Sulfur Markets to Carbon Markets

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LECTURE NUMBER 19
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Class News

- Some business
  - Nina Mendelson is set for March 30.
    - This Friday
    - Time: 10:00 AM
    - Room TBD

Readings for Mendelson

- Minimum, pp. 1-5 and 8-11 of petitioner Massachusetts's brief to the Supreme Court. That brief is posted at: http://www.abanet.org/publiced/preview/briefs/pdfs/06-07/05-1120petitioners.pdf

- In addition, pp. 1-5, 7-9, and 20-25 of the US government's response, which is posted at: http://www.abanet.org/publiced/preview/briefs/pdfs/06-07/05-1120respondents2.pdf

  In addition, here is the relevant text of Section 202(a) of the Clean Air Act for you to pass along: "The Administrator [of EPA] shall by regulation prescribe . . . standards applicable to the emission of any air pollutant from any class or classes of new motor vehicles or new motor vehicle engines, which in his judgment cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare."

  Section 302(g) of the Clean Air Act defines "air pollutant" as "any air pollution agent or combination of such agents, including any physical . . . substance or matter which is emitted into or otherwise enters the ambient air." 302(h) states that "effects on welfare" include "effects on soils, water, crops, . . . wildlife, weather . . . and climate . . ."

Class News

- New experimental web site
  - http://climateknowledge.org/class/aoss605/tiki-index.php
- Lecture Road Map
  - 3/6: Rood, Science-Policy-Business, Sulfur Market as Model, Link to Next Set of Lectures
  - 3/8: Lemos, Winners and Losers
  - 3/13 & 3/15: McCormick and O'Neill, Public Health
  - 3/20: Andy Hoffman, Business and Climate Change
  - 3/22: Phil Rasch, Geo-engineering
  - 3/27: Rood, Sulfur Market to Carbon Market
  - 3/29: Bierbaum, Energy, National Policy, Adaptation
  - 4/3: Rabe: Local and State Initiatives: Policy Development
  - 4/5, 4/10, 4/12, 4/17

Ideas and Things

- NEWS: Anyone hear or read any news they want to discuss – or come back to?
  - Carry away messages from the last classes>

Projects

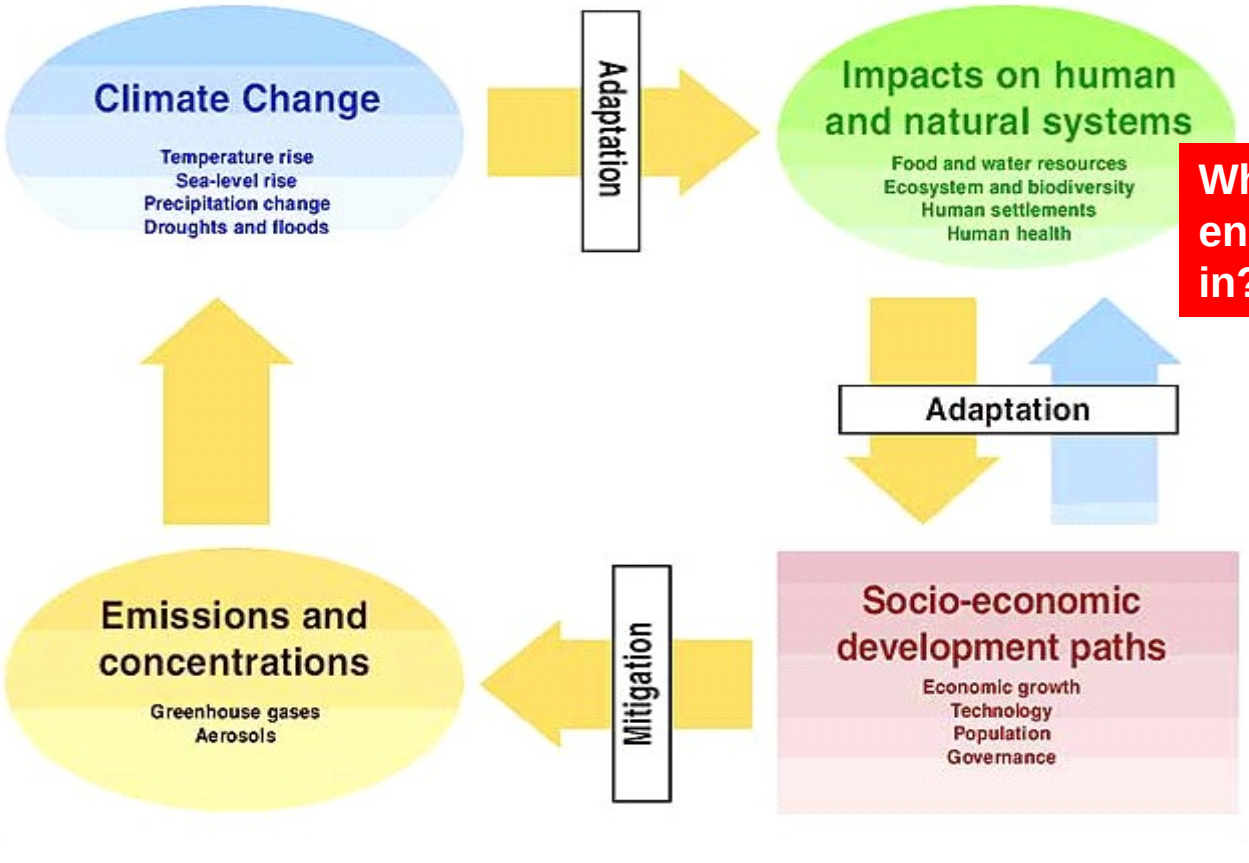
Outline

- Sulfur Market as a Model

Science, Mitigation, Adaptation Framework

Adaptation is responding to changes that might occur from added CO_2

It's not an either / or argument.



Mitigation is controlling the amount of CO_2 we put in the atmosphere.

Basic Management

- If there is a goal which you must meet, then you need to manage towards that goal.
  - If the goal is critical to success,
  - If the goal must be met on some schedule,
  - then this raises the level of management that is needed.

Basic Management

- In management of complex problems (with no known solutions)
  - You manage towards a set of possible solutions
  - The first steps are just that, first steps. They should be viewed as mutable, iterative. They help define the next steps.
  - There is at the beginning no known solution. Therefore, don't try to define the solution at the beginning.
  - There is constantly changing information and beliefs and priorities. Need to manage in the presence of this change.

