Overview and Insights on the Three Basic CO_2 Capture Options

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by

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Presentation Overview

Background

- SFA Pacific's recent activities on CO_2 capture
- Why coal-fired electric utilities are at greatest risk <u>if</u> a carbon constrained world ever develops
- <u>If</u> a carbon constrained world every develops, CO_2 capture & storage would become strategic to coal's future

Three fundamentally different options for CO_2 capture

- <u>Post combustion</u> - flue gas amine scrubbers after the boiler
- <u>Oxygen combustion</u> - converting boilers from air to oxygen
- <u>Pre combustion</u> - gasification & shifting CO rich syngas to hydrogen

Our insightful view and assessments of each CO_2 capture option relative to U.S. coal based power generation

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SFA Pacific Background

Founded in 1980

Performs technical, economic & market assessments for the major international energy & engineering companies

- **Over a third of our work is consistently outside the United States**

Principal work involves residual oil upgrading, syngas (H_2 & CO), electric power generation & emissions control

Niche is objective outside opinion & comparative analysis before companies make major decisions or investments

Unique perspective with no vested interest in engineering, resources, technologies, R&D or project development

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Representative SFA Pacific Clients

UTILITIES	*INDUSTRIALS*	*MANUFACTURERS + E&C*
Epcor	BHP	ABB/Alstom
EdF	BP (Amoco Arco Veba Oil)	B&W/McDermott
Electrabel	Chevron Texaco	Black & Veatch
EPDC (Japan)	Conoco Phillips	Bechtel
EPRI	Dow Chemical	Chiyoda
Eskom (South Africa)	ENI	Cummins
National Power	Exxon Mobil	Fluor Daniel
Nova Scotia Power	PDVSA	Foster Wheeler
Ontario Power	Rio Tinto (Kennecott Energy)	General Electric
Power Gen	Saudi Aramco	Kellogg Brown & Root
RWE/Rheinbraun	Shell International	JGC
Taiwan Power	Sinopec	MHI
Tokyo Electric Power	Statoil	Siemens/Westinghouse
TransAlta	Total Fina Elf	Snamprogetti
Vattenfall	Weyerhaeuser	Toyo

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Background of SFA Pacific CO_2 Capture Related Projects

1989 - CO_2 Capture analysis for EPRI

1992 - CO_2 Capture analysis for DOE

2001 - Private Mulitclient Analysis of CO_2 Mitigation Options sponsored by over 25 major international energy companies

2002-2004 - Technical Advisory Board (TAB) to the oil industry lead CO_2 Capture Project (CCP)

2002-2004 - Canadian Clean Power Coalition (CCPC)

2003-2005 - Lead author on the IPCC Special Report on CO_2 Capture & Geologic Storage - to be made public in 2005

Most of our recent CO_2 mitigation work is for private industry

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CO_2 Mitigation Options

Man-made CO_2 emissions & growth rate are simple to calculate via the *Kaya Identity* where CO_2 emissions =

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

Only four options:

- 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 & energy intensity in the USA & China

- USA is 25% of world GHG emissions, but also over 25% of world GDP
- China will pass the USA in GHG emissions in only 20-25 years

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Standard of Living & Fossil Fuels Consumption

The fundamental greenhouse gas (GHG) issue of fairness

The USA must set the GHG example for others, especially China

Source: Scott Willis of the San Jose Mercury News (California)

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What About Coal

Coal is a "4 letter word", nevertheless the key fossil fuel

- **Largest fossil fuel resource with lowest price & stable supply**
- **Principal use for power generation via large steam boiler central power stations - over one third of worldwide electricity**

Coal is under attack due to:

- **Low efficiency & high emissions - SO_2, NO_x, fine particulates, mercury, solid waste & especially CO_2 in the future**
- **Deregulation favored NGCC for new capacity due to the much lower capital costs, lower emissions & ease of permitting**

However, coal utilities may be the winners of deregulation due to the low cost of power from their existing paid-off coal units

