CO_2 Capture Technologies

Presentation at the

Working Group Meeting on AB-1925 Report to the California Legislature on Accelerating Geologic Carbon Sequestration Strategies

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by

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Presentation Overview

Overview of CO_2 sources & CO_2 capture & storage (CCS)

- CCS economics favors big "CO_2 point sources" into proven secure geologic formations - in California mostly NGCC power plants, oil refineries & cement kilns sources into oil & gas formations first

Summary of current CO_2 capture methods

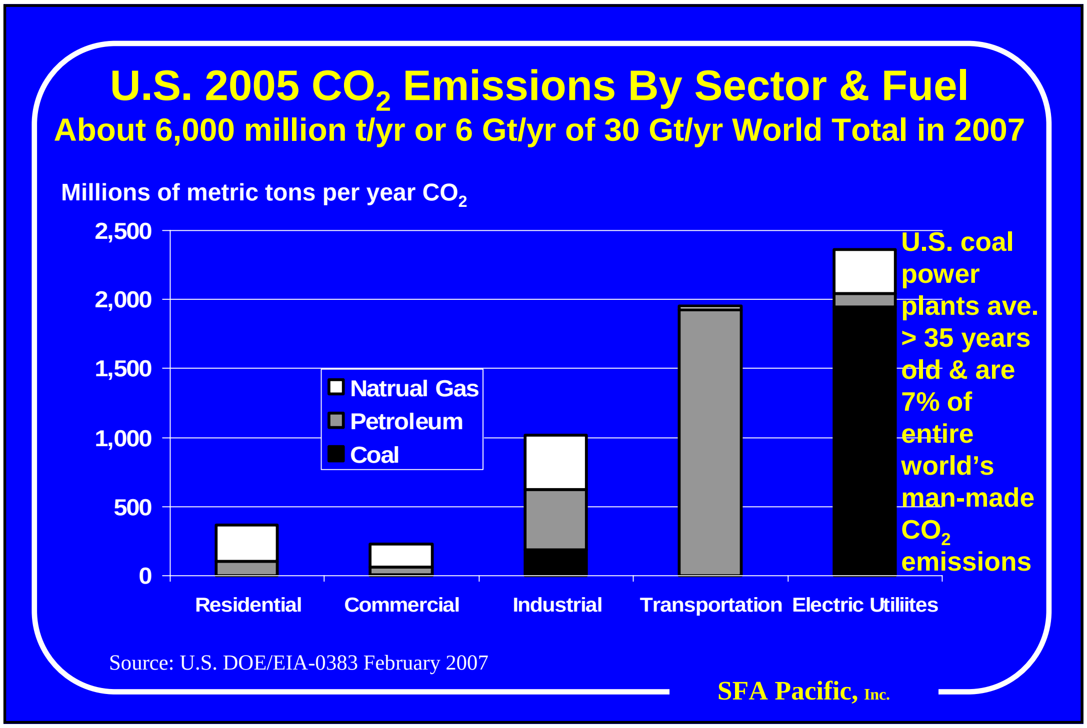
- Pre-combustion
- Post-combustion
- Oxygen-combustion