NEED CARBON POLICY

- We need a carbon policy which is integrated with energy policy.
  - Some alternative energy sources don't do much for reducing carbon dioxide in atmosphere.
  - Coal is viewed as our easy energy security
    - Without sequestration (carbon removal), coal makes the problem worse.

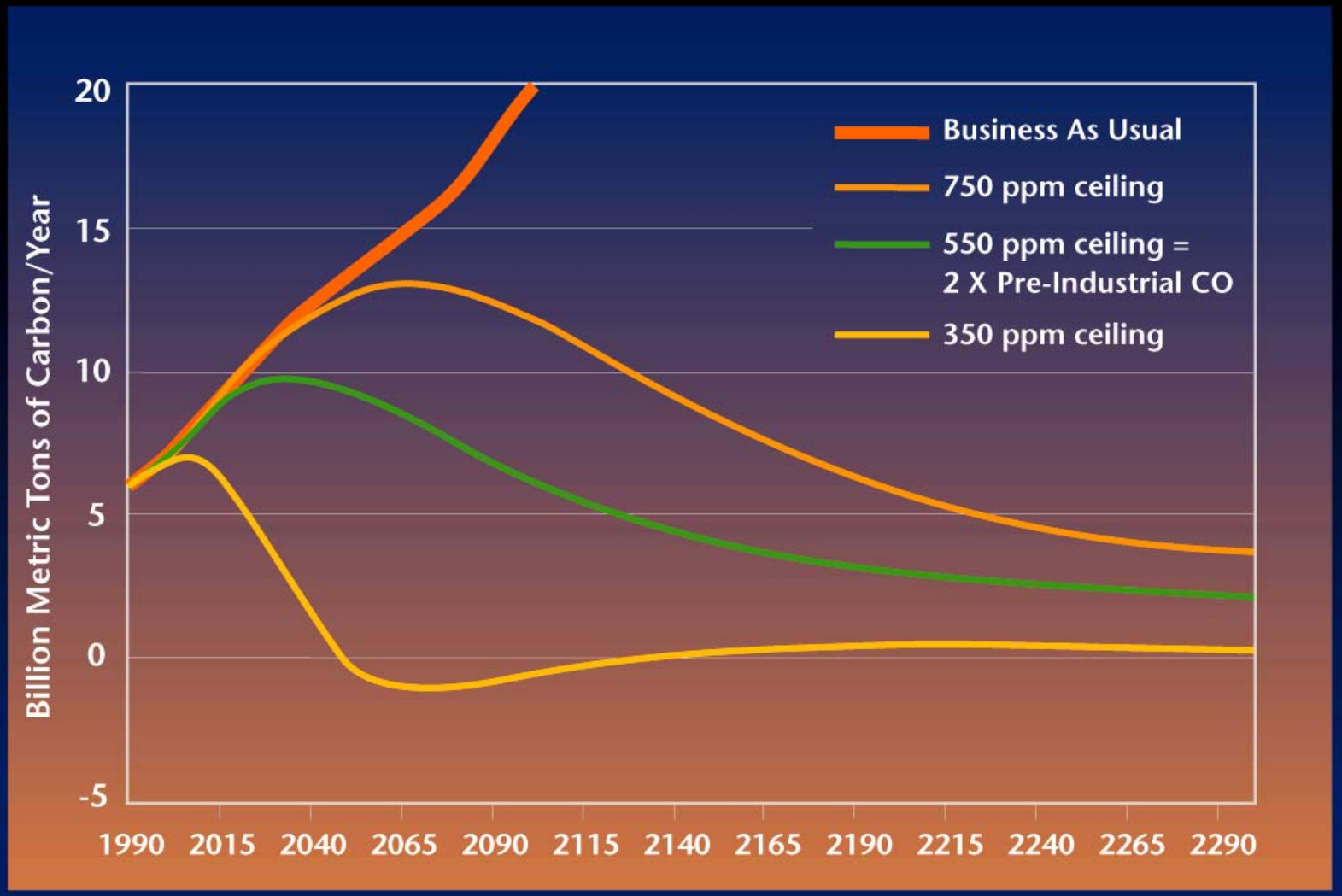
- Concern: Quest for energy security-national security, demand for cheap energy will reduce priority we give to reduction of carbon dioxide in the atmosphere.

Some carry away messages

- Determine what is a tolerable ceiling for carbon dioxide.
  - Gives cap for a cap and trade system.
  - Tolerable ceilings have been posed as between 450 and 550 ppm.
    - Ice sheet melting and sea level?
    - Oceanic circulation / The Gulf Stream?
    - Ocean acidification?
- Determine a tolerable measure of increased temperature
  - British policy → 2^{o} C

Basic constraint on carbon policy

Atmospheric Stabilization Emissions Paths



Basic constraint on carbon policy

Stabilizing concentrations Means Action Now …

This gives us a nominal time scale of 10 years.

Ceiling (ppmv)	350	450	550	650	750
Start Date	Too late	2007	2013	2018	2023
Max Emission	6.0	8.0	9.7	11.4	12.5
Max Year	2005	2011	2033	2049	2062

1950 – 1.8 tons // 1990 – 5.8 tons // 2000 – 6.5 tons

A personal conclusion

- If we are going to manage the climate change problem, as opposed to fixing it, we need to develop a stable, integrated policy.
  - This is a massive task.
  - Are there new paradigms for developing this?
    - Do we have to rely on ozone model?
    - Do we have to rely on sulfur model?

Where does this leave us?

CLIMATE CHANGE ↔ ENERGY

ENVIRONMENTAL SECURITY
ENERGY SECURITY
FOOD SECURITY
NATIONAL SECURITY

CARBON / ENERGY POLICY

P1 P2 Pn

UNCERTAINTY
INFRASTRUCTURE
RISK // OPPORTUNITY
LIABILITY

ECONOMY
Cost of Mitigation / Adaptation ↔ BUSINESS

OTHER MOTIVATORS

MARKET-BASED SOLUTIONS?

Market-based Solutions

- Based upon success of the sulfur market.
  - Provides flexibility in meeting the goal of reduced sulfur emissions
- For large parts of the world money and markets constitute the link between different elements of society, nations.
  - Infrastructure of developed society
  - Assumption that it is value based

Sulfur Market as a paradigm for CO_2 Market

- How is the same how is it different?

