Global Warming and Carbon Management – Timing, Costs, Priorities

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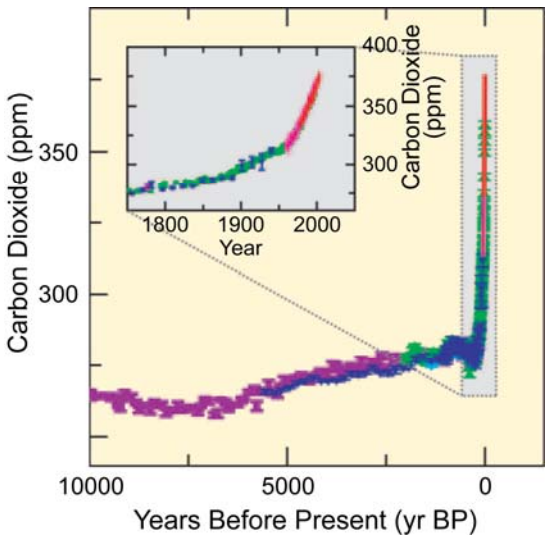
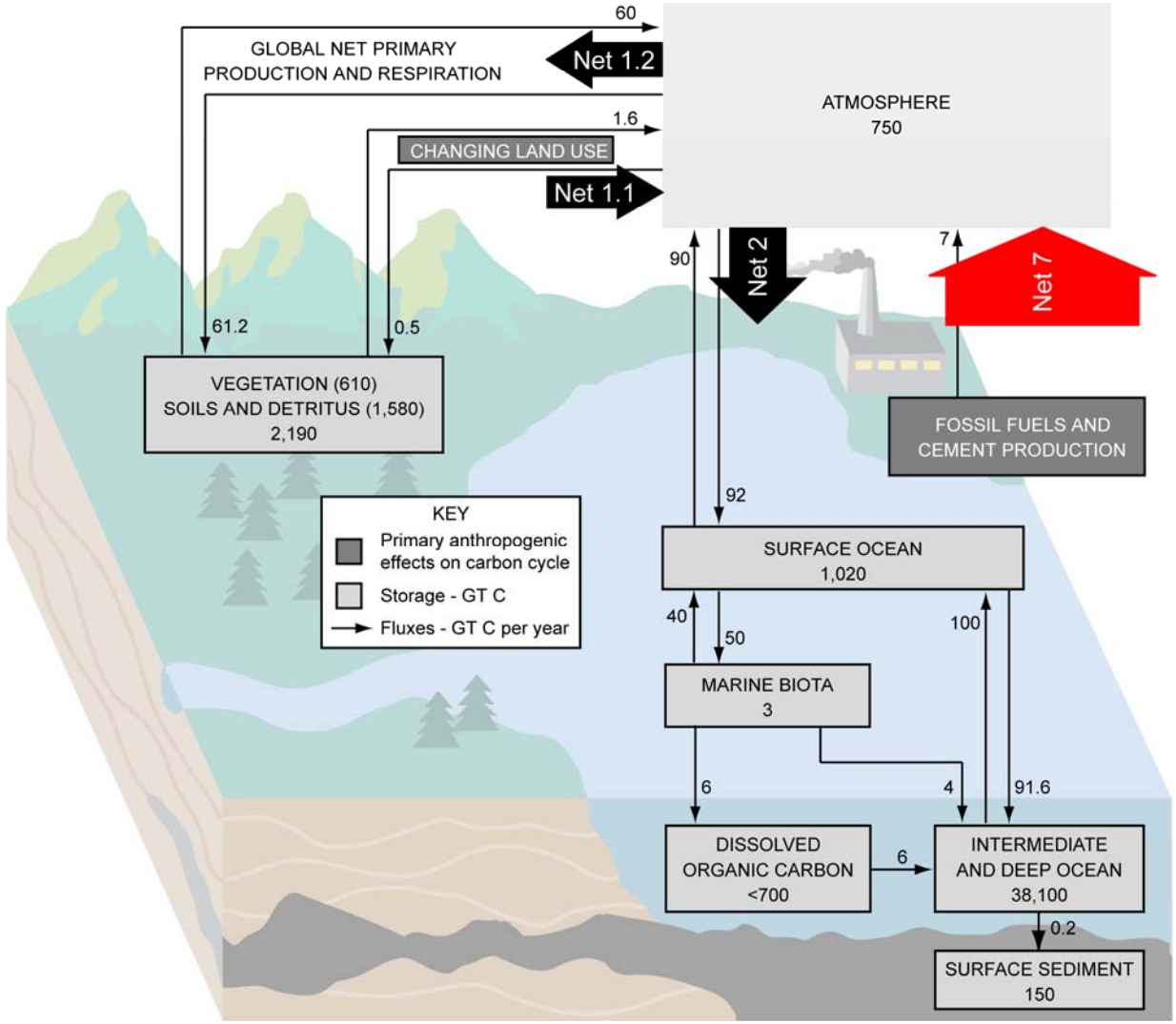
GEOLOGICAL CO2 STORAGE

