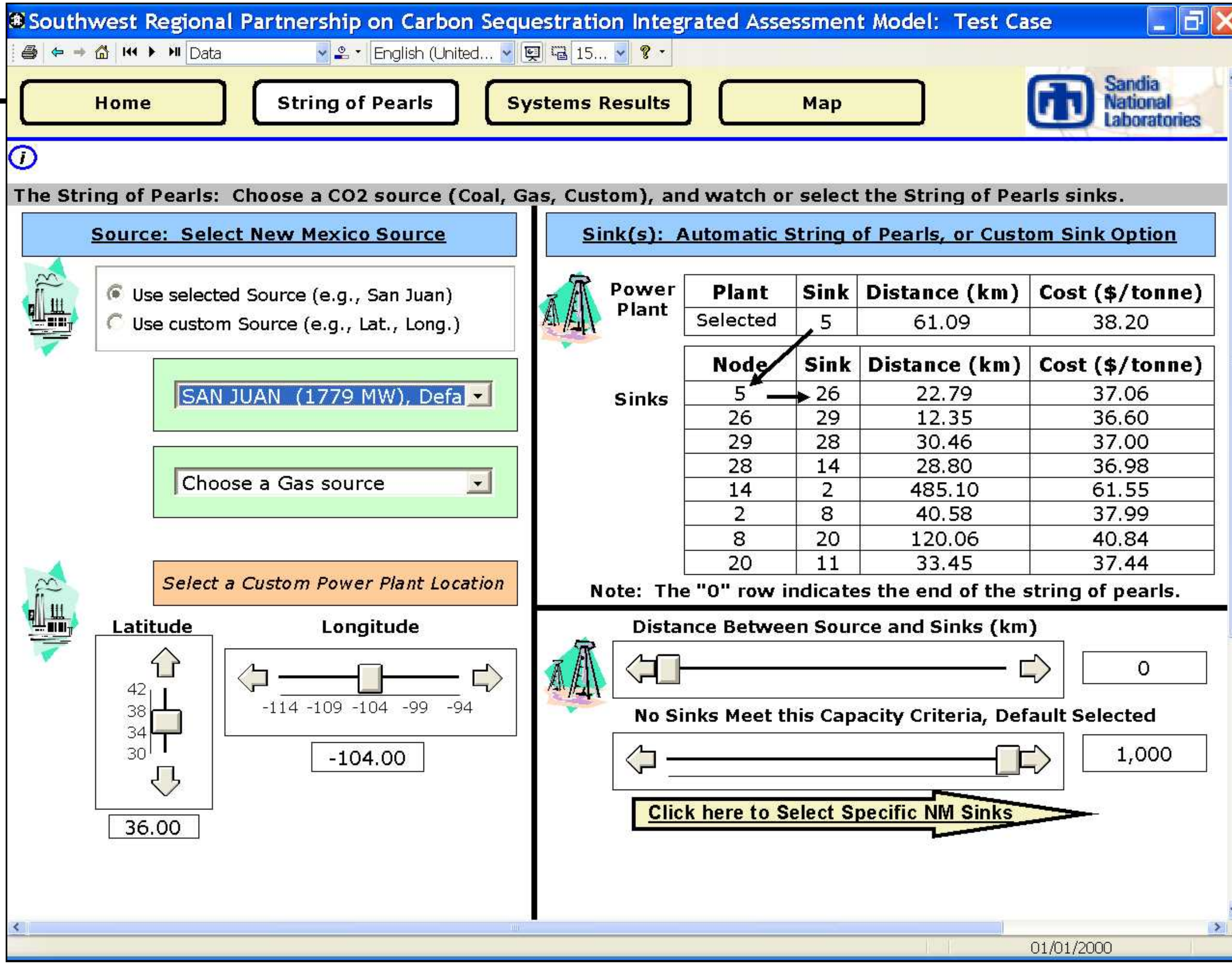

Southwest Regional Partnership on Carbon Sequestration Integrated Assessment Model: Test Case
Data
English (United...
15...
Home
String of Pearls
Systems Results
Map
Sandia National Laboratories
The String of Pearls: Initial New Mexico String of Pearls Region (Sources and Sinks)
sinks selected
0
Region
Power Plant(s)
Sink(s)
Existing CO2 Pipeline
Albuquerque, NM
Sheep Mountain Pipeline
Bravo Dome Pipeline
Cortez Pipeline
Socorro
Main
Sources
Sinks
Map Courtesy of Steve Hook and NMT
01/01/2000


