Advances in CO_2 Capture Technologies

Presentation at the

CEC Staff Workshop on CO_2 Capture and Geologic Storage - 2009 Integrated Energy Policy Report (IEPR)

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by

Dale Simbeck
Vice President Technology
SFA Pacific, Inc.

444 Castro Street, Suite 720
Mountain View
California 94041

phone: 1-650-969-8876
fax: 1-650-969-1317
internet: www.sfapacific.com

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Presentation Overview

Quick background of SFA Pacific work on CO_2 mitigation

Quick background of CO_2 sources by sector and fuel

Why the CO_2 capture & storage (CCS) option will likely be important if CA is to meet its ambitious CO_2 reduction goals

Summary of current CO_2 capture technologies

- Pre-combustion
- Post-combustion
- Oxygen-combustion

Advanced CO_2 capture developments

General costs of CCS

CCS applications, projects and developments relative to CA

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SFA Pacific's Background on CO_2 Mitigation

1989: CO_2 Capture analysis for EPRI

1994: Consultant for China's National Response Strategy on Global Climate Change

2001: Private Multiclient Analysis of CO_2 Mitigation Options

2002-2009: Advisory Board to the CO_2 Capture Project - CCP

2003-2005: Lead author of the UN IPCC Special Report on CO_2 Capture & Geologic Storage – part of 2007 Nobel Peace Prize

2007: CCS economics for Canada's Government & Industry Expert Economic and Policy Working Group

2008: New plant CCS economics for the Business Roundtable

2009: Existing coal power plant retrofit CCS economics for MIT

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CO_2 Mitigation Options

Current fossil fuel CO_2 emissions of 30 Gt/yr - most effective to analyze via the famous *Kaya Identity* where CO_2 emissions =

people x GDP/person x energy/unit GDP x CO_2/unit energy

Thereby only four basic options to impact our CO_2 emissions:

- Population (number of people)
- Standard of living (GDP/person)
- Energy intensity (energy/unit of GDP)
- Carbon intensity (CO_2/unit energy)

Any meaningful worldwide CO_2 reduction requires focus on carbon intensity and energy intensity in the USA & China

- USA - 20% of world man-made CO_2, however, also 20% of world GDP
- China - appears to have passed the USA in CO_2 emissions in 2007