Key Issues for Geologic Carbon Sequestration

- Motivation
  - Carbon capture and storage (CCS) is necessary for stabilization of CO_2 levels in atmosphere
  - CCS alone is not sufficient for stabilization
  - Time is of the essence
    - Geologic carbon storage (GCS) technology available now

Anthropogenic CO_2 emissions comparable to net fluxes in Earth's carbon cycle

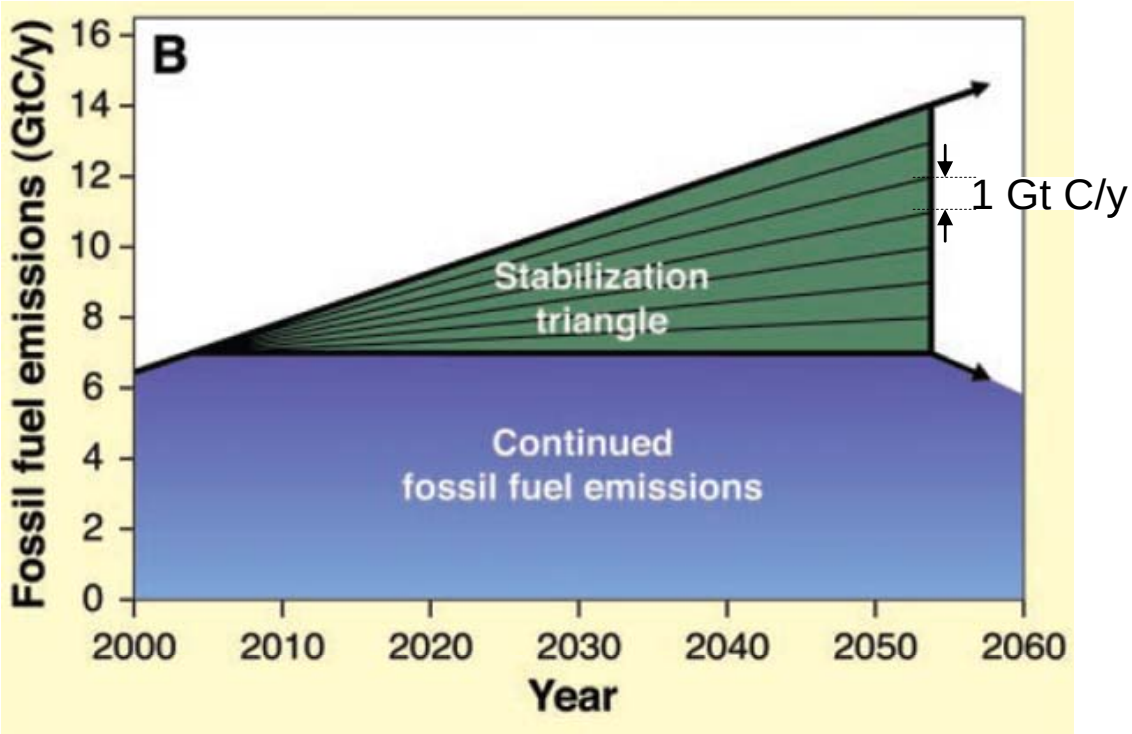




Source: OSTP NanoEnergy Brief, 10 August 2005, available at www.er.doe.gov/bes/presentations/OSTP_NanoEnergyBrief_10AUG05.pdf
(based on D. Schimel, D. Alves, I. Enting, M. Heimann, F. Joos, D. Raynaud, and T. Wigley, 1996: "CO_2 and the Carbon Cycle").