- **Depending on how long they will be allowed to "life extend" their many existing, dirty, inefficient coal boiler units called the "big dirties"**
- **Marginal load dispatch favors the 3-4 times lower fuel cost coal units**

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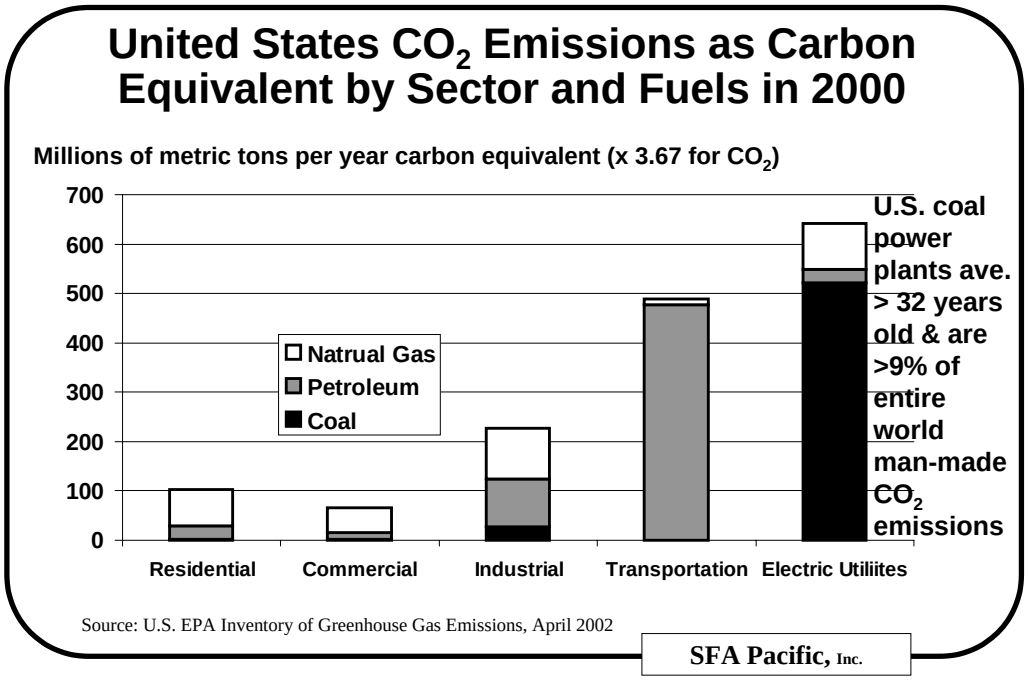
United States CO_2 Emissions as Carbon Equivalent by Sector and Fuels in 2000
Millions of metric tons per year carbon equivalent (x 3.67 for CO_2)
700
600
500
400
300
200
100
0
Natrual Gas
Petroleum
Coal
Residential
Commercial
Industrial
Transportation
Electric Utiliites
U.S. coal power plants ave. > 32 years old & are >9% of entire world man-made CO_2 emissions
Source: U.S. EPA Inventory of Greenhouse Gas Emissions, April 2002
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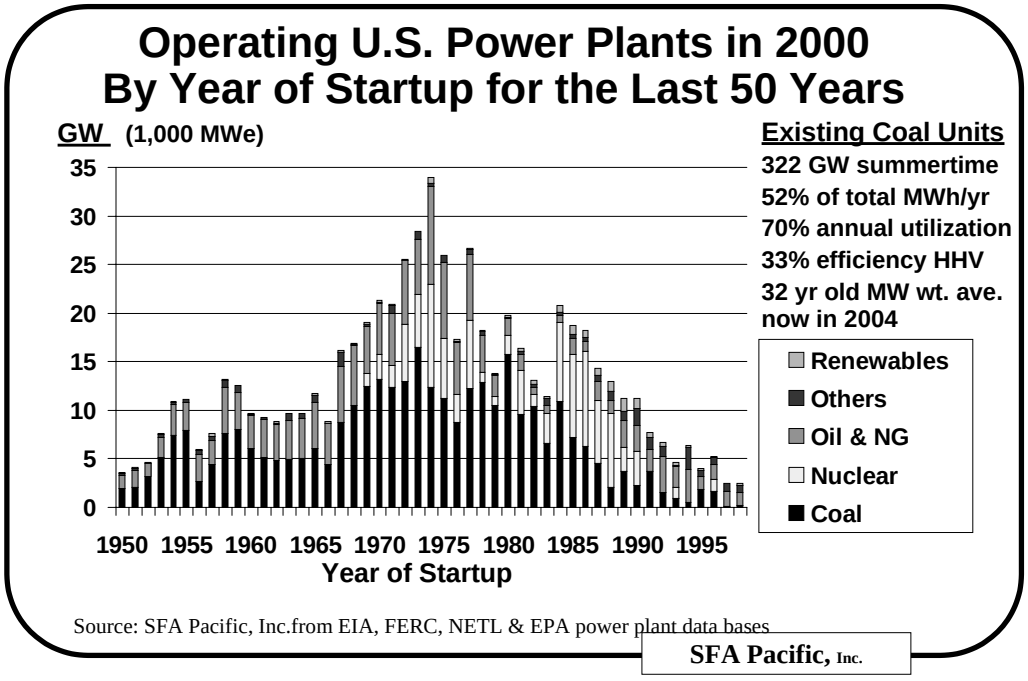
Operating U.S. Power Plants in 2000
By Year of Startup for the Last 50 Years
GW (1,000 MWe)
35
30
25
20
15
10
5
0
1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
Year of Startup
Existing Coal Units
322 GW summertime
52% of total MWh/yr
70% annual utilization
33% efficiency HHV
32 yr old MW wt. ave. now in 2004
Renewables
Others
Oil & NG
Nuclear
Coal
Source: SFA Pacific, Inc.from EIA, FERC, NETL & EPA power plant data bases
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Power Generation Will Be Forced to Meet a Disproportionate Share of Any CO_2 Reductions

