SLIDES: Getting onto a Path for Stabilizing Atmospheric CO2 at 450 ppmv with “Near-at-Hand” Energy Technologies

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Climate Change and the Future of the American West: Exploring the Law and Policy Dimensions

Getting onto a Path for Stabilizing Atmospheric CO₂ at 450 ppmv with “Near-at-Hand” Energy Technologies

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OUTLINE

• Rationale for early action in mitigating climate change

• Introduction to Thought Experiment designed to explore feasibility of getting onto a 450 ppmv atmospheric CO₂ stabilization path using “near-at-hand” energy technologies

• Technologies considered for Thought Experiment

• Discussion of electricity and fuels used directly (FUD) components of total energy in Thought Experiment

• Estimation of incremental costs for low carbon energy supplies in Thought Experiment

• Lessons learned from Thought Experiment
RATIONALE FOR EARLY ACTION

• “Lock-in” carbon commitment from delay—e.g., lifetime C for ~ 1400 GW<sub>e</sub> coal electric capacity expected to be built 2003-2030 is comparable to:
  – historical global emissions from coal burning
  – 0.3 X 21<sup>st</sup> century C budget for 450 ppmv stabilization path

• For a given stabilization target, the alternative to early action is a more economically challenging steeper rate of decline in C emissions later

• Many low C technologies are “near-at-hand”

• Cost reductions via accumulating experience (“learning by doing”)

• Ancillary benefits: mitigation of air pollution/oil insecurity risks; first-mover technological leadership; manufacturing/construction employment opportunities via domestic clean energy production/infrastructure development
A 2 - 2.5 °C warming above pre-industrial level is often discussed as climate-change mitigation target (e.g., EU goal). Realization would probably require reducing atmospheric CO₂ concentration of 450 ppmv or less.

Is it feasible to mitigate climate change to this extent?
INTRODUCTION TO THOUGHT EXPERIMENT

- Is it technically and economically feasible to stabilize atmospheric CO$_2$ at 450 ppmv?

- What would be the major challenges?

- A Thought Experiment is developed to explore these questions

- It will be shown that such a stabilization goal is daunting but plausibly achievable...at least technically and economically

- Moreover, it is suggested that “near-at-hand” technologies (energy end-use efficiency + small # of energy supply technologies) could get us through the first $\frac{1}{2}$ century on this path
ASSUMPTIONS FOR GLOBAL ENERGY
THOUGHT EXPERIMENT, 2002-2061

- Emphasis on efficient energy use—extrapolate to 2061 energy demands of WEO 2004 Alternative Scenario (International Energy Agency):
  - GWP up 4.6 X by 2061 relative to 2002
  - Electricity generation up 2.6 X
  - Fuels used directly (FUD) up 1.8 X
  - Coal power generation fixed beyond 2030 at 2030 level

- New energy supply technologies emphasized:
  - Coal IGCC with CO₂ capture and storage (CCS)
  - Bioenergy with CCS (“negative CO₂ emissions”)
    - Biomass IGCC with CCS
    - F-T liquids from coal and biomass with CCS
  - Baseload electricity from wind + natural gas CAES (compressed air energy storage)

- Coal and biomass are completely “decarbonized” over 50 years (by 2061)…thereby “making room in atmosphere” for substantial fossil fuel expansion
OPTIONS FOR CO$_2$ STORAGE

- **Goal:** store 100s/1000s Gt CO$_2$ for 100s/1000s years

- **Major options:**
  - Deep ocean (*concerns about storage effectiveness, environmental impacts, legal issues, difficult access*)
  - Carbonate rocks (*safe, costly, embryonic*)
  - Geological media (*focus of current interest*)
    - Enhanced oil recovery (*likely to be major initial focus*)
    - Depleted oil and gas fields (*geographically limited*)
    - Beds of unminable coal (*CO$_2$ adsorbed in coal pore spaces*)
    - Deep saline aquifers—huge potential, ubiquitous

- **Most large anthropogenic CO$_2$ sources are within 0-200 km of geological disposal sites**
  (*800 km = longest US CO$_2$ pipeline for EOR*)

- **Experience:**
  - EOR (*30 million tonnes CO$_2$/y—4% of US oil production*)
  - Sleipner, North Sea—storage in aquifer under seabed
  - In Salah, Algeria—storage in natural gas field
  - Other projects being planned
MAIN MESSAGES ON CO$_2$ STORAGE FROM IPCC SPECIAL REPORT ON CCS (2005)

- IPCC is:
  - positive on geological storage,
  - not so positive on ocean storage/mineralization

- 66-90% probability that worldwide geo-storage capacity is at least 2000 Gt CO$_2$
  (fossil fuel emissions = 24 Gt CO$_2$ in 2002)

- IPCC estimates of fraction retained if geological storage reservoirs are carefully selected:
  - 90-99% probability that retained fraction will exceed 99% over 100 y
  - 66-90% probability that retained fraction will exceed 99% over 1000 y
Gasification in O$_2$/steam converts carbonaceous feedstock into syngas (mostly CO, H$_2$)

Water-gas-shift reaction (CO + H$_2$O $\rightarrow$ H$_2$ + CO$_2$) converts all or some CO

CO$_2$ is captured at high pressure/concentration
COAL IGCC WITH CO$_2$ CAPTURE/STORAGE (CCS)

~ 90% of coal C is captured/stored as CO$_2$

All components proven, commercially ready...though no integrated system has been built

Impacts of shifting from CO$_2$ venting to CCS:
- Coal input up ~ 1/6 with capture,
- Generation cost up ~ ¼ with capture,
- Generation cost up ~ 2/5 with capture/storage
BIOMASS IGCC WITH CCS