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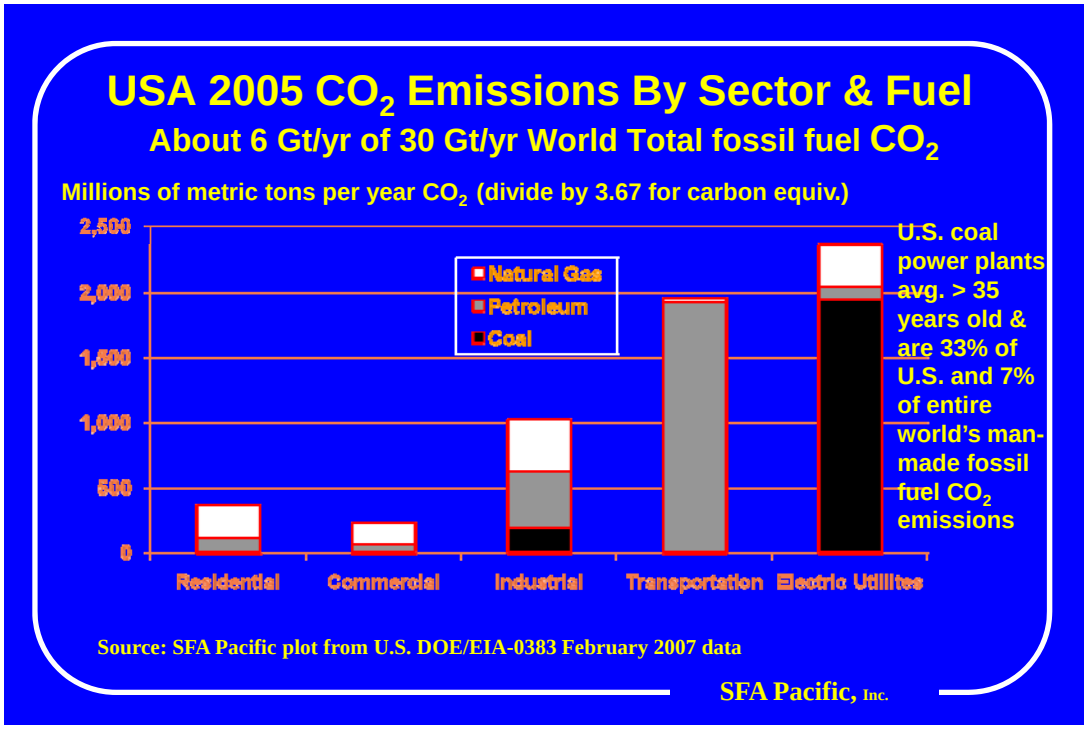
USA 2005 CO_2 Emissions By Sector & Fuel
About 6 Gt/yr of 30 Gt/yr World Total fossil fuel CO_2
Millions of metric tons per year CO_2 (divide by 3.67 for carbon equiv.)
2,500
2,000
1,500
1,000
500
0
Natural Gas
Petroleum
Coal
Residential
Commercial
Industrial
Transportation
Electric Utilities
U.S. coal power plants avg. > 35 years old & are 33% of U.S. and 7% of entire world's man-made fossil fuel CO_2 emissions
Source: SFA Pacific plot from U.S. DOE/EIA-0383 February 2007 data
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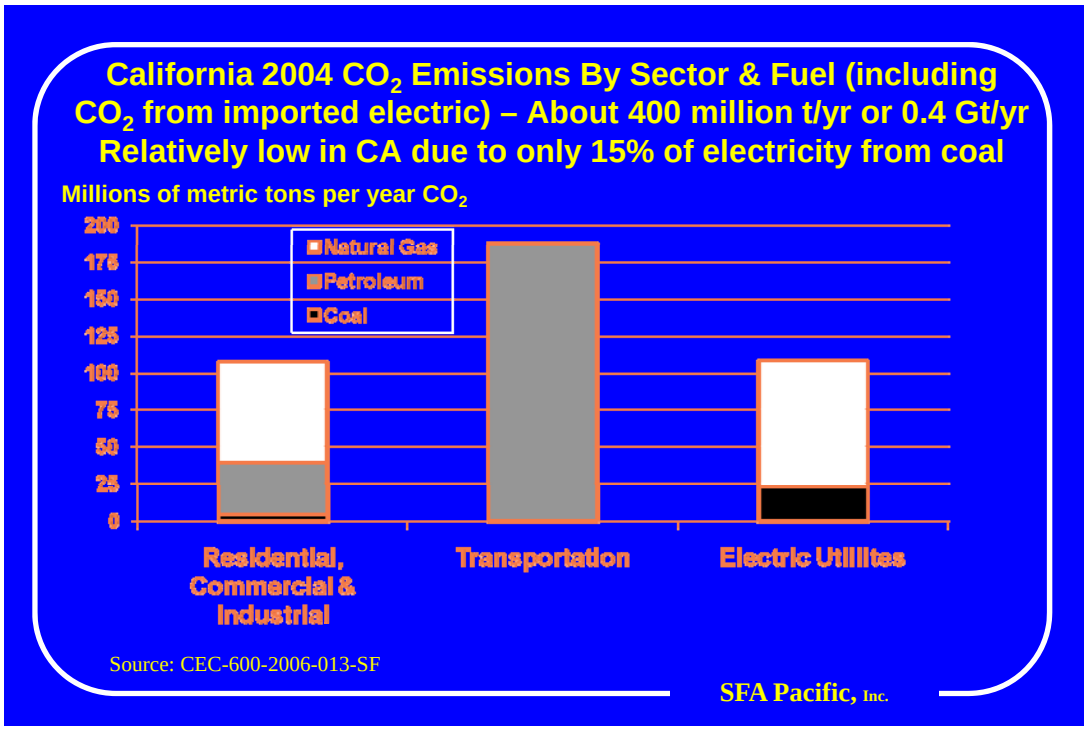
California 2004 CO_2 Emissions By Sector & Fuel (including CO_2 from imported electric) – About 400 million t/yr or 0.4 Gt/yr
Relatively low in CA due to only 15% of electricity from coal
Millions of metric tons per year CO_2
200
175
150
125
100
75
50
25
0
Natural Gas
Petroleum
Coal
Residential, Commercial & Industrial
Transportation
Electric Utilities
Source: CEC-600-2006-013-SF
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For a "Carbon Constrained World" to Ever Develop Requires All of the Following

More conservation & energy efficiency via higher energy prices & CO_2 taxes

Natural gas demand/prices go up while coal demand/prices go down as CO_2 avoidance, CO_2 emission liabilities & CO_2 taxes gain "real" market value

Nuclear makes a big comeback, however, starts slow: first life-extensions & upgrades & eventual decommissioning of current fleet while the industry demonstrates effective waste disposal & competitive costs of new units