Cost-effective regulation

- Context: SO_2 emissions (1980 baseline)
  - 14.92 million tons of SO_2
  - primarily from coal-fired electricity generation
  - acidification of lakes, rivers, and forests
- Acid Rain Program (1990)
  - 1990 amendments to Clean Air Act
  - SO_2 allowance market
- The “Cap”
  - 8.95 million tons per year of SO_2 …therefore,
  - 5.97 million tons per year of SO_2 abatement

Cost-effective regulation (cont.)

- "cost effectiveness": what is the least-cost way of achieving a specific goal?
- Goal – "The Cap"
  - SO_2 emissions of 8.95 million tons per year
- Cost: SO_2 abatement cost
  - Aggregate cost: abatement cost summed over all electricity generators
- Policy tool – "Cap-and-trade" program
  - Theoretical finding: a market provides the incentive for companies to undertake least-cost abatement in the aggregate.

Cost-effective regulation (cont.)

Estimates for the SO_2 market:

Abatement cost without trading = $1.82 billion/yr

Abatement cost with trading = $1.04 billion/yr

(least-cost abatement)

Cost savings = $0.78 billion/yr

Cost-effective regulation (cont.)

- The “trade” in “cap and trade” is environmentally neutral
  - The cap remains fixed regardless of trading activity
- The cap is the intersection of science-based knowledge and the market

Company compliance decisions

- Context: SO_2 “allowances”
  - An allowance = 1 ton of SO_2 emission
  - Companies (electricity generators) are given a “quota” -- a fixed number of allowances each year

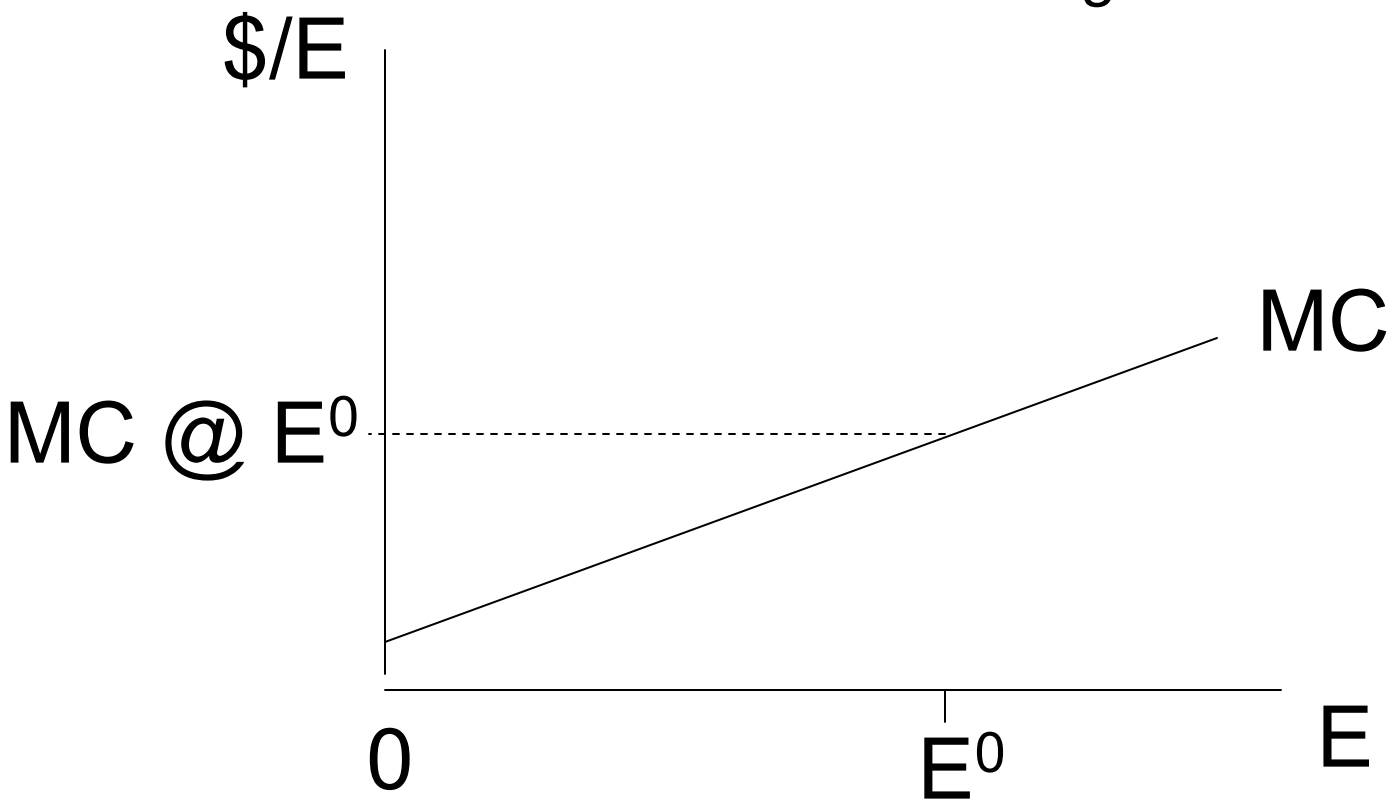
- Compliance options:
  - Without trading: Reduce SO_2 emissions to comply with their quota
    - Install new abatement technology (SO_2 “scrubbers”)
    - Use cleaner fuel sources (e.g., switch to low-sulfur coal)
    - Produce less electricity (typically not considered!)

Example (Detailed Link)

- Monroe Power Plant (Monroe, MI)
  - Owned by Detroit Edison
  - 4th largest coal-fired power plant in country
- 2004 data
  - 95,364 allowances allocated
  - 99,735 tons of emissions
  - 4,371 tons in excess
    - Purchased these on the market
    - Or, banked them from a prior year

Marginal cost (MC) of abatement (cont.) (without trading)

The area in red is the company's total cost of abating to E^0.