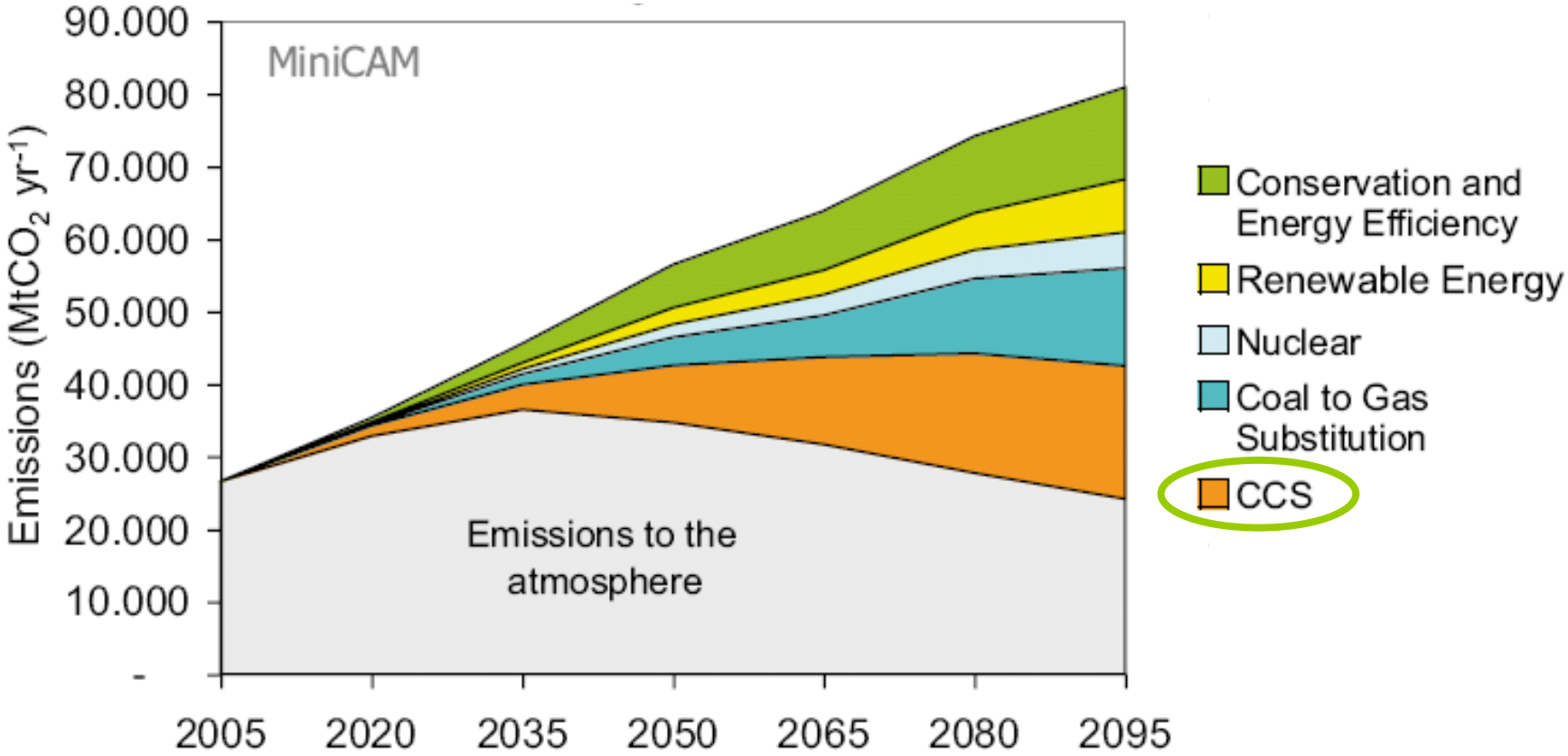
CCS necessary – but not sufficient

Wedges of CO_2 emissions



Pacala and Socolow, *Science* **305**:968, 2004

CCS necessary – but not sufficient



IPCC SRCCS Technical Summary

Key Issues for Geologic Carbon Sequestration

- Feasibility
  - GCS must be implemented at scale of existing oil & gas industry
  - Storage capacity estimates are not time-weighted
  - Two prerequisites for CCS industry
    - Price for carbon
    - Regulatory framework