Renewables become increasingly important in spite of inherent limitations

- Intermittent solar PV & wind turbines need back-up fossil power & can only marginally replace baseload coal supplying >40% of total world electricity
- Beyond waste biomass limited by yield per ha/yr, fertilizer & water needs, impact on food & deforestation plus: land, transport, storage & labor cost

CO_2 capture & storage becomes strategic for technical, economic, energy supply & most importantly, large CO_2 reduction potential via coal/biomass

- Once developed for coal/coke units, increasing CO_2 taxes enables more co-processing of waste biomass whenever available for "double reductions"

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Power Generators Will Be Forced to Meet a Disproportionate Share of Any CO_2 Reductions

Key conclusion of our 2001 CO_2 Mitigation Multiclient analysis

CO_2 emissions from mobile vehicles are more challenging to reduce than large point sources of stationary big industrials

Power plants cannot move to China, as other CO_2 intensive industries in Annex 1 nations will, if faced with high CO_2 taxes

Big CO_2 reduction potential from coal and pet. coke power gen.

- Reduce coal/coke CO_2 emissions via conservation & efficiency
- Replace coal/coke with NG, nuclear, biomass and wind/solar
- CO_2 capture & storage due to the large CO_2 point sources and potential to co-process waste biomass for much bigger reductions, if needed

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CO_2 Mitigation Options for California

California is unique as its major CO_2 emissions are oil for transportation with distant second - NG for electricity

- Most areas of the world the major CO_2 source is coal for electricity
- Thus strong focus in CA on lowering CO_2 in transportation via higher efficiency vehicles, CNG, liquid biofuels and plug-in electric vehicles

Thus CO_2 mitigation likely more challenging and costly in CA

Nevertheless, the CO_2 capture & storage (CCS) option will likely be important if CA is to meet its ambitious CO_2 reduction goals

- Attributes of CCS: large CO_2 reductions without changes in fuels plus much larger reductions if waste biomass is eventually added
- Biggest challenge: public acceptance of large geologic CO_2 storage

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CO_2 Capture & Storage (CCS) Overview

Simple concept: recover CO_2 from fossil fuel or waste biomass utilization then geologically store CO_2 deep underground

However, the "devil is in the details", requires the following:

- Locations with specific geologic formations of sedimentation and cap rock - typically oil & NG and/or deep saline aquifers geology
- Large "point sources" of CO_2 for essential economy-of-scale
  - Typically coal power plants, cement kilns and other big "smoke stack" industrial complexes: oil refineries, bulk chemicals & iron/steel making
- Concentrate & compress to high pressure for geologic CO_2 injection
  - Some pure CO_2 vents but usually only 15% CO_2 in coal boiler flue gas thus large costs & energy use to recover or capture CO_2 as pure stream
  - Compress the recovered or captured CO_2 to high pressure supercritical conditions for pipeline transport and injection into geologic storage

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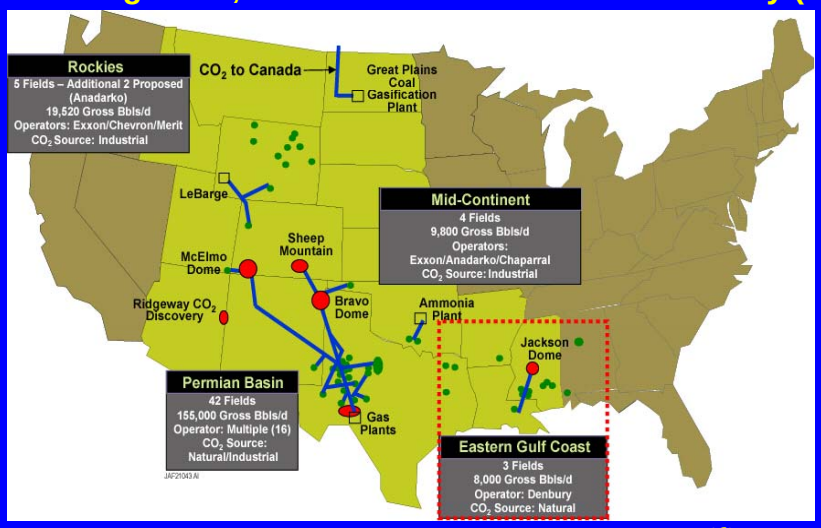
30 Years of CO_2 Experience ~ 40 million t/yr CO_2 storage with ~ 20% from man-made CO_2 sources (squares below) used in producing ~ 200,000 bbl/d of Enhanced Oil Recovery (EOR)