Transportation fuel users have more "voting power" than the CO_2 intensive power industries as demonstrated in June 2000 when gasoline taxes were reduced in both the U.S. & Europe

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

Large potential for improvements in power generation

- Increase old coal-boiler power plants efficiency
- Replace coal with: co-firing biomass, natural gas or wind turbines

Large point sources of power generation reduces both CO_2 mitigation & capture/storage costs

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Post Combustion CO_2 Capture

Overview

- Chemical solvent flue gas absorption with regeneration of the lean amine by heated with low pressure steam in a stripper to generate a pure CO_2 stream that is compressed to supercritical conditions

Status

- Commonly used for CO_2 removal from NG & syngas, <u>not</u> flue gas
- Only a few relatively small units used for flue gas CO_2 capture, the biggest in current operation is only 330 t/d CO_2 capture

Attributes

- Viewed as just other flue gas scrubber, like the familiar FGD system
- Can be retrofitted behind existing coal boilers, thereby viewed as a potentially lowest "absolute" ($, not $/kW net) capital cost option
- Maintains the traditional steam boiler technology - "save the boiler"

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Post Combustion CO_2 Capture - Issues

- Very large scrubbers diameter & height to obtain >90% CO_2 capture
- Must first remove most of the SO_2 & NO_x to minimize deactivation of the expensive amine solvent- requires high efficiency FGD & SCR
- Large stripping steam requirements
  - Requires about 1.5 ton low pressure (50 psig) steam per ton CO2 removed or about 1,200 Btu per pound CO_2 removed
    - Only extraction LP steam, but still a significant drop in gross power vs. this same steam going to the vacuum condenser
- Large compression of "wet" CO_2 from about 1 to 135 atm or 135 compression ratios - thereby high capital and electric power demand
- The "absolute" net efficiency losses are about 8-11% HHV & U.S. rating
  - Can reduce the steam boiler power plant "relative" net capacity & efficiency by 15-25%HHV, depending on the baseline - USC is the smaller %

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Post Combustion CO_2 Capture - Assessment