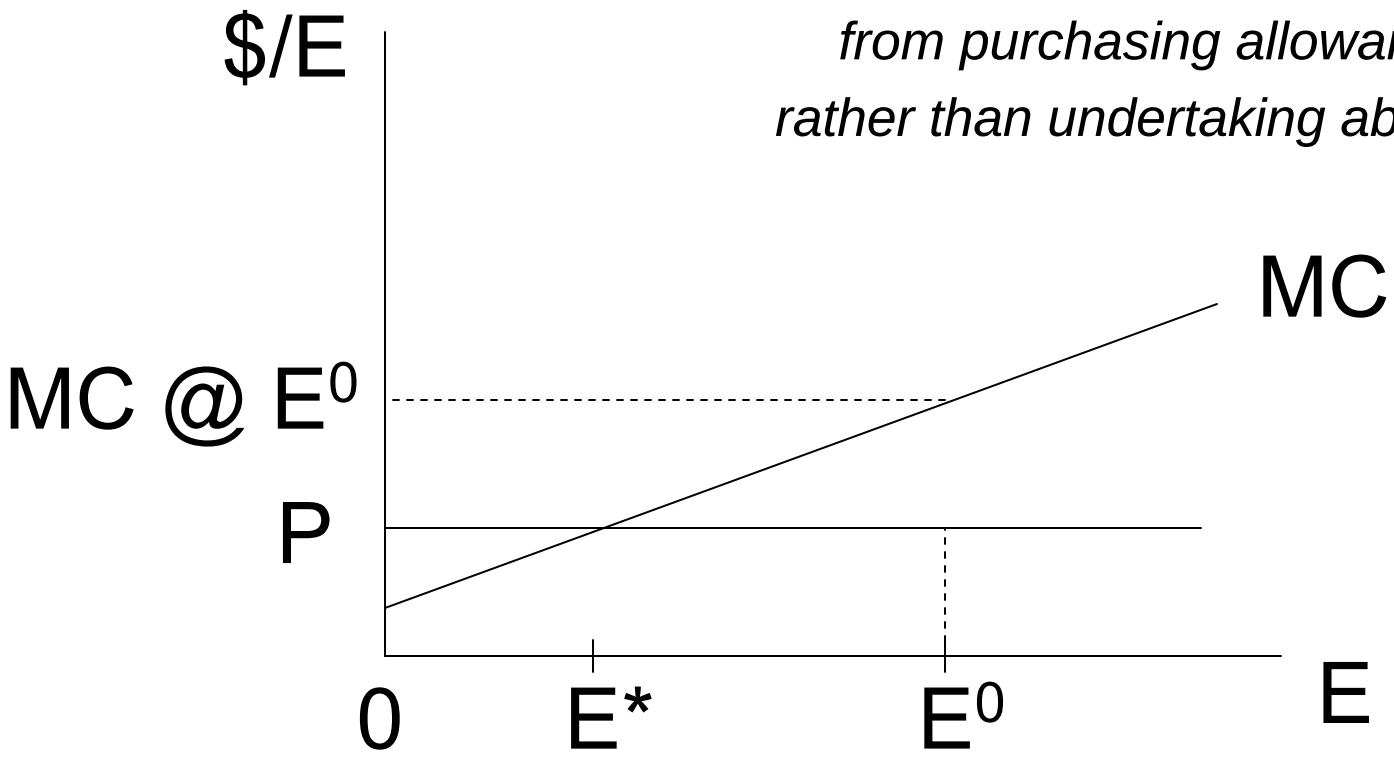
Company compliance options (with trading as an option)

- Compliance options:
  - Without trading: Reduce SO_2 emissions to comply with their quota (scrubbers, low-sulfur coal)
  - With trading: *Same options as above* ***plus***
    - Purchase allowances at the market price (P)

Purchasing allowances as a compliance option

At price P, the company purchases ($E^0 - E^*$)

The area in red is the cost savings from purchasing allowances rather than undertaking abatement



Cost-effective regulation (*repeat*)

Estimates for the SO_2 market:

Abatement cost without trading = $1.82 billion/yr

Abatement cost with trading = $1.04 billion/yr

(least-cost abatement)

Cost savings = $0.78 billion/yr

43% reduction in abatement cost!!!

General results

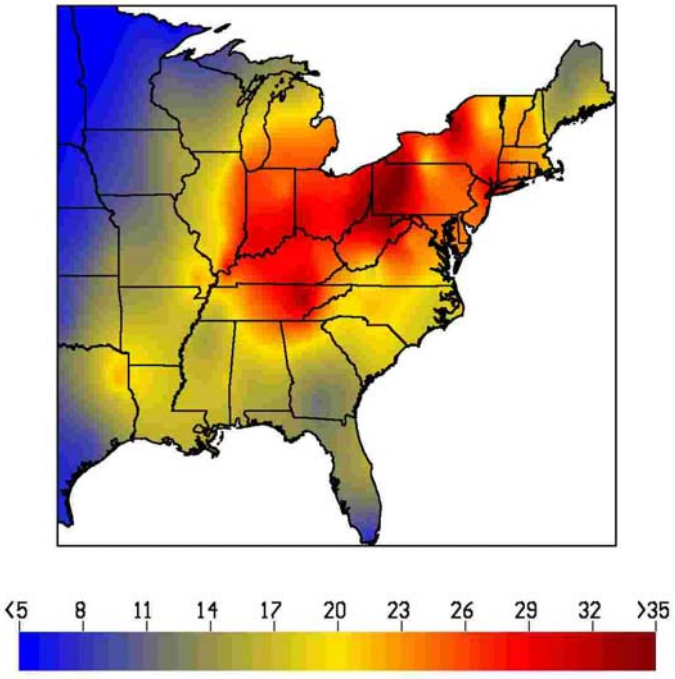
- **P < MC** implies a *buyer* on the market
  - A buyer saves money by purchasing allowances to cover its emissions.
- **P > MC** implies a *seller* on the market
  - A seller makes money by undertaking extra abatement and selling its excess allowances.
- These incentives give rise to least-cost abatement.
  - We achieve cost-effective regulation
- The existence of this tension or balance between marginal cost and price of abatement implies that there is a market. There are options.
  - There is the requirement that
    - The purchased allowance is a real reduction of sulfur
    - That P (Price per share) comparable to Marginal Cost (of abatement).

