CO_2 Taxes & NG Prices where Coal with CO_2 Capture & Storage (CCS) Starts Becoming an Economic Option

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Presentation Overview

Background

- CO_2 mitigation options and why there is a strategic need for CO_2 capture & storage to become an politically acceptable option

CO_2 capture & storage (CCS) challenges – many!

- Biggest being: locations, liability, public acceptance & especially costs as economics beats technology, every time

Summary of current CO_2 capture technologies by generic types

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

Advanced CO_2 capture technologies under development

Outlook

Background of SFA Pacific CO_2 Capture & Storage (CCS) Related Projects

1989 - present: CO_2 Capture analysis for EPRI

2001 - Private Multiclient Analysis of CO_2 Mitigation Options

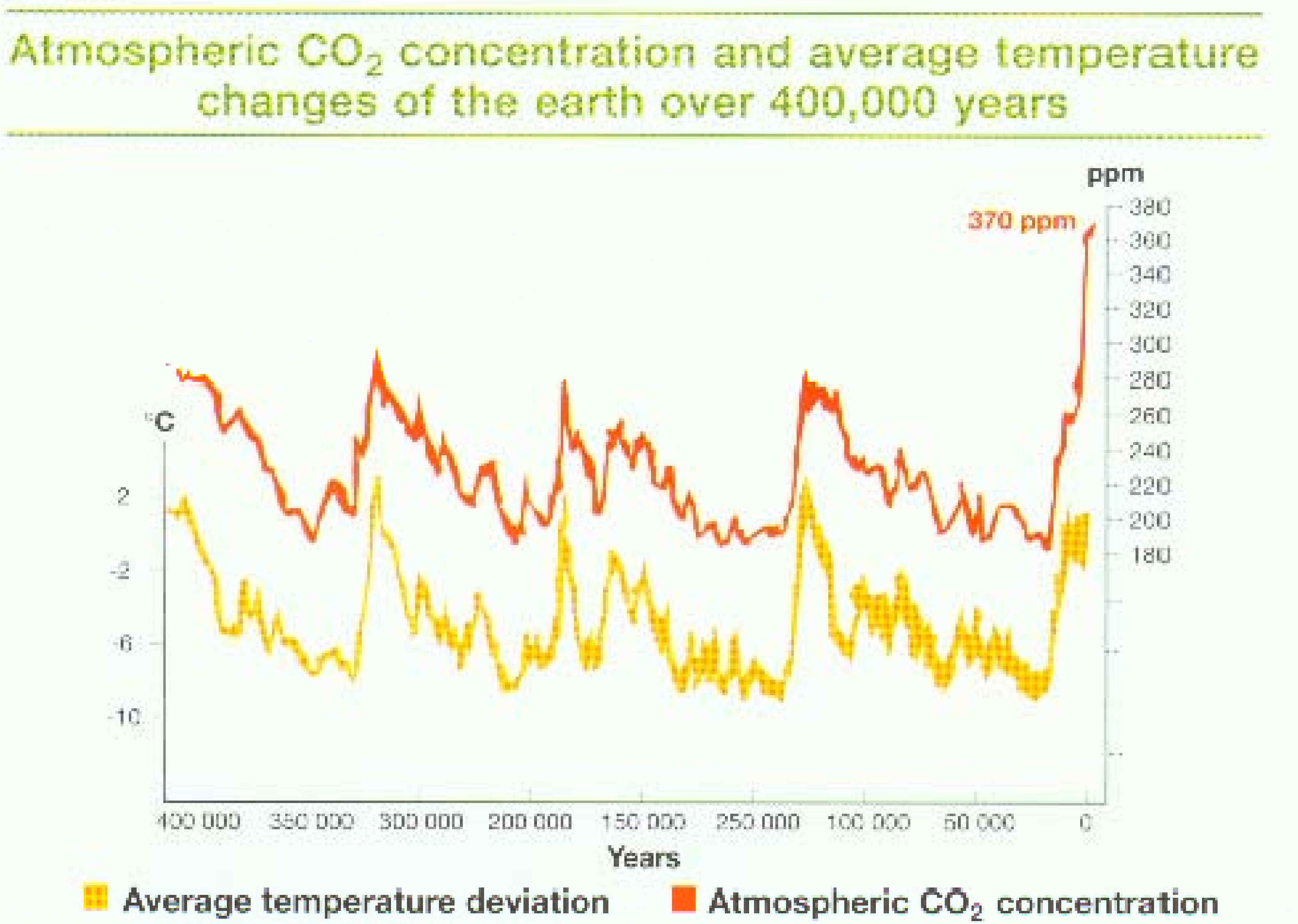
2002- present - Technical Advisory Board (TAB) to the CO_2 Capture Project (CCP)