Favored by traditional coal boiler power engineers

- Familiar with flue gas scrubber (like FGD) & "saves the boiler"

Best application - <u>effective</u> retrofits of existing coal units

- Retrofit of newer coal boilers that already have relatively high thermal efficiency <u>plus</u> existing high efficiency FGD & SCR systems
  - <u>If</u> the lost capacity is replaced by new clean NGCC, <u>not</u> old dirty coal units
- Retrofit of older coal boilers, <u>only if</u> the boiler/ST & emission controls are all upgraded at the same time to minimize efficiency losses
  - Net efficiency & capacity losses can be minimal (from original baseline) via USC steam cycle rebuild with resulting near zero emissions coal unit
  - However, the "absolute" capital costs are much higher than just a simple CO2 flue gas scrubber retrofit (better to think about unit cost of $/kW net)
  - USC boiler/ST rebuilds have several issues, like costs & available sizes

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Oxygen Combustion CO_2 Capture

Overview

- Simply replaces air combustion with oxygen combustion, but requires a large CO_2 flue gas recycle or water injection to about the same mass or volume flows as air combustion + a less pure CO_2 to compress

Status

- Only small pilot plant boilers testing, however, commercially done in large nickel ore kilns to concentrate SO_2 capture as just flue gas

Attributes

- Can "theoretically" capture 100% of the CO_2 & avoid all flue gas cleanup by leaving SO_2, NO_x, Hg in the "raw" CO_2
- Maintains the traditional steam boiler technology - "save the boiler"
- Can avoids all chemical processes, even the simple FGD & SCR as power engineers view chemical processes as "the work of the devil"

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Oxygen Combustion CO_2 Capture - Issues

- Massive oxygen requirements - > 3 time that of IGCC - tons O_2/MWh net
  - High capital costs & very large electric power requirements of O_2 production
- Large compression of "wet & raw" CO2 with 5% inerts (N_2, O_2, SO_2& NO_x) from about 1 to 150 atm or 150 compression ratios - higher due to inerts
  - Can "raw" CO_2 actually be compressed, transported & geologically storage? If this raw CO_2 must be purified, requires CO2 liquefaction & inert stripping (more power & capital), SO_2 & NOx controls + only about 90% CO_2 capture
- Acceptable % O_2 in recycle CO_2 (vs air) or some O_2 injection into burners
  - If just 21 vol.% O_2 in the recycle CO2, large mass flow increases in the boilers
- Many advanced O_2 combustion power cycles only for NG or syngas
- The "absolute" net efficiency losses are about 10-13% HHV & U.S. rating
  - Can reduce the steam boiler power plant's "relative" net capacity & efficiency by 20-30%HHV, depending on the baseline performance - USC is the smaller %

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Oxygen Combustion CO_2 Capture Assessment

Favored by mostly researchers & oxygen vendors

- Due to the many R&D issues yet to be resolved (especially for advanced cycles) + the massive oxygen requirements (>3 x IGCC)

Best Applications - effective retrofit of existing coal units

- Newer & larger coal boilers with high thermal efficiency but no emission controls if SO_2 & NO_x can stay in the "raw" CO_2 to storage
  - Very few of these type plants in the U.S., more in Eastern Europe
- Retrofit older & dirtier coal boilers, only if the boiler/ST is upgraded at the same time to minimize efficiency losses & if "raw" CO_2 storage
  - Net efficiency & capacity losses can be minimal (from original baseline) via USC steam cycle rebuild with resulting near zero emissions coal unit
  - However, the "absolute" capital costs are much higher than just a simple oxygen combustion retrofit (better to think about unit cost of $/kW net)
  - USC boiler/ST rebuild + O_2 have more issues than the post combustion

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Pre Combustion CO_2 Capture

Overview

- IGCC firing a H_2 rich gas via "shifting" the normal CO rich syngas + H_2O to mostly H_2 & CO_2 then physical solvent CO_2 absorption with low to moderate pressure flashing to generate a pure & dry CO_2 to compress

