Opportunities for Low Cost CO_2 Mitigation via Existing and Future Industrial Gasification CO_2 Vents

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by

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Presentation Overview

Background

- SFA Pacific work on CO_2 mitigation & CO_2 capture & storage (CCS)
- All CO_2 mitigation options required but CCS is likely most important
- Business Roundtable and its recent macroeconomic analysis trying to estimate the cost of CO_2 mitigation to the U.S. economy

CCS economics for the Business Roundtable analysis

- Definitions: CO_2 avoidance costs are best, CO_2 capture costs confuse
- SFA Pacific CCS screening model
- Modifications of the SFA Pacific CCS model for the BRT analysis
- Results of the CCS costs for the BRT analysis

Conclusions

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Background of SFA Pacific CO_2 Mitigation and CCS Related Projects

1989: present: CO_2 Capture analysis for EPRI

2001: Private Multiclient Analysis of CO_2 Mitigation Options

2002 - present: 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 – Member IPCC group awarded the 2007 Nobel Peace Prize along with Al Gore

2007: CCS costs for Canada Gov. & Industry Working Group

2008: CCS costs of both new coal power plants (PC & IGCC) and industrial gasification for the Business Roundtable

2009: CCS costs of existing of coal power plants 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 & energy intensity in the USA & China

- **USA - 20% of world man-made CO_2, however, also 20% of world GDP**
- **China - 21% of world man-made CO_2 surpassing the USA in 2006**

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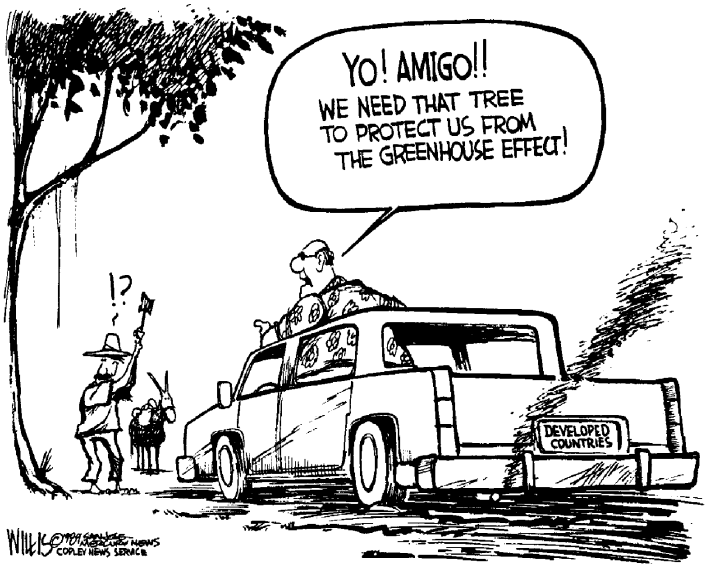

Source: Scott Willis of the San Jose Mercury News (California)

Classic Ugly American Confess "US" with U.S.

Standard of Living & Fossil Fuels Consumption

The fundamental greenhouse gas (GHG) issue of fairness

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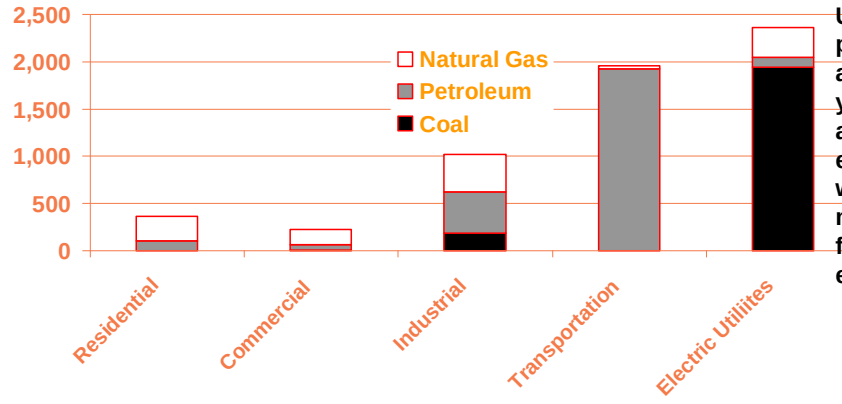
USA 2005 CO_2 Emissions By Sector & Fuel