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Pre-Combustion CO_2 Capture

Overview

- Gasification at high pressure of <u>any carbonaceous fuel</u> with O_2 to make H_2 & CO "syngas" then CO reaction with H_2O to just H_2 & CO_2
  - Easy separation of CO_2 from H_2 due to high pressure (HP) & concentration via physical solvents with high CO_2 loading & low energy use flashing to LP

Status

- Many commercial gasification based hydrogen and ammonia plants are making pure H_2 & CO_2 - with units >5,000 t/d CO_2 capture operating
  - Over 40 GWt large-scale gasification plants operating worldwide <u>already have CO_2 capture</u> - only the few IGCC power units (4 GWt or 2 GWe) do not
  - Over 500,000 hours operation of commercial GTs firing H_2 rich fuel, <u>however</u> this experience is mostly in low firing temperature GTs for oil refinery cogen

Attributes

- H_2 or high H_2/CO ratio fuels have many strategic long-term utilization advantages over just steam in a boiler via polygeneration of high power/heat ratio cogeneration & syngas to clean liquid, NG or H_2 fuels

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Post-Combustion CO_2 Capture

Overview

- CO_2 capture from flue gas, after conventional combustion of <u>any fuel</u>
- Harder separation of CO_2 due to low pressure and concentration + O_2
  - Amine chemical solvent liquid absorber/stripper system requiring large amounts of steam for stripping (over 1.5 ton steam per ton CO_2)

Status

- Many big commercial amine chemical CO_2 capture systems usually for natural gas <u>but</u> at high pressure and without the presence of O_2
- However, only a few, relatively small units used for flue gas CO_2 capture - the biggest in operation is just 330 t/d CO_2 capture

Attributes

- Viewed as just another flue gas scrubber by traditional coal power plant people already familiar with flue gas desulphurization (FGD)
- Potential advantage to retrofit <u>any</u> existing flue gas with minimal impact of existing system beyond big additional steam & power needs

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Oxygen-Combustion CO_2 Capture

Overview

- Replaces air with oxygen (O_2) combustion of <u>any fuel</u> plus mixed with a large CO_2 rich flue gas recycle or water injection to about the same properties, flows and heat flux rates as traditional air combustion
  - Requires over twice as much O_2 per net MWe as pre-combustion

Status

- Only small pilot plant testing, however, commercially done in large high sulfur nickel ore kilns to concentrate SO_2 for conversion to H_2SO_4

Attributes

- Avoids complex chemical processes like pre-combustion
- Can "theoretically" capture 100% of the CO_2 & avoid flue gas cleanup or even a stack – however, this added additional technical challenges
- Potential advantage to retrofit existing systems, especially when oxygen replacement of air combustion can increase existing capacity such as existing fluid cat. crackers (FCC) and cement kilns

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Advanced CO_2 Capture Developments

Pre-combustion

- Demonstrations of coke/coal H_2-IGCC power & industrial polygeneration
- SNG with CCS: commercially proven, disconnects CO_2 storage from NG use and NG price/supply backstop in a carbon constrained world

Post-combustion

- Demonstrations of amine systems for: coal & NG plus new & retrofit
- Alstom's chilled ammonia system may greatly reduce both stripping steam & CO_2 compression power, warrants its fast track development

Oxygen-combustion

- Demonstrations of coal boiler, oil refiner FCC and modified ST/GT
- Clean Energy Systems innovative ST/GT development on NG here in CA

Needs both "learning-by-doing" and improved technology R&D

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The CCS Cost Basics

CCS costs can be separated into its 3 distinct process steps: 50% for capture to pure CO_2 stream, 25% for compression & 25% for CO_2 pipeline, injection & geologic storage monitoring

- If use CO_2 for EOR, can reduce the overall CCS costs in about half

CCS costs are mostly from added capital & internal energy use

- Adding CCS to new fossil unit reduces capacity & efficiency ~ 15-30%
- However, existing older fossil unit via rebuilds + CCS can avoid this capacity & efficiency loss while reducing all emissions to near zero

CCS bottom line costs: best matrix is electricity cost increase, as \$/t CO_2 avoidance cost vary greatly depending on baseline

- Nevertheless, CO_2 avoidance cost is the minimal required CO_2 tax at which CCS starts to become an economic option for CO_2 mitigation
- \$/t CO_2 avoided = (\$/MWh_{CCS} - \$/MWh_B) / (to atm: t CO_2/MWh_B - t CO_2/MWh_{CCS})

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CCS Costs Relative to California

CCS costs: capital charges, CO_2 avoided + fuel price/efficiency

- Coal/coke: high capital charges but high CO_2 & low $/million Btu
- NG: lower capital charges but low CO_2 and high $/million Btu - thus if high NG prices, higher CCS CO_2 avoidance costs for NG than coal/coke