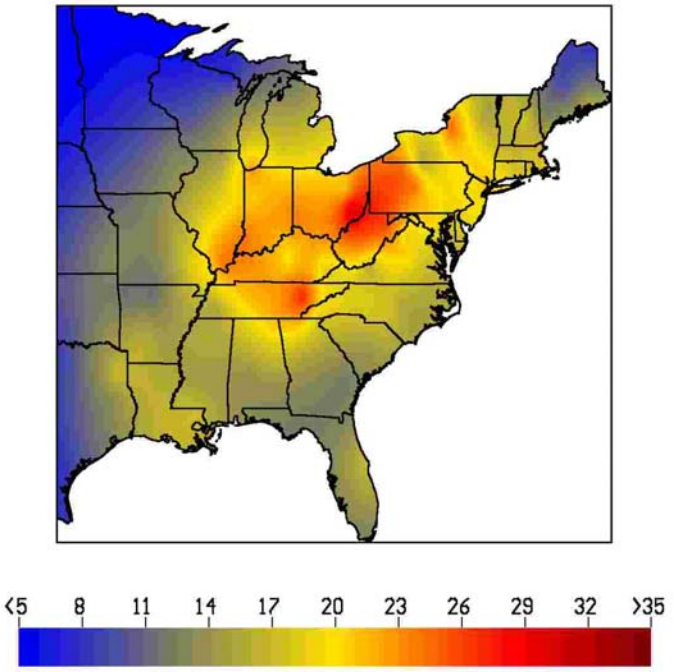
Some Specifics of Acid rain program and evidence on the SO_2 market

The Acid Rain Program

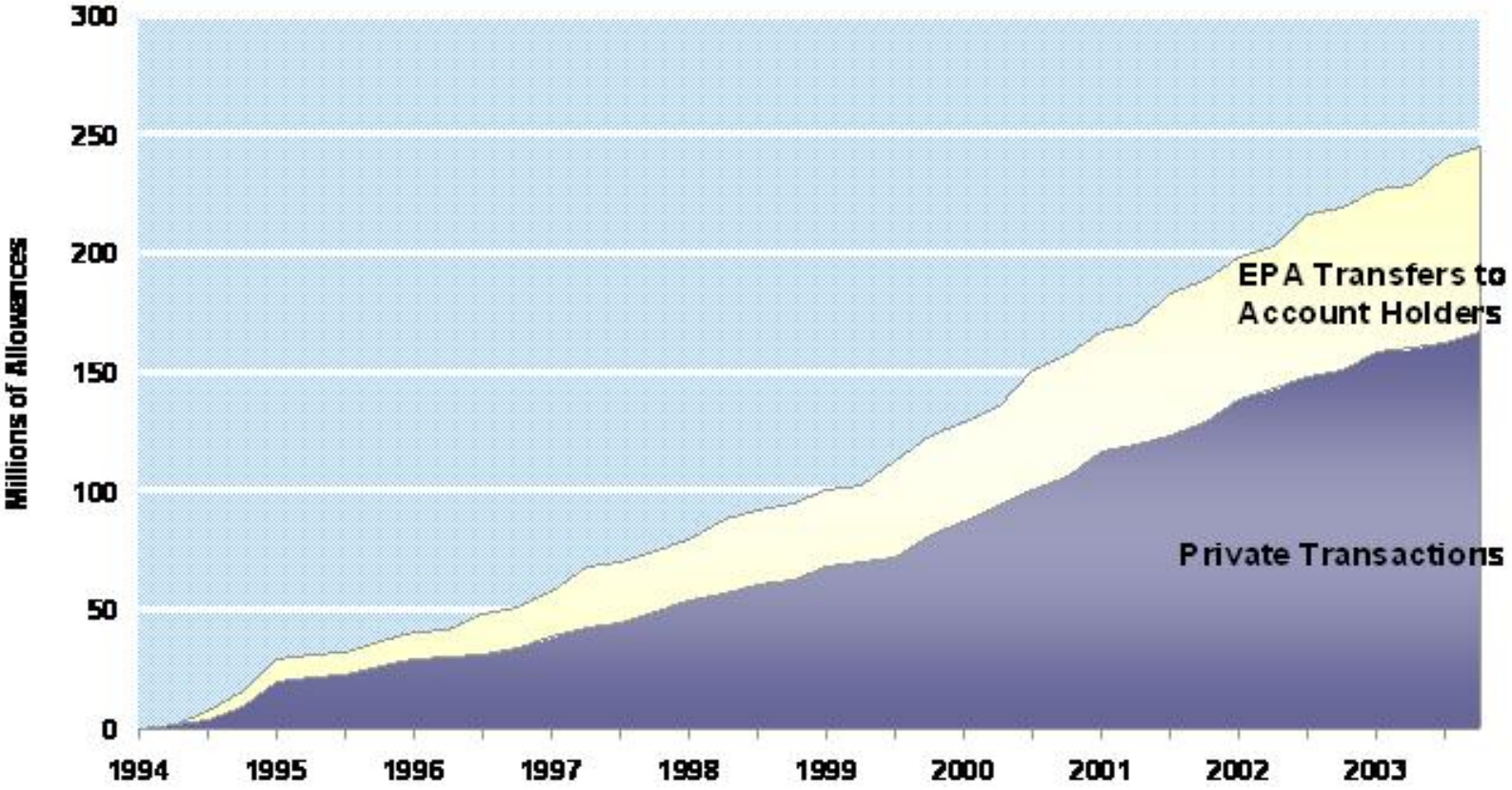
- Phase I: 1995-1999
  - 110 dirtiest electric power plants
  - 7-8.7 million allowances allocated per year
- Phase II: 2000-2010
  - All fossil-fueled electric power plants
  - 9.2-10 million allowances allocated per year
- After 2010: 8.95 million allowances/year
- Banking of allowances permitted

Trends in Wet Sulfate Deposition in the Eastern United States (1989-1991 vs. 1995-1998)