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

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



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

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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

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 cannot 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 & potential to co-process waste biomass for double reductions as CO_2 taxes increase**

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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 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/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

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Business Roundtable - Overview

"Business Roundtable (www.businessroundtable.org) is an association of chief executive officers of leading U.S. companies with over $4.5 trillion in annual revenues and more than 10 million employees. Member companies comprise nearly a third of the total value of the U.S. stock market and represent more than 40 percent of all corporate income taxes paid to the federal government."

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Business Roundtable CO_2 Mitigation Analysis

Macro-economic analysis of the impact of CO_2 mitigation on the U.S. economy – called "Sustainable Growth Initiative"

- **Project managed and led by Keybridge Research a Washington, DC "K Street" consulting firm**
  - **Macroeconomic modeling by U of Maryland "INFORUM" team**

Best public overview of project is Keybridge President Robert Wescott's U.S. Senate Briefing dated July 14, 2008

Nine working groups with 5-10 key BRT members in each

- **Wind/solar, Biofuels, CCS, Coal, Efficiency (non-transportation), Expanding Access, Grid Modernization, Nuclear, Transportation**
- **CCS working groups members include: AEP, Arch Coal, Chevron, Duke, Eastman, ExxonMobil, Peabody, Praxair & Southern Company**

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How SFA Pacific Become Involved

Seven of the nine BRT CCS working group members are SFA Pacific clients – thus they knew of our CCS screening model

Eastman wanted industrial gasification included in additional to traditional major focus on coal & NG power gen. CCS costs

- **Eastman was right-on - of the >30 GWt (syngas) large-scale commercial coal gasification plants operating worldwide, all have large CO_2 capture except the few coal-IGCC units ~ 2 GWt syngas into 1 GWe power**
  - **Most industrial gasification utilize high H_2/CO ratio syngas thus large CO shift & CO_2 capture to a pure CO_2 vents, regardless of CO_2 mitigation issue**

The SFA Pacific CCS model was able to quickly & cost effectively be modified to estimate without & then with CCS costs for coal & NG based power gen. as well as industrial gasification - all on a totally consistent & transparent basis

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SFA Pacific CCS Model Structure & Challenges

Essential to understand CO_2 avoidance cost formula as it is impacted by baseline, fuel price & unit CO_2 emissions

\$/t CO_2 avoided = (\$/MWh$_{CCS}$ - \$/MWh$_{BAU}$) / to atm (t CO_2/MWh$_{BAU}$ - t CO_2/MWh$_{CCS}$)

- **CO_2 avoidance is thus the CO_2 tax where adding CCS economics starts making economic sense vs. the lower capital & CO_2 storage risk (but higher operating cost) of just paying the CO_2 emissions tax and/or changing from coal to lower CO_2 emissions fuel, like NG**

Trying to estimate energy project capital & required product prices are dangerous to your professional health these days

- **From 2005 until about Oct. 2008 equipment, material, engineering & construction costs were all escalating at very high rates due to massive developments in China plus worldwide oil/NG developments**
- **Since about Oct. 2008. big drop in oil/NG prices + financial crisis & recession is quickly killing projects & but also reducing costs**

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Keybridge Set Key Input Basis & Requests

Constant 2008 dollars (no future dollars or escalation rates)

Capital costs without capitalization of interest during construction or other special site specific owner costs

Capital charges: levelized simple 14% per year of total capital

- **Similar to typical overall rates for power gen. with debt leveraging**
- **Lower than typical industrial rates at usually less to no debt leveraging**

Economics requested for 2008 + every 5th year 2010 to 2050

CO_2 tax: starting in 2015 with both a low and high CO_2 tax case

- **Low case starts at \$21/metric ton CO_2 in 2015 to \$118/mt CO_2 in 2050**
- **High case starts at \$51/metric ton CO_2 in 2015 to \$197/mt CO_2 in 2050**