2003-2005 - Lead author of the UN IPCC Special Report on CO_2 Capture & Geologic Storage - Published Nov. 2005

- Member of the large IPCC group awarded the 2007 Nobel Peace Prize

2007 - CO_2 Capture & Storage costs for Canada Government & Industry Expert Economic and Policy Working Group

Most of our CO_2 mitigation work is for private industry



Global Warming: What is the Big Concern?

Atmospheric CO_2 ppm the main greenhouse gas (GHG) at historic high & increasing

Current Atmospheric CO_2 Inventory & Cycle

Current inventory of CO_2 in our atmosphere @ 380 ppm is 3,040 billion metric tons (Gt) CO_2 or 825 Gt as carbon equivalents

- **Note that just 1 ppm CO_2 in atm. = about 8 Gt CO_2 or 2.17 Gt as carbon**

Current annual CO_2 atmospheric cycle as carbon equivalents

Natural sources from ocean & vegetation decomposition	150 Gt/y -	93.8%
Anthropogenic (man-made) CO_2 from fossil fuels	8 Gt/y -	5.0%
Anthropogenic (man-made) CO_2 from land use	2 Gt/y -	1.2%
Total	160 Gt/y	
Natural CO_2 absorption (ocean & photosynthesis)	156 Gt/y	
Net CO_2 annual build-up in atmosphere @ 2 ppm/year	4 Gt/y -	2.5%

The big growth in man-made CO_2 emissions is in developing nations as they increase their standard of living via more fossil fuel use plus continued deforestation for biofuels & food

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

Classic Ugly American: Confuses "US" with U.S.

<u>Food for fuel</u>

Driving a vehicle using gasohol from corn

Ugly European if driving a vehicle using biodiesel from palm plantations

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)

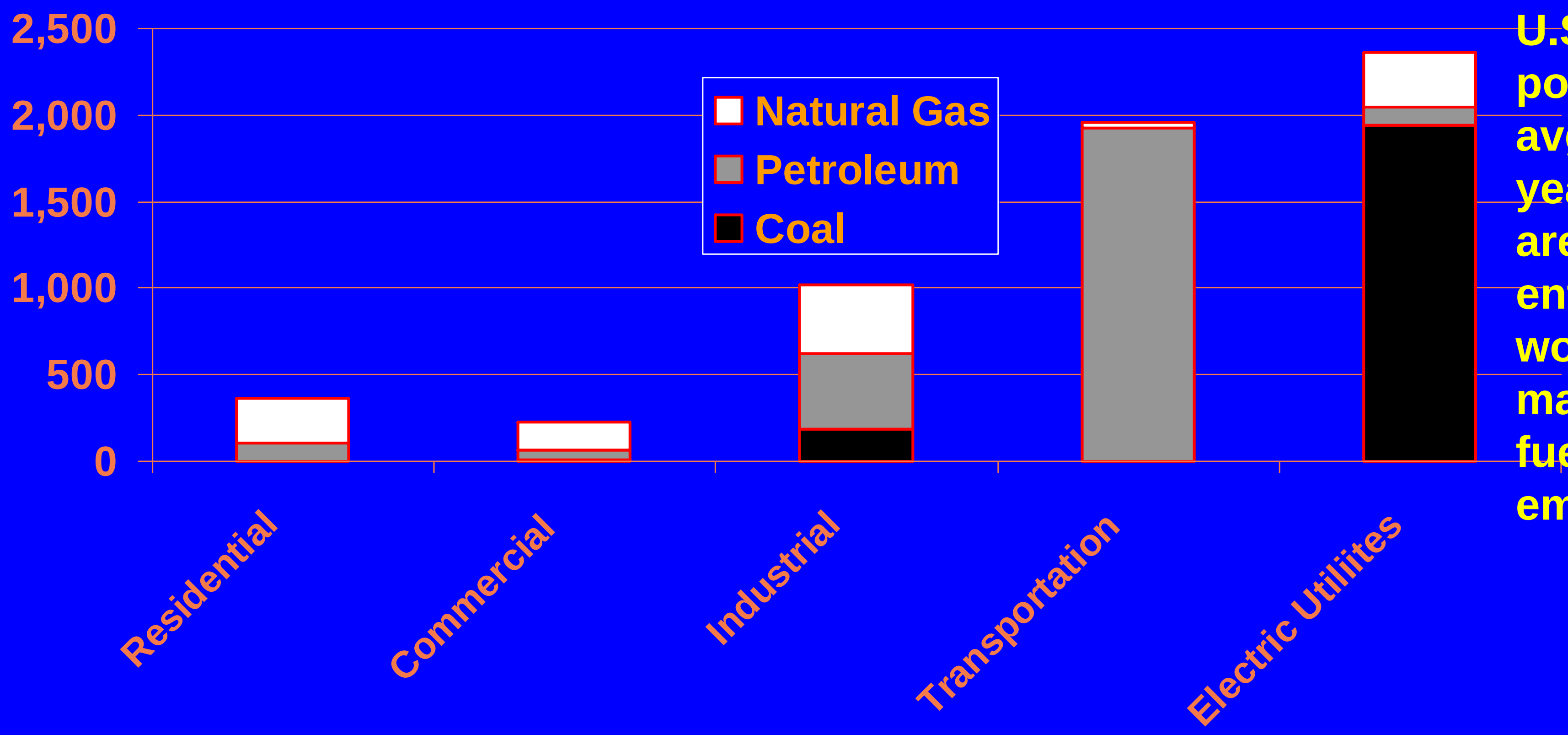
Any meaningful worldwide CO_2 reduction requires focus on carbon intensity & energy intensity in the USA & China