Southwest Regional Partnership on Carbon Sequestration Integrated Assessment Model: Test Case
Data
English (United...
15...
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String of Pearls
Systems Results
Map
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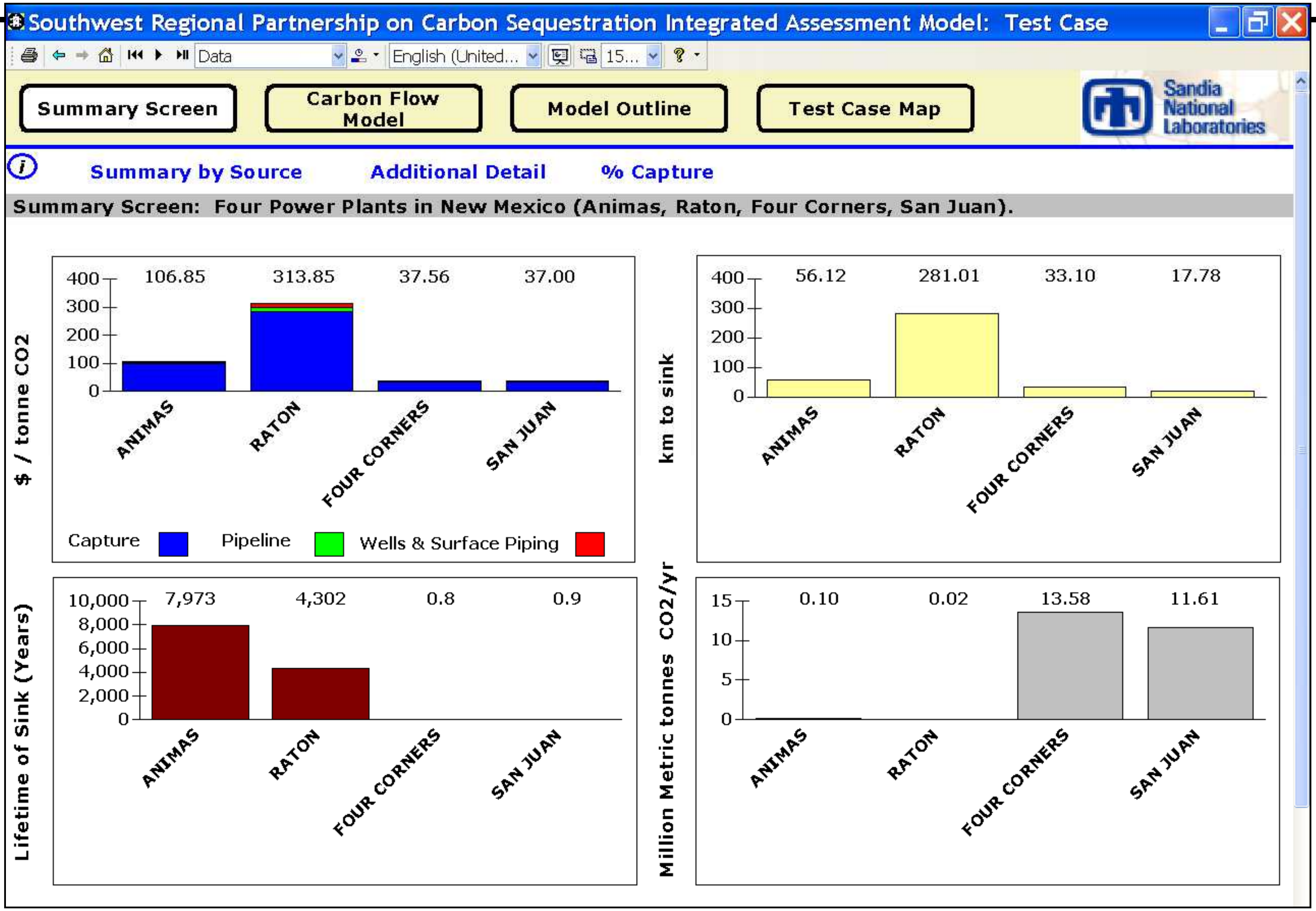
The String of Pearls: Choose a CO2 source (Coal, Gas, Custom), and watch or select the String of Pearls sinks.
Source: Select New Mexico Source
Use selected Source (e.g., San Juan)
Use custom Source (e.g., Lat., Long.)
SAN JUAN (1779 MW), Defa
Choose a Gas source
Select a Custom Power Plant Location
Latitude
42
38
34
30
36.00
Longitude
-114 -109 -104 -99 -94
-104.00
Sink(s): Automatic String of Pearls, or Custom Sink Option
Power Plant
Plant | Sink | Distance (km) | Cost ($/tonne)
Selected | 5 | 61.09 | 38.20
Sinks
Node | Sink | Distance (km) | Cost ($/tonne)
5 | 26 | 22.79 | 37.06
26 | 29 | 12.35 | 36.60
29 | 28 | 30.46 | 37.00
28 | 14 | 28.80 | 36.98
14 | 2 | 485.10 | 61.55
2 | 8 | 40.58 | 37.99
8 | 20 | 120.06 | 40.84
20 | 11 | 33.45 | 37.44
Note: The "0" row indicates the end of the string of pearls.
Distance Between Source and Sinks (km)
0
No Sinks Meet this Capacity Criteria, Default Selected
1,000
Click here to Select Specific NM Sinks
01/01/2000


Southwest Regional Partnership on Carbon Sequestration Integrated Assessment Model: Test Case
Summary Screen
Carbon Flow Model
Model Outline
Test Case Map
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Summary by Source
Additional Detail
% Capture
Summary Screen: Four Power Plants in New Mexico (Animas, Raton, Four Corners, San Juan).
$ / tonne CO2
106.85
313.85
37.56
37.00
ANIMAS
RATON
FOUR CORNERS
SAN JUAN
Capture
Pipeline
Wells & Surface Piping
km to sink
56.12
281.01
33.10
17.78
Lifetime of Sink (Years)
7,973
4,302
0.8
0.9
Million Metric tonnes CO2/yr
0.10
0.02
13.58
11.61

Changes in U.S. Primary Energy Consumption by Fuel Across Stabilization Scenarios, Relative to Reference Scenarios (EJ/yr).