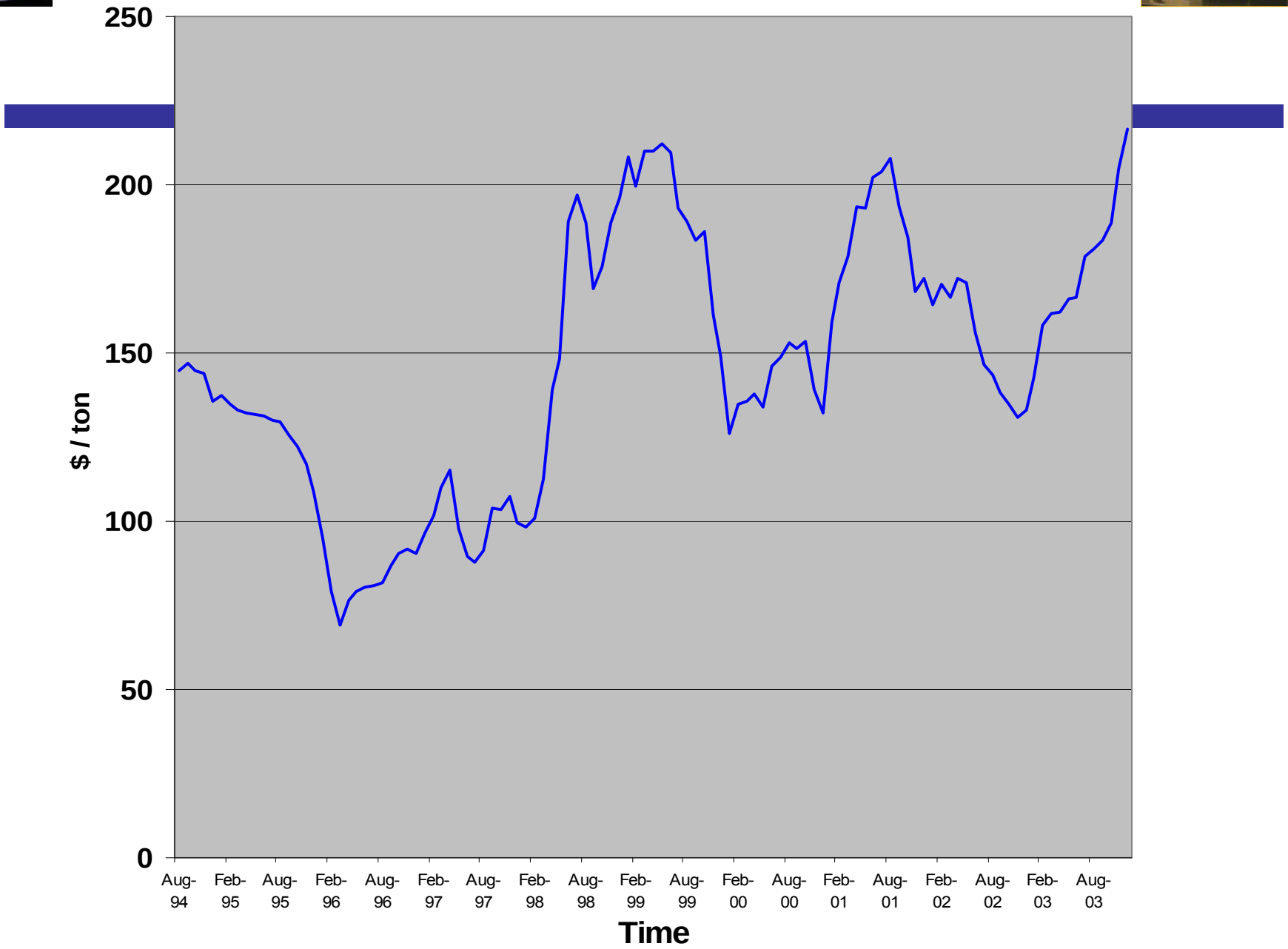




Cumulative SO_2 Allowances Transferred (through 2003)



SO2 Spot Market Prices, Aug 1994 - Dec 2003



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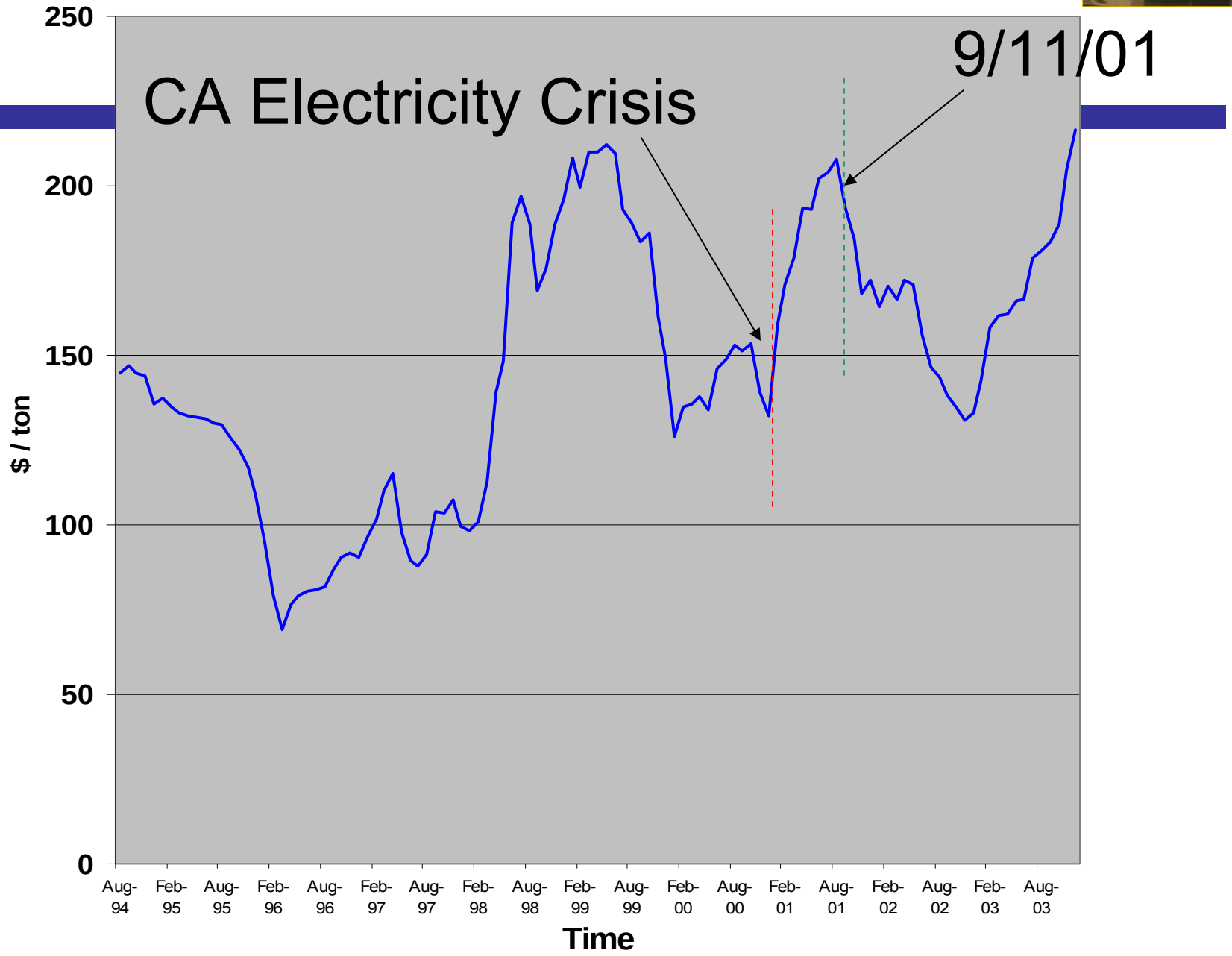