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SFA Pacific CCS Model Run for BRT

All cases with the same fuel analysis & feedrate w/wo CCS

- **This made it easy to see the net capacity & efficiency losses of CCS**
- **Midwest bit coal basis for 630 MWe PC/IGCC both 38.5% HHV wo CCS**
  - **CTL: 12,000 bbl/d, SNG: 80 MM scf/d & H_2:265 MM scf/d all wo CCS**

All similar technologies with similar designs w/wo CCS

- **Gasification based on 3 HP GE quench gasifiers <u>except</u> IGCC wo CCS GE IGCC reference design: 2 bigger gasifiers with radiant coolers**

Additional extra 10% contingencies for just gasification & CCS whereas all cases with the same 85% annual load factor

- **Power gen was baseline, thus for consistency industrial gasification designs had no spare gasifier (just like IGCC) & the same 85% annual load factors (industrial gasification usually has added capital cost of a spare gasifier but also higher annual load factor)**

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Original Energy Prices Inputs Were a Problem

Keybridge's original energy price inputs were directionally questionable as they projected NG prices going down during much of the time CO_2 taxes were going up

- **That is highly unlikely as NG prices & demand would increase as CO_2 taxes increase due to more NG replacing coal**
  - **See EPRI May 22, 2008 Congressional Staff Briefing – key slide 19**

As expected, SFA Pacific model economics showed coal with or without CCS was usually not economical vs. NG options

BRT CCS working group comments on this first run were useful

- **Suggested higher energy costs, especially NG as CO_2 tax increased**
  - **Revised higher energy costs now look high with today's low prices**
- **Suggested the SFA Pacific model power plant capital costs were low**

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SFA Pacific CCS Model Second Run Changes

Increased SFA CCS costs for coal power units to <u>force match power costs ($/MWh) with the newest EPRI CCS costs</u>

- **EPRI data of September 16, 2008 at MIT Carbon Sequestration Forum**
- **EPRI GE IGCC reference design no CCS - 32% higher capital than PC**
  - **EPRI GE IGCC costs - higher radiant syngas cooler than GE quench & even GE quench with entire CCS were lower total capital (not $/kW)**
    - **EPRI GE IGCC reference (no CCS) design at $2.08 billion for 630 MWe**
    - **EPRI GE quench IGCC (no CCS) at $1.68 billion for 600 MWe**
    - **EPRI GE quench IGCC <u>with CCS</u> at $1.92 billion for 520 MWe**
- **EPRI post combustion CCS was higher loss in capacity & efficiency**

Net changes to SFA CCS model in second run: CO_2 avoidance cost of pre over post & oxy for CCS was bigger but higher $/MWh & NG price before coal is competitive (w/wo CCS)

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SFA Pacific CCS Cost to Keybridge for BRT

SFA Pacific CCS screen model results were inputted into a Keybridge supplied complex spreadsheet with requested data specified by the macroeconomic modelers at U. of Maryland

Total of 12 complex spreadsheets:

- **6 options (NGCC, PC, IGCC, CTL, SNG & H_2) times low & high CO_2 tax**
  - **NG prices were $1-2/MM Btu higher for high vs. low CO_2 tax case**
- **2008 then every 5 years to 2050 for 10 different year columns of various inputs & requested data w/wo CCS**

Unclear what will end-up in the final BRT report currently being reviewed and may become public this summer

- **Of the 9 BRT working groups expect biofuels, CCS & nuclear to be the most contentious & economically complex CO_2 mitigation options**

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SFA Pacific Concerns About BRT CCS Costs

High capital costs thus high product & CCS costs - unclear if other BRT working group costs are relatively consistent

- **Renewables & nuclear groups commonly assume: optimistic capital costs, include subsidies without mentioning & optimistic "learning curves"**

Revised higher energy prices projected to 2050 now higher than current energy prices (all in constant 2008 dollars):