Storing 1 Gt/y carbon is same magnitude as current global oil and gas business

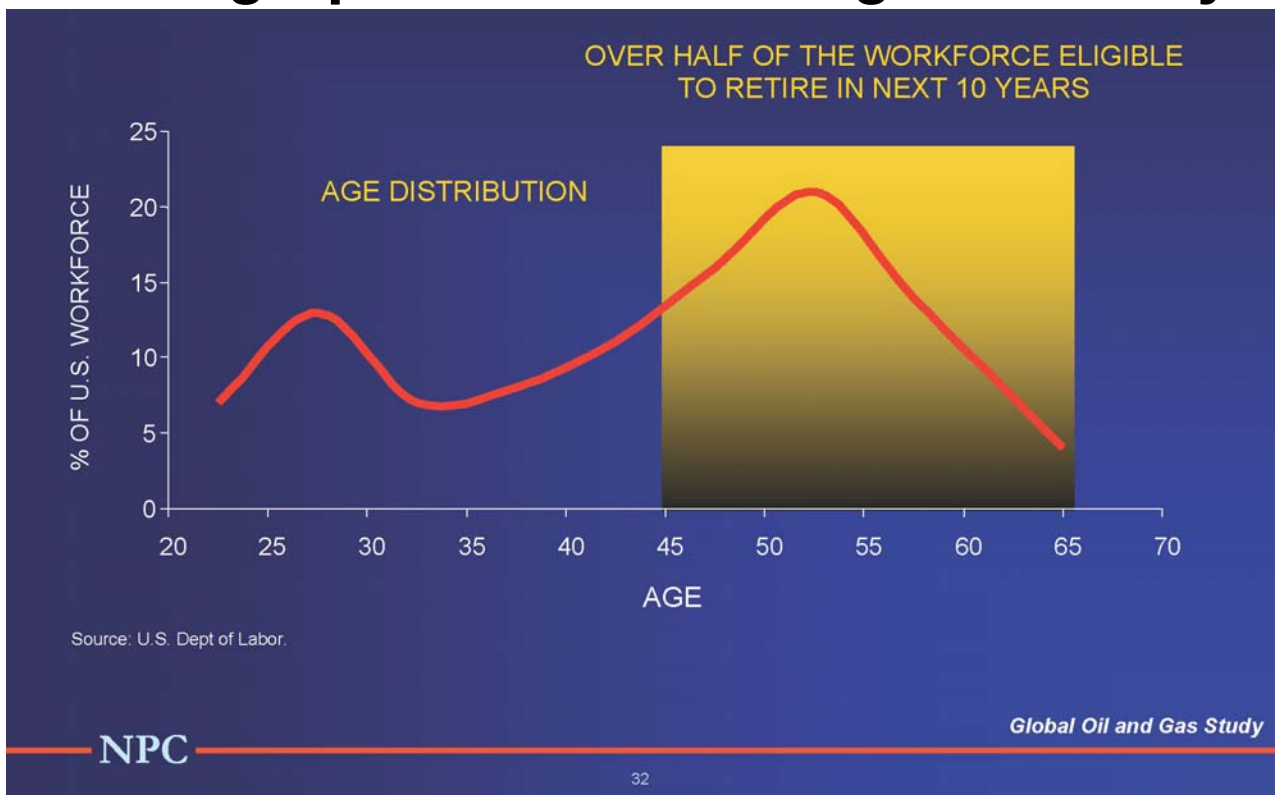
- One wedge of CO_2 sequestration
  - Injection rate at deep aquifer conditions
    - 17 million m^3/d
    - **100 MMBD**
  - Transportation from sources to sinks
    - **190 BCFD**
- Global upstream business, 2007
  - Oil consumption
    - 13 million m^3/d
    - **85 MMBD**
  - Gas production
    - **285 BCFD**
  - Permian Basin CO_2 pipeline capacity for enhanced oil recovery
    - 4 BCFD