Other air pollution markets under the Clean Air Act

- Nitrogen oxides (NO_x)
  - Precursor to smog (ground-level ozone)
  - Adverse effects on respiratory system
  - Interstate market for NO_x in 19 eastern states
- Mercury
  - Impaired brain and nervous system development in infants and children
  - Neurological disorders in adults
  - *Proposed* market for mercury
  - Very controversial. Concern about "hot spots" – mercury emissions concentrated in a relatively small geographic area.

CO_2 markets to implement climate policy

(details of EU Market)

- Kyoto Protocol (1997)
  - Participating nations: ~ 7-8% below 1990 emissions
  - European Union's CO_2 market most advanced
  - Expansion to all participating nations
- Kyoto's Flexibility Mechanisms
  - Emissions Trading System (ETS)
    - Can comply by purchasing CO_2 credits from the ETS market
  - Joint Implementation (JI)
    - Can comply by purchasing CO_2 credits from an entity in an industrialized country
  - Clean Development Mechanism (CDM)
    - Can comply by purchasing CO_2 credits from an entity in a developing country

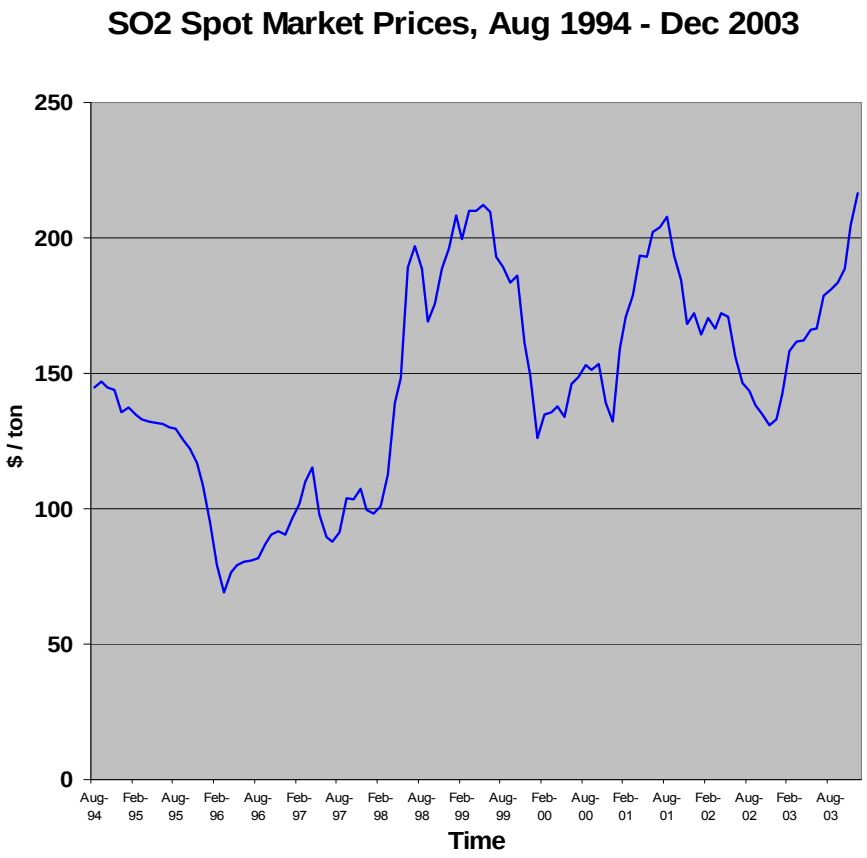
Miscellaneous issue: emission tax vs. cap-and-trade

- Regulated firms strongly prefer cap-and-trade
  - quota distributed for free – enormous $$ value!
  - compare to: tax per unit of emissions
- Monroe power plant example
  - 95,364 SO_2 allowances allocated for free in 1994
  - All allowances were used to cover emissions
  - What if taxed at $200/ton?

95,365 * 200 = $19,073,000

Emission tax vs. cap-and-trade (cont.)

- The regulator likes the certainty of the cap; tax has an uncertain effect on aggregate emissions
  - Environmentalists probably like this certainty, too
- Example: volatile SO_2 prices, yet certain cap.



Emission tax vs. cap-and-trade (cont.)

- What politician will support a tax program?
  - Clinton/Gore's failed BTU tax, early in 1st term
- Cap-and-trade as the consensus strategy …at the moment.

Conclude: Political economy of cap-and-trade programs

- Environmentalist perspective
  - Set the cap as low as politically feasible
- Business perspective
  - Maintain flexibility in compliance options
  - Cap and trade is most flexible
- Regulator perspective
  - Buy-in from stakeholders
    - Good for environment *and* cost effective
  - Enforceable