Oil	**$17.24/MM Btu ($100 per barrel) constant for all years**
NG	**$8.52/MM Btu in 2010 to $17.20 in 2050 for low CO_2 tax cases**
NG	**$8.52/MM Btu in 2010 to $19.11 in 2050 for high CO_2 tax cases**
Coal	**$2.11/MM Btu in 2010 to $2.09 in 2050**

Lower energy prices now by limit the interest in this analysis

Never addressed the much higher CO_2 avoidance costs for our >300 GWe of existing coal power plants - SFA Pacific recently addressed this in a MIT project at http://web.mit.edu/mitei/

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SFA Pacific CCS Cost to Keybridge for BRT

CCS avoidance costs lower for industrial coal gasification than any power case but all CCS cases requires higher NG prices to compete

	CO_2 Avoidance Cost	Product cost with CCS but no CO2 tax
Industrial gasification pre CCS	$30-38/mt	$16.50-19.50/MM Btu
NGCC post combustion	$100/mt	$108/MWh electric
PC post combustion	$ 66/mt	$122/MWh electric
IGCC pre (from PC, not IGCC base)	$48/mt	$106/MWh electric

Power cost "triple point" lowest CO_2 avoidance as CO_2 tax of $48/mt and NG price of $11.15/MM Btu has the same power costs of $113/MWh for three key options: NGCC & PC without CCS (just pay CO_2 tax) and cheapest coal with CCS - IGCC (avoid paying most of CO_2 tax)

Industrial coal gasification "triple point" for lowest NG price at which it is competitive: H_2 case at only $$9.80/MM Btu NG & $38/mt CO_2 tax

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Summary

SFA Pacific CCS screening model was used for CCS economics in the Business Roundtable analysis of CO_2 mitigation costs

- **Public report likely this summer, but unclear what will be included**
- **Without/with CCS costs for new coal & NGCC power plants + industrial coal gasification: CTL, SNG & H_2 all on the same consistent basis**

Results show the lowest CCS costs of industrial gasification

- **CO_2 capture, sequestration "ready", regardless of CO_2 mitigation issue**
- **Likely limited overall CO_2 reduction until reforms to allow expansion into polygeneration for large cogen power sales to grid at a fair price**

BRT projected CO_2 tax & energy prices suggests coal with CCS via gasification becomes the lower cost CO_2 mitigation option

- **However, did not address the >300 GWe of existing coal power plants that likely require higher CO_2 tax than required for new power plants to economically encourage CO_2 mitigation**

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June 26 Update- BTR Report Now Public

The Business Roundtable release its major economic modeling study with policy recommendations to reduce GHG emissions, while minimizing economic consequences June 25

- **Can be down loaded at the following web site**

http://businessroundtable.org/sites/default/files/2009.06.24_The_Balancing_Act_FINAL.pdf

As expected, the renewable & nuclear working groups assume more optimistic estimates of cost, performance & improved learning curve with time than the CCS working group

- **Appears that only the CCS working group use the same learning curve factors as used by EIA in their Annual Energy Outlook (AEO) model**

- **More optimistic cost estimates and learning curves of wind & nuclear made them dominate future power gen., especially high CO_2 tax case**
- **Optimistic cost estimates cost estimate and learning curve of cellulosic ethanol (much lower CO_2 than coal ethanol) made it expand in future transportation while traditional oil stays dominate until high CO_2 tax**

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June 26 Update- BTR Report Now Public

Big losers in the BTR report:

- **Natural gas due to the high assumed NG prices**
  - **The shale NG promoters will be quite upset**
- **New coal power gen. until CCS starts to expand in the later years**
- **Existing coal power plants (only in the high CO_2 tax case)**

Big winners:

- **Renewables (mostly cellulosic ethanol and wind) plus nuclear**
- **Transportation:**
  - **Low CO_2 tax: clean diesels, gasoline hybrids and flex-fuel ethanol**
  - **High CO_2 tax: electric via plug-in hybrids & hydrogen via fuel cells with some coal to H2 & CLT both with CCS**
- **Electric:**
  - **Low CO_2 tax: nuclear followed by wind and old coal without CCS stays flat**
  - **High CO_2 tax: more nuclear & wind & big coal drop but more coal CCS**

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