Key Issues for Geologic Carbon Sequestration

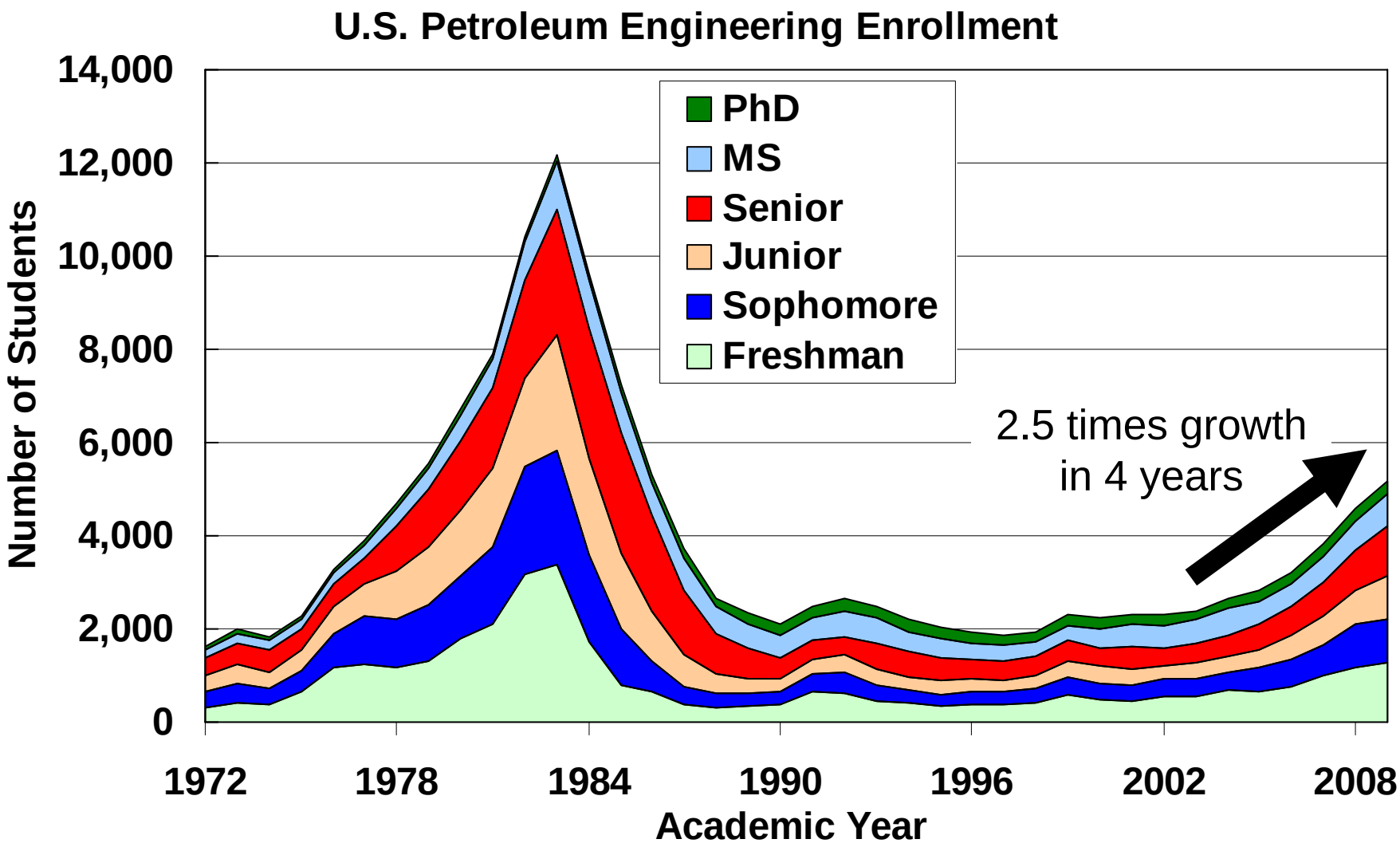
- Hurdles
  - Single biggest gap
    - Lack of human capital: subsurface engineers
  - Single biggest environmental risk
    - Avoid displacing brine into groundwater
  - Single biggest legal difficulty
    - Acquiring rights to vast volume of pore space
  - Single biggest political/economic risk
    - Getting public to pay
  - Single biggest technical risk
    - Low-cost assurance of secure storage

Demand for Subsurface Engineers by Oil & Gas (US) will Strain Education Capacity for Next 20 Years

Demographics of US oil & gas industry



Subsurface Engineering Educational Capacity in the US is Already Full



GCS and Brine Displacement

- Conventional CO_2 storage
  - Displaces equal volume of brine
  - Pressure elevation extends farther than CO_2
- Unconventional CO_2 storage
  - Deep ocean sediment
  - Deep ocean basalt
  - Surface dissolution
    - Inject saturated brine

Natural gas storage industry as analogue to GCS industry

- Natural gas storage
  - 8 TCF (in US)
  - Typical project 75 BCF
- CO_2 storage
  - Cumulative (in US to 2050) ~100 Gt CO_2
    - Need pore space equivalent to **750 TCF** natural gas
  - Typical project ~100 Mt CO_2
    - **700 BCF** natural gas pore space equivalent

Curry et al., GHGT7, paper 137. Will citizens pay for solutions to GHG emissions?