New CO_2 capture technologies under development

Retrofit vs. new construction

Costs – general overview relative to California

- Presentation by Howard Herzog of MIT will more fully address costs


U.S. 2005 CO_2 Emissions By Sector & Fuel
About 6,000 million t/yr or 6 Gt/yr of 30 Gt/yr World Total in 2007
Millions of metric tons per year CO_2
2,500
2,000
1,500
1,000
500
0
Natrual Gas
Petroleum
Coal
Residential
Commercial
Industrial
Transportation
Electric Utiliites
U.S. coal power plants ave. > 35 years old & are 7% of entire world's man-made CO_2 emissions
Source: U.S. DOE/EIA-0383 February 2007
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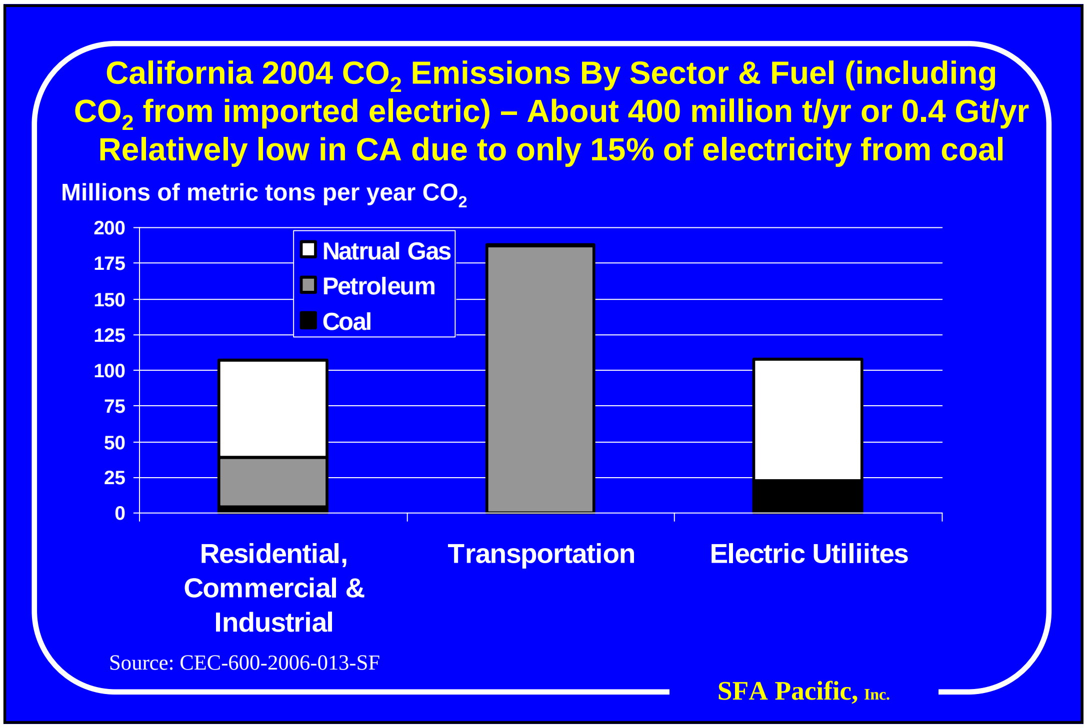
California 2004 CO_2 Emissions By Sector & Fuel (including CO_2 from imported electric) – About 400 million t/yr or 0.4 Gt/yr
Relatively low in CA due to only 15% of electricity from coal
Millions of metric tons per year CO_2
200
175
150
125
100
75
50
25
0
Natrual Gas
Petroleum
Coal
Residential, Commercial & Industrial
Transportation
Electric Utiliites
Source: CEC-600-2006-013-SF
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CO_2 Mitigation Options

Man-made CO_2 emissions of about 30 Gt/yr & growth 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 - 20% of world man-made CO_2, however also 20% of world GDP
- China - appears to be passing the USA in CO_2 emissions this year

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For a "Carbon Constrained World" to Ever "Really" 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 & oil residue demand/prices go down as CO_2 avoidance & emission liabilities gains "real" market values

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 becomes increasingly important in spite of some 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 land & water needs + land & labor costs

CO_2 capture & storage (CCS) of fossil fuels becomes strategic for technical, economic, energy supply & overall CO_2 reduction perspectives

- – Once developed for big fossil power plants as CO_2 taxes increase, can co-process waste biomass when ever available for "double reductions"

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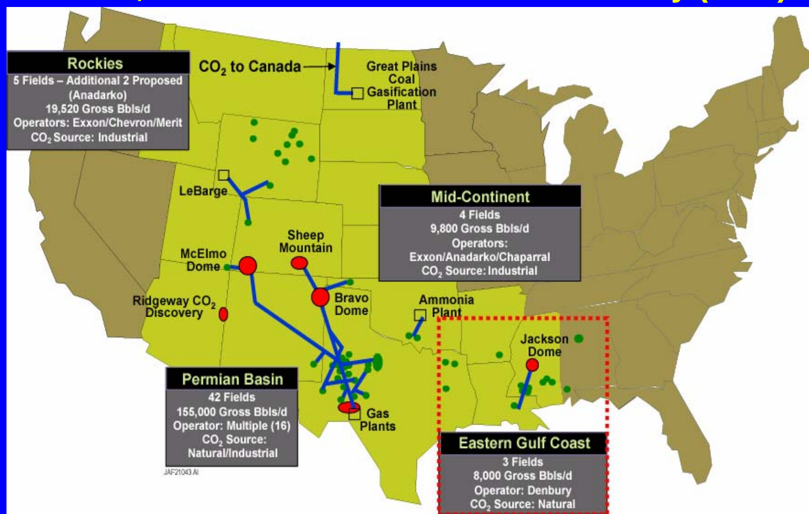
Over 25 Years of Experience - Currently 35 Million t/y CO_2 Storage (with 30% from Man-Made CO_2 Sources) producing 250,000 bbl/d of Enhanced Oil Recovery (EOR)