Status

- Many commercial gasification based hydrogen and ammonia plants making pure H_2 & CO_2 - with units >3,500 t/d CO_2 capture operating
- GE claims over 450,000 hrs of commercial GTs firing H_2 rich gas

Attributes

- Hydrogen or high H_2/CO ratio "syngas" has many strategic long-term flexibility advantages over just making steam in a boiler
  - Cogen, "hydrogen economy" & premium liquid transportation fuels - GTL
- CO_2 capture from oxygen free, high pressure H_2/CO_2 syngas has many advantages over CO_2 capture from N_2 rich low pressure flue gas

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Pre Combustion CO_2 Capture - Issues

- Gasification based hydrogen, ammonia and even IGCC without CO_2 capture are expensive & complex chemical processes
  - The traditional coal-based power industry considers IGCC even without CO_2 capture too expensive and unreliable plus is clearly "the work of the devil"
- GE's experience with H_2 firing are mostly older, lower temperature GTs
  - Will likely require GT/O_2 integration for N_2 to add for <65% H_2 firing in GT
- Generally favor very high pressure gasifers limited to slurry feeding to obtain the big energy saving of physical solvent CO_2 adsorption
  - Low or no stripping steam & only moderate compression of "dry" CO_2 from about 5 to 135 atm or only 27 compression ratios
- Power plants site limit the "polygeneration" advantages of gasification
- The "absolute" net efficiency losses are about 5-8% HHV & U.S. rating
  - Can reduce the IGCC power plant's "relative" net capacity & efficiency by 10-15% HHV, depending on the baseline performance

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Pre-Combustion CO_2 Capture - Assessment

Favored by chemical engineers - but few in the power industry

- Would likely require over-the-fence syngas by chemical experts "devils" similar to the most successful utility IGCC demo - Wabash River CCT

Best Applications - both new & retrofit repowering

- New units likely favor polygeneration at oil refineries & chemical plants sites for maximum power to heat ratio GT cogen plus excess H2 & GTL
  - Let chemical experts operate the gasification & cleaner H2 + GTL transport fuels with over-the-fence power/steam cogen by the power & steam experts
- Repowering of the older, dirtier & smaller coal units - like Wabash River
  - Net efficiency can be slightly better plus net capacity 2-3 times as large while converting to a near zero emission coal unit

Strategic flexibility of making clean power & transportation fuel from domestic energy while reducing emissions & oil imports

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Summary

Successful demo of CO_2 capture & especially long-term storage is likely too important to coal's future to wait for FutureGen

- **Require demos of all 3 options at large-scale as soon as possible ASAP**
- **Successful demos require commercial technology & the true experts**
  - **Storage is the bigger issue, CO_2 capture costs will be reduced by creating competition amount the proponents of all the CO_2 capture options**
  - **Cost reductions may be faster from evolutionary "learning by doing" than waiting for the few successful revolutions advanced technologies**

Post Combustion CO_2 Capture

- **Clearly favored by the traditional coal boiler people because it "saves the boiler" and looks like just an other flue gas scrubber (I.e. like FGD)**
- **Focus on USC rebuild demo that is typical of less efficient subcritical boilers already with or considering high efficiency FGD & SCR add-ons**

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Summary

Oxygen Combustion CO_2 Capture

- **Favored by researchers & oxygen vendors plus it "saves the boiler"**
- **Focus on USC rebuild demo with"raw" CO_2 storage of a typical low efficiency subcritical unit where adding emission controls is an issue**

Pre Combustion CO_2 Capture

- **Favored by "the devils" but also likely the most strategic to our future if done right - power & chemical experts working together for our good**
- **Focus on low risk, over-the-fence gasification demo GT repowering of older & smaller subcritical unit, thus no efficiency losses plus the 2-3 times capacity increase, while reduction to near zero emissions**
- **Focus on a polygeneration demo with CO_2 for EOR at a chemical or oil refining site where the "devils" & power experts each do what they do best as will be explained in more detail this October in our GTC presentation titled "The Future of Gasification, the Green Refinery"**

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