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

USA 2005 CO_2 Emissions By Sector & Fuel

About 6 Gt/yr of 30 Gt/yr World Total fossil fuel CO_2 in 2007

Millions of metric tons per year CO_2 (divide by 3.67 for carbon equivalents)



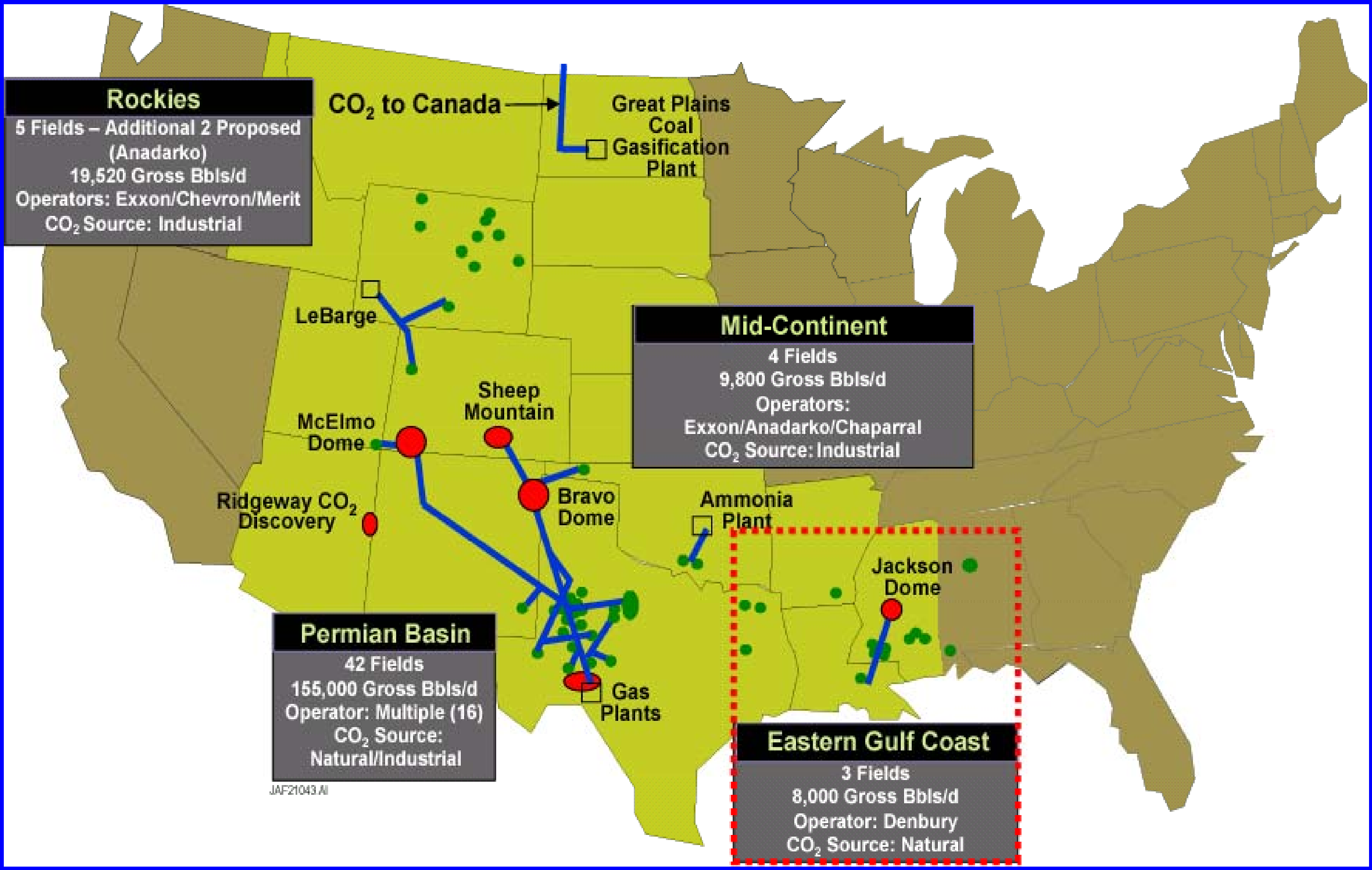
U.S. coal power plants avg. > 35 years old & are 7% of entire world's man-made fossil fuel CO_2 emissions