The only CO_2 geologic storage with any value is CO_2 EOR

- Good EOR potential in California, but would likely cover < half the total CCS costs + total CA oil reservoir capacity limited to about 3.6 Gt CO_2

Cogen potential in California due to existing heavy oil steam stimulation oil production - via GT power & HRSG EOR steam

- Cogen (combined heat & power) can be about twice as efficient as a central power plant while significantly reducing water consumption
- However, requires efficiency incentives plus better industry and electric utility cooperation

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Cost Estimating At This Time is Dangerous to Your Professional Health

From 2005 until about Oct. 2008 equipment, material, engineering and construction (E&C) costs were all escalating at very high rates due to massive developments in China plus worldwide oil/NG developments with high oil prices

Since about Oct. 2008. big drop in oil/NG prices + financial crisis & recession is quickly killing projects but also reducing costs

Costs are now coming down but at a much slower rate than they went up

California E&C costs are about 25% higher than U.S. Gulf Coast

Following are just generic U.S. Gulf Coast costs in 2006 dollars <u>without</u> special owner's costs & California site specific costs

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The CCS Cost Challenge

What is the minimum CO_2 tax at which coal-based power with or without CCS has the same power cost?

- New coal plant: ~ \$50/mt CO_2 & 11 cent/kWh plant gate or ~ 4 cent/kWh higher delivered baseload (industrial) power Gulf Coast & 2006 dollars
- Existing paid-off coal plant: ~ \$75/mt CO_2 for the same power price, thus need a "cap & trade" system or better: CO_2 tax with plant age inflator

If faced with a ~ \$50/mt CO_2 tax for a new power plant, what is the NG price where NGCC without CCS is the same power cost as coal-based power with or without CCS or the "triple point"?

- \$11-12/million Btu NG for 11 cent/kWh with a \$50/t CO_2 tax and no CCS
  - In a carbon constrained world: NG demand & prices will increase due to much lower risk & capital of lower carbon NG wo CCS vs. coal w/wo CCS
  - At high NG prices, NGCC with CCS costs more than coal with CCS

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CCS Relative to California

Opportunities in CA oil production and refining industry

- Already large fluid catalytic cracking (FCC) and delayed pet coke capacity in existing CA oil refineries
  - Potentially lower CCS CO_2 avoidance costs with high carbon fuels vs. NG
  - Pet coke utilization with CCS would reduce both CO_2 and NG use
  - Solid fuel pet coke with CCS enables easy co-processing of waste biomass (whenever available) for "double" CO_2 reductions
- CO_2 EOR: increases CA oil production plus the lowest cost, most secure and least mineral rights contentious CO_2 storage option
- Cogen steam heavy oil EOR: twice as efficiency & significantly less water use than central power plants plus increases CA oil production
  - CA is a world leader in progressive utility pricing structures to improve conservation and efficiency, yet Alberta is way ahead in cogen steam EOR

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Comments on Potential California CCS Projects

Pre-Combustion: Kern County, Hydrogen Energy with pet coke

- Commercial GE gasifiers/GT ~ 250 MWe net @2 million mt/y CO_2 to EOR
  - Could also make CO_2 free H_2 for CA Fuel Cell Vehicle fueling stations as CA's big CO_2 emissions are in transportation, not power generation
  - Could use local waste biomass co-processing for double CO_2 reductions

Oxy-Combustion: Kern County, Clean Energy Systems with NG

- Smaller advanced technology demo @0.2 MM/y CO_2 to important saline aquifer testing plus an existing successful pilot unit as a CO_2 source
  - Potential "game changer" if can be "no stack" or really "zero emissions"
- Follow the Petrobras (Brazil) oxyfuel FCC developments

Post-Combustion: needed retrofits for NG based systems in CA

- Most post combustion developments are coal-based CCS in US & Canada, however NG CCS developments in Europe & the Middle East

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Summary

Over 30 years of large commercial experience in CO_2 capture & storage (CCS) in the USA for enhanced oil recovery (EOR)

Pre-combustion CCS is the most developed + advantages of H_2 over steam, however not yet all parts in a central power plant

- Advantages of SNG or polygeneration CCS over central power plant

Post- & oxygen-combustion CCS are less developed but advantages for retrofits, simpler processing & power plants

CCS costs are mostly from higher capital & internal energy use

- CCS costs improvements via both learning-by-doing & improved tech.
- CCS costs likely high in California as most large point sources are from low carbon & expensive NG (relatively to coal or pet coke)
  - Potential ways to reduce costs and increase efficiency for California CCS is to utilize CO_2 for EOR + cogen steam for heavy oil production

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