Similar to coal IGCC except that:

• S cleanup not needed
• Less O₂ needed to gasify biomass than coal
• No commercial biomass gasifier...but could be commercial by ~ 2015
• With ~ 90% of biomass C stored underground, these systems are characterized by strong negative CO₂ emissions that can offset emissions from difficult-to-decarbonize fuels (e.g., crude oil-derived transport fuels)
FISCHER-TROPSCH LIQUIDS FROM COAL + BIOMASS WITH CCS

- Same gasifiers as for coal/biomass IGCC
- Synthesis gas partially shifted to get H₂/CO ratio needed for synthesis in catalytic reactor
- Final products are synthetic diesel and gasoline
- Ultra-low net CO₂ emission rate exploiting negative emissions potential of photosynthetic CO₂ storage
- All components proven/commercial except biomass gasifier...which could become commercial ~ 2015
Net CO$_2$ emissions = 3.7 + 20.3 − 21.6 = 2.4 kgC/GJ of F-T liquids (~ 10% of rate for crude oil products)
Net CO$_2$ emissions = 3.7 + 20.3 − 21.6 = 2.4 kgC/GJ of F-T liquids (~ 10% of rate for crude oil products)

For comparison, the emission and storage rates per GJ of H$_2$ derived from coal with CCS are 1.3 and 1.7 times as large as for this F-T liquids option
CARBON/ENERGY BALANCES FOR MAKING FISCHER-TROPSCH LIQUIDS FROM COAL + BIOMASS WITH CCS

Net CO$_2$ emissions = $3.7 + 20.3 - 21.6 = 2.4$ kgC/GJ of F-T liquids (~ 10% of rate for crude oil products)

For comparison, the amount of biomass input required per GJ of conventional biofuels such as cellulosic ethanol is ~ 2X as much
Huge potential relative to electricity demand, but

- Wind intermittency $\rightarrow$ declining economic value with increasing grid penetration

- Best resources often remote from markets
CAN WIND PROVIDE BASELOAD POWER & COMPETE WITH FOSSIL ELECTRICITY AT HIGH GRID PENETRATION LEVELS?

Output power (fraction of demand) vs. Fraction of the year

“Normal” wind farm

Baseload demand

Required system uptime (assumed to be 90% for baseload power)
STEP 1: OVERSIZE WIND FARM

Fraction of the year

Output power (fraction of demand)

“Oversized” wind farm

“Normal” wind farm

Baseload demand

Required system uptime (90%)
Among storage options, compressed air energy storage (CAES) is especially attractive...offering good prospects that wind/CAES baseload units could compete with coal IGCC systems with CCS.
Compressed Air Energy Storage (CAES)

1) Excess power is used to compress air

2) Air is pumped underground and stored

3) When electricity is needed, stored air is utilized to run a gas turbine expander (fueled, e.g., with natural gas)
WHAT IS GEOGRAPHICAL AVAILABILITY
OF GEOLOGIES SUITABLE FOR CAES?

- Suitable geology for compressed air storage found over 80% of the area of the USA
- Locations coincident with high quality wind resources
- Also suitable CAES fuel (e.g., natural gas) must be available for wind/CAES systems deployment
FUELS USED DIRECTLY IN THOUGHT EXPERIMENT

Projected F-T liquids use in 2061 = 1.3 X oil use in 2002
Emissions from electricity and from fuels used directly—by component, 2002 and 2061

Fuels used directly account for 60% and 103% of emissions in 2002 and 2061, respectively.
44% of CO₂ emissions from oil in 2002 $\rightarrow$ less dependence on oil via end-use efficiency + fuel switching to realize deep reduction of CO₂ emissions
NG is least C-intensive fossil fuel that can typically be used at higher efficiency than other fossil fuels → large role for NG in thought experiment
Oil + NG emissions exceed total emissions after 2060
...and coal emissions have not even been considered!
COAL ROLE IN THOUGHT EXPERIMENT

After 2060 coal C extracted from ground ~ 7 GtC/y...rate of global CO\textsubscript{2} emissions from fossil fuel combustion in 2002

Coal is most C-intensive fossil fuel...but also most abundant, least costly, most secure

...and it is the fossil fuel for which CCS is least costly
Coal + biomass are completely decarbonized by 2061, when CO₂ storage rate exceeds 2002 emission rate.
Global bioenergy potential (long-term): ~ 100-300 EJ/y (World Energy Assessment, 2000)
NET NEGATIVE EMISSIONS FROM COAL + BIOMASS WITH CCS AFTER 2060 BRINGS TOTAL EMISSIONS IN LINE WITH 450 PPMV TRAJECTORY
COST OF MITIGATING CLIMATE CHANGE FOR ENERGY SUPPLY IN THOUGHT EXPERIMENT

PW of future cost (8% discount rate) ~ $1 trillion (1/2 cost of Iraq War) = 0.07% of PW of future GWP
LESSONS LEARNED

• With technologies “near at hand” can plausibly move along 450 ppmv stabilization path for ~ ½ century...at modest cost

• Electricity is far easier to decarbonize than FUD

• Fossil CCS and renewable energy/energy efficiency are complementary—not competitive strategies

• More nuclear electricity would not change emissions outlook

• Huge CCS effort is required to decarbonize FUD

• Can we reduce future FUD demand via more energy efficient energy use and/or find ways to shift more FUD to electricity?

• Radical new technologies needed for second ½ of century....liquid fuels via artificial photosynthesis?