Source: SFA Pacific plot from U.S. DOE/EIA-0383 February 2007 data

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 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 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/y, fertilizer & water needs, impact on food & deforestation + basic economics of land & labor costs
- **CO_2 capture & storage becomes strategic for technical, economic, energy supply & most importantly, overall CO_2 reduction perspectives**
  - Once developed for big coal units, increasing CO_2 taxes enables more co-processing of waste biomass whenever available for "double reductions"

25 Years of CO_2 Experience – about 35 million t/y CO_2 storage with 25% man-made CO_2 sources (squares below) used in producing 250,000 bbl/d of Enhanced Oil Recovery (EOR)



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 & 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 & 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 & injection into geologic storage**

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

SUV owners have voting power over CO_2 intensive industries

- Politicians believe they cannot get re-elected if they increase transportation fuel taxes via adding a CO_2 tax on gasoline or diesel

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

Big CO_2 reduction potential from coal-based power generation

- Reduce coal CO_2 emissions via conservation & efficiency
- Replace coal with NG, nuclear, biomass and wind/solar
- CO_2 capture & storage due to the large CO_2 point sources, pass-though pricing structure of traditional regulated power generation & potential to co-process waste biomass for double reductions

The CCS Basic Challenge

Magnitude required for 0.5 ppm/yr CO_2 or 50 ppm in 100 years reduction from BAU - 4 Gt/yr or total 400 Gt CO_2 reduction

- 500 GWe of zero CO_2 emissions baseload nuclear (as solar & wind are only cycling load) replacements of existing coal power plants
- 500 GWe of replacement new for old coal power unit with 100% CCS = 4 Gt/y CO_2 which at 100°F & 150 atm. pressure = 80 million bbl/d CO_2
- Only 333 GWe of replacement coal power plants with 100% CCS when co-processing 50% biomass energy = 2.67 Gt or 53.3 million bbl/d CO_2

Who needs CCS: coal & coal-based electric power industries

- CO_2 capture is the easy part – costly but available technology plus cap & trades allocations handouts & cost pass-through power pricing
- The key issue is public acceptance of CO_2 storage plus the reality that the oil & gas industries have the essential geologic expertise required

The CCS Liability Challenge

CCS in the USA is limited to just EOR until fundamental changes in USA liability & mineral rights laws plus tort reform

- USA tort litigation + mineral rights laws would turn “ambulance chasing lawyers” into “CO_2 injection chasing lawyers”
  - Classic “David vs. Goliath” easy to win, regardless of the facts
- States like Texas are trying to address this key CCS limitation for EOR
- EPA and IOGCC heading toward a power struggle over control of CCS

CCS likely to develop in areas of world where the government owns the mineral rights & pore space underground plus litigation is rational & fair