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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 & concentration
  - Done via physical solvent liquid absorber/stripper system & then compress pure CO_2 to high pressure for transport & geologic injection for storage

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 has over 450,000 hrs operation of commercial GTs firing H_2 rich gas

Attributes

- Hydrogen (H_2) or high H_2/CO ratio fuels has many potential strategic long-term utilization advantages over just making steam in a boiler
  - High power/heat ratio cogen, clean transportation fuels & "the H_2 economy"

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Post-Combustion CO_2 Capture

Overview

- Similar to pre-combustion but now after combustion from flue gas
- Harder separation of CO_2 due to low pressure & 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 but at high pressure and without the presents of O_2
  - Only a few, relatively small units used for flue gas CO_2 capture - the biggest in operation is only 330 t/d CO_2 capture

Attributes

- Viewed as just another flue gas scrubber, like flue gas desulphurization (FGD) familiar to traditional power plant engineers
- Potential advantages to retrofit any existing flue gas with minimal impact of existing system other than added steam & power needs

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Oxygen-Combustion CO_2 Capture

Overview

- Replaces air combustion with oxygen (O_2) combustion, but requires a large CO_2 flue gas recycle or water injection to about the same mass or volume flows or heat flux (Btu/hr per cubic foot) as air 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

- Can "theoretically" capture 100% of the CO_2 & avoid flue gas cleanup by leaving trace O_2, N_2, SO_2, NO_x & Hg in this "raw" CO_2 to CCS
- Potential advantages to retrofit existing systems, especially when oxygen replacement of air combustion can increases existing capacity
  - Perhaps cement kilns or fluid cat crackers (FCC) units in oil refineries

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New CO_2 Capture Technologies Under Development

Pre-combustion

- Complete H_2-IGCC power plant with CCS (BP Carson or FutureGen)
- Longer-term: solid oxide fuel cells to directly convert CO rich syngas to higher efficiency electricity & high-pressure CO_2 in one step

Post-combustion

- Demonstration in large power gen. with CCS (Statoil in Norway)
- Longer-term: chilled ammonia CO_2 absorber/stripper to greatly reduce both the stripping steam & CO_2 compression power needs

Oxygen-combustion

- Demonstration in large coal boiler with CCS (Sask Power in Canada)
- Longer-term: NG or syngas O_2 fired with water injected modified high temp. reheat gas/steam turbine (Clean Energy Systems in California)

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

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Retrofit vs. New Construction

Generally requires a higher CO_2 tax to economically justify existing paid-off CO_2 sources to CCS retrofit than for new construction CO_2 sources

- New construction with CCS only reduces growth of CO_2 unless it replaces existing CO_2 sources for the same product

New or minimal retrofit CCS result in a significant loss in net capacity & efficiency: about 20-30% relative loses

- Conversion to cogen or co-products can avoid efficiency loses

Major retrofit of older systems can enable CCS to obtain the same capacity & efficiency as the old original CO_2 source

- Generally requires replacement of old boiler systems with bigger & higher efficiency supercritical boiler or gas turbine repowering
- Potential for reductions in existing SO_2, NO_x & PM as well as CO_2

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Costs - General Overview Relative to California

CCS costs about 50% in CO_2 capture, 25% in CO_2 compression and 25% in CO_2 transport, geologic injection & monitoring

CCS costs are mostly from higher capital & internal energy use

- Lower $/t CO_2 avoidance costs for big, high-carbon cheap coal uses, however in California, most of the larger existing CO_2 point sources are from low-carbon & more expensive NG – thus higher CCS costs in CA

The only CO_2 geologic storage with any market value is 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

Large cogen potential in California due to existing heavy oil steam stimulation oil production near Bakersfield

- Cogen can be about twice as efficient as a central power plant while significantly reducing water consumption

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Summary

Over 25 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 single power plant

Post- & oxygen-combustion CCS are less developed but potential advantages for retrofits + simpler processing

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 & increase efficiency for California CCS is to utilize CO_2 for EOR & cogen steam for heavy oil production

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