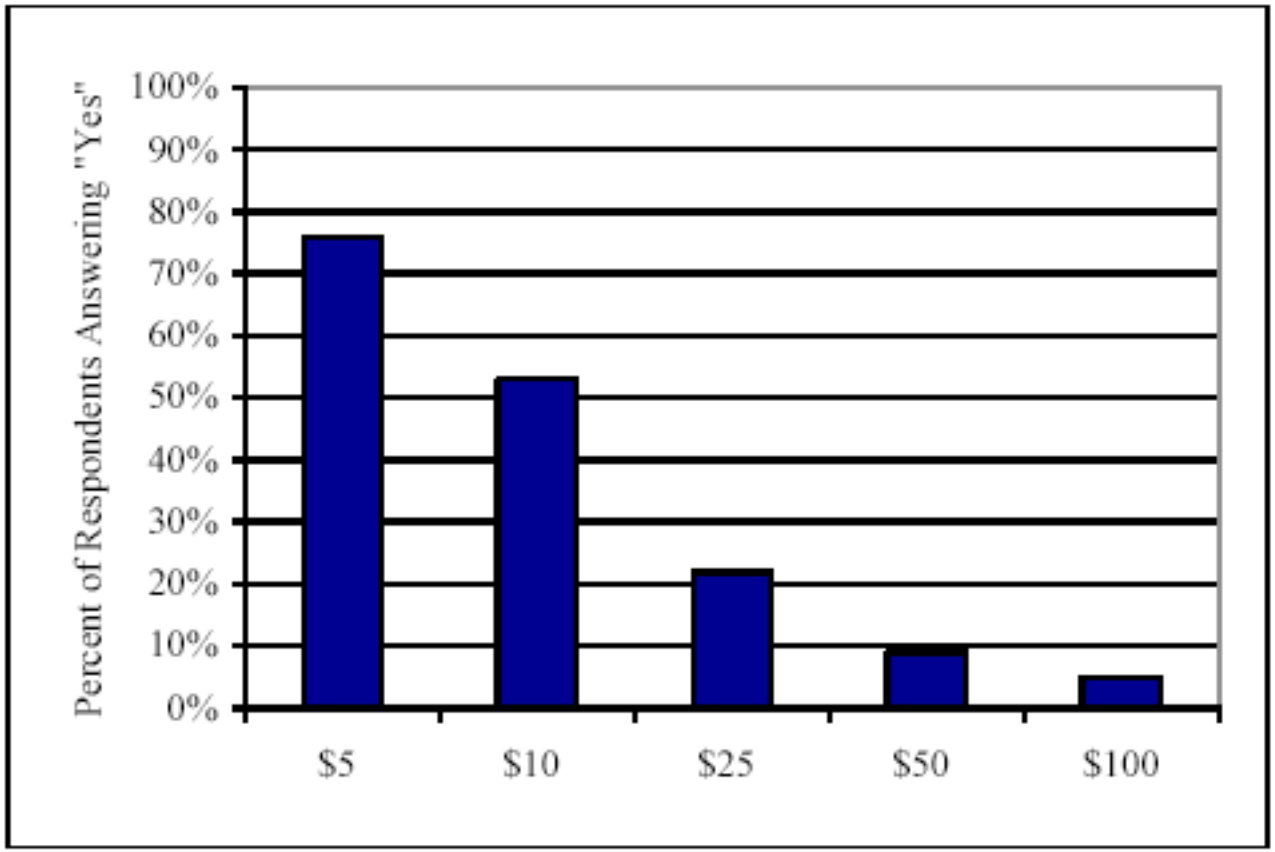
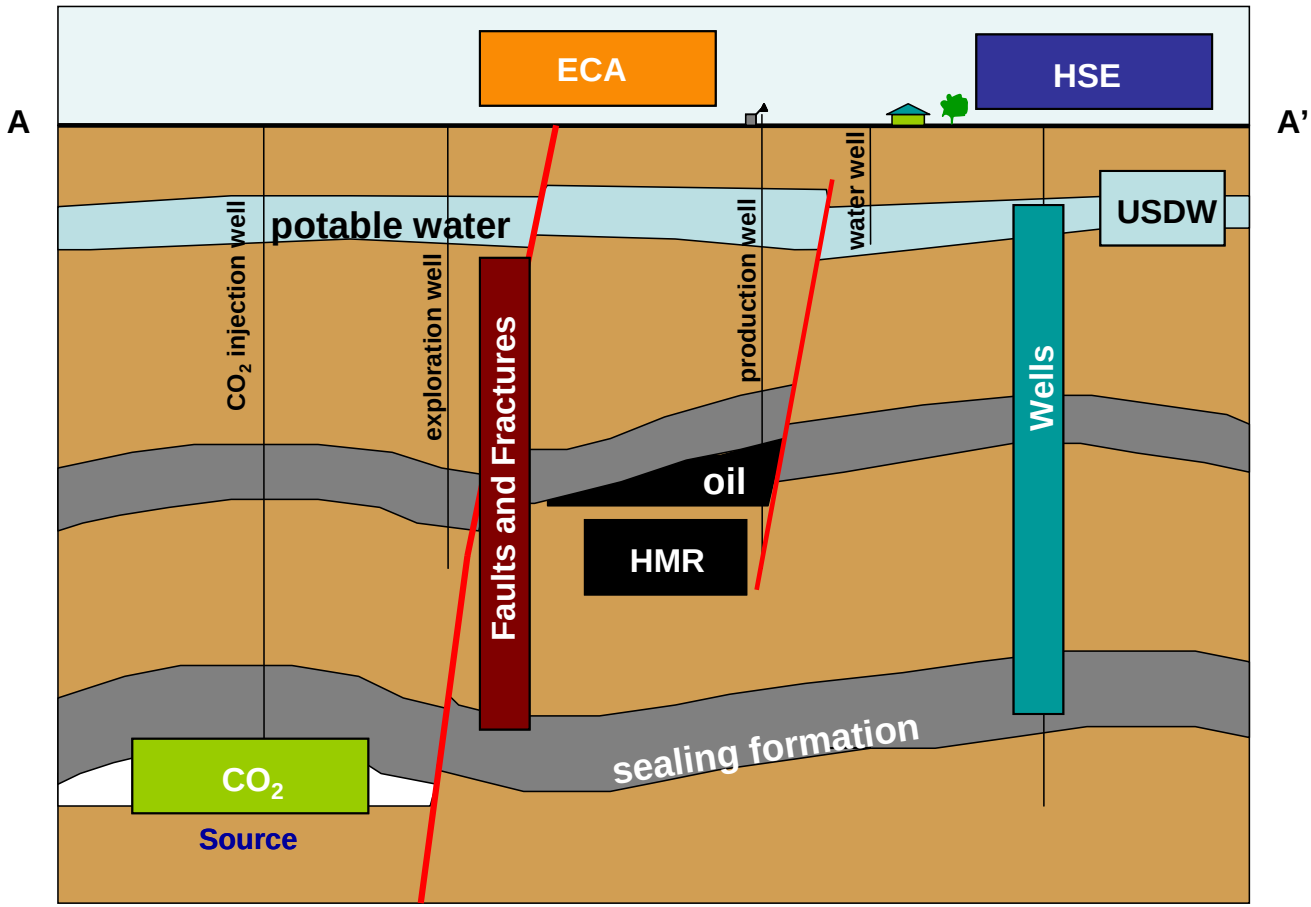


Figure 4. Response to: ***If it solved global warming, would you be willing to pay ___ more per month on your electricity bill?*** **Percentage of respondents who answered "yes" to each dollar amount is shown.**

Substantive Carbon Storage Will Require Regulation Comparable to Oil & Gas, USDW



GCS and Leakage Risk

- Conventional CO_2 storage
  - Density CO_2 less than density of brine
- Unconventional CO_2 storage
  - Deep ocean sediment
  - Deep ocean basalt
  - Surface dissolution
    - Inject saturated brine
    - No bulk phase CO_2 in subsurface