- Like Australia, Canada, China and Europe

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

CCS costs are mostly from added capital & internal energy use

- Added internal energy use for <u>new</u> coal plants w/wo CCS reduces capacity from 400 to 300 MWe & net efficiency from 40% to 30%
  - <u>Existing</u> coal unit CCS replacements avoids this capacity & efficiency loss
- Added capital costs of CCS increases $/kW for new coal w/wo by about 40-80% due to added capital + lower net capacity & efficieny

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 <u>starts</u> to become an economic option for CO_2 mitigation
- $/t CO_2 <u>avoided</u> = ($/$MWh_{CCS}$ - <u>$/$MWh_B$</u>) / (to atm <u>t CO_2/MWh_B</u> - t CO_2/MWh_{CCS})

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: ~ \$30/mt CO_2 & 9 cent/kWh plant gate or ~ 3 cent/kWh higher delivered baseload power – low Gulf Coast costs in 2006 dollars
- Existing paid-off coal plant: ~ \$60/mt CO_2 & same power increase, thus need cap and trade allocations or CO_2 tax with plant age adjuster

If faced with a \$30/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?

- About \$9/MM Btu NG based on low \$1.50/MM Btu coal
- In a carbon constrained world: NG demand & prices will increase due to lower risk & capital of lower carbon NG wo CCS vs. coal w/wo CCS
  – At high NG prices, NGCC with CCS is higher cost than coal with CCS

Pre-Combustion CO_2 Capture

Overview

- Gasification at high pressure of any carbonaceous fuel 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 making pure H_2 & CO_2 - with units >3,500 t/d CO_2 capture operating
  - Of the >50 GWt (syngas) of commercial gasification plants now operating all except the few IGCC units (<8 GWt or <4 GWe) already have CO_2 capture
  - Over 500,000 hours operation of commercial GTs firing H_2 rich fuel, however 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 making steam in a boiler - such as high power/heat ratio cogen, clean transportation fuels & perhaps "the H_2 economy"

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 & 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

Oxygen-Combustion CO_2 Capture

Overview

- Replaces air with oxygen (O_2) combustion of any fuel plus mixed with a large CO_2 rich flue gas recycle or water injection to about the same properties, flows & 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 (only Ch. E. like IGCC or FGD)
- Can "theoretically" capture 100% of the CO_2 & avoid flue gas cleanup
- Potential advantage to retrofit existing systems, especially when oxygen replacement of air combustion can increase existing capacity
  - Perhaps cement kilns or fluid cat crackers (FCC) units in oil refineries

Advanced CO_2 Capture Tech. Under Development

Pre-combustion

- <u>Demonstrations</u> of H_2-IGCC with CCS by traditional coal-based utilities
- 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

- <u>Demonstrations</u> of large coal boiler power plants with CCS
- Longer-term: Alstom chilled ammonia CO_2 absorber/stripper to greatly reduce both the stripping steam & CO_2 compression power needs

Oxygen-combustion

- <u>Demonstrations</u> of large coal boiler power plants with CCS
- Longer-term: NG or syngas O_2 fired with water injected modified high temp. reheat gas/steam turbine of Clean Energy Systems

Needs <u>both</u> "learning-by-doing" & improved technology R&D

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 integrated in coal-based utilities

Post-combustion CCS is less developed but advantages for retrofits + viewed like FGD: familiar to coal-based utilities

Oxygen-combustion CCS is least developed but risks are minimal if large flue gas recycle to match traditional boilers

CCS costs for coal-based power mostly due to added capital

- CCS costs & performance will improve with time via both learning-by-doing as well as development of advanced technologies
- However, the more important issue than CCS cost reduction is gaining public acceptance of CO_2 geologic storage – requires big demos ASAP

Summary

Effectively protecting status quo & delaying CCS by waiting for the "leap-frog" advanced technologies of the future – forever!

Conservation & efficiency require major lifestyle changes plus regulatory changes & incentives to encourage both

Renewables & biofuels are great, but likely cannot generate big enough CO_2 reductions due to intermittent wind/solar power & biofuel impacts on food, land use + low net CO_2 reductions

Big enough CO_2 reductions to impact ppm of CO_2 in the atmosphere before the oil & gas peak, will likely require CCS

- The coal based power generators have the big CO_2 point sources, cannot move to China & less economic risks via regulated pricing
- The challenges are many: locations, liability, costs & <u>public acceptance</u>
  - Once CCS begins with coal can gain big "double CO_2 reduction" by co-processing waste biomass whenever it can be economically delivered