Many environmental organizations are now advocates for cap-and-trade programs

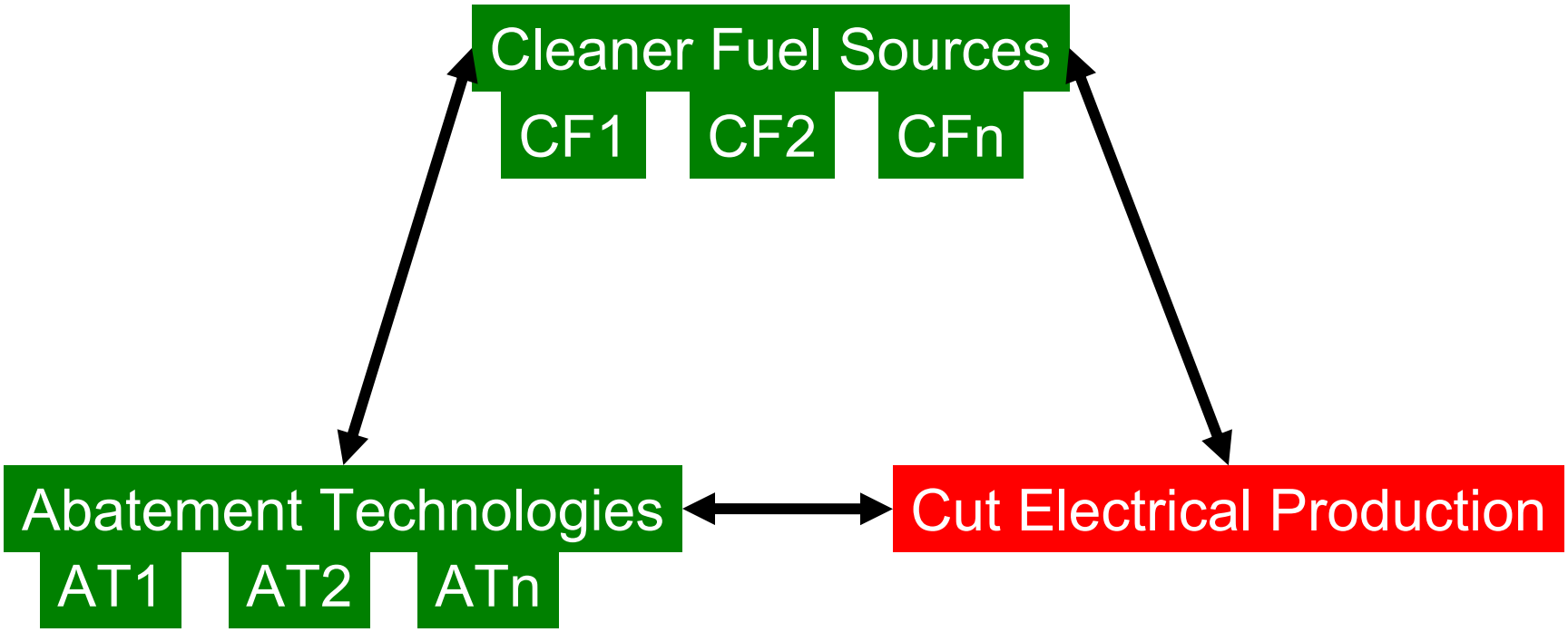
Further Reading

- Tom Tietenberg, *Environmental and Natural Resource Economics*, 7th Edition, 2006.
  - It includes several chapters on environmental regulation—both principles and applications.
- Ellerman, Joskow, Schmalensee, Montero, and Bailey, *Markets for Clean Air: The U.S. Acid Rain Program*, 2000.
  - An exhaustive evaluation of the acid rain program and SO_2 market by a team of great economists.

Some Market Issues

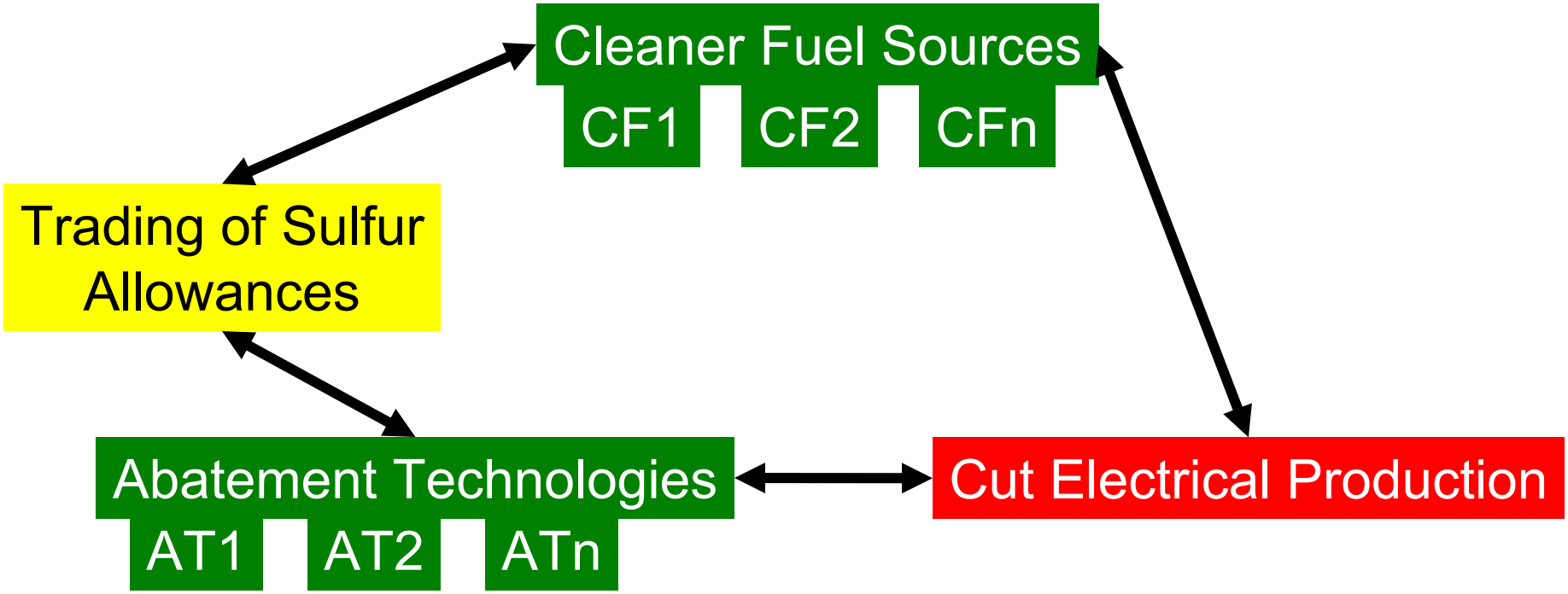
- How do we make a carbon market?
- What is the role of allowances?
  - Savings relative to what baseline?
- Cost of allowance relative to other choices?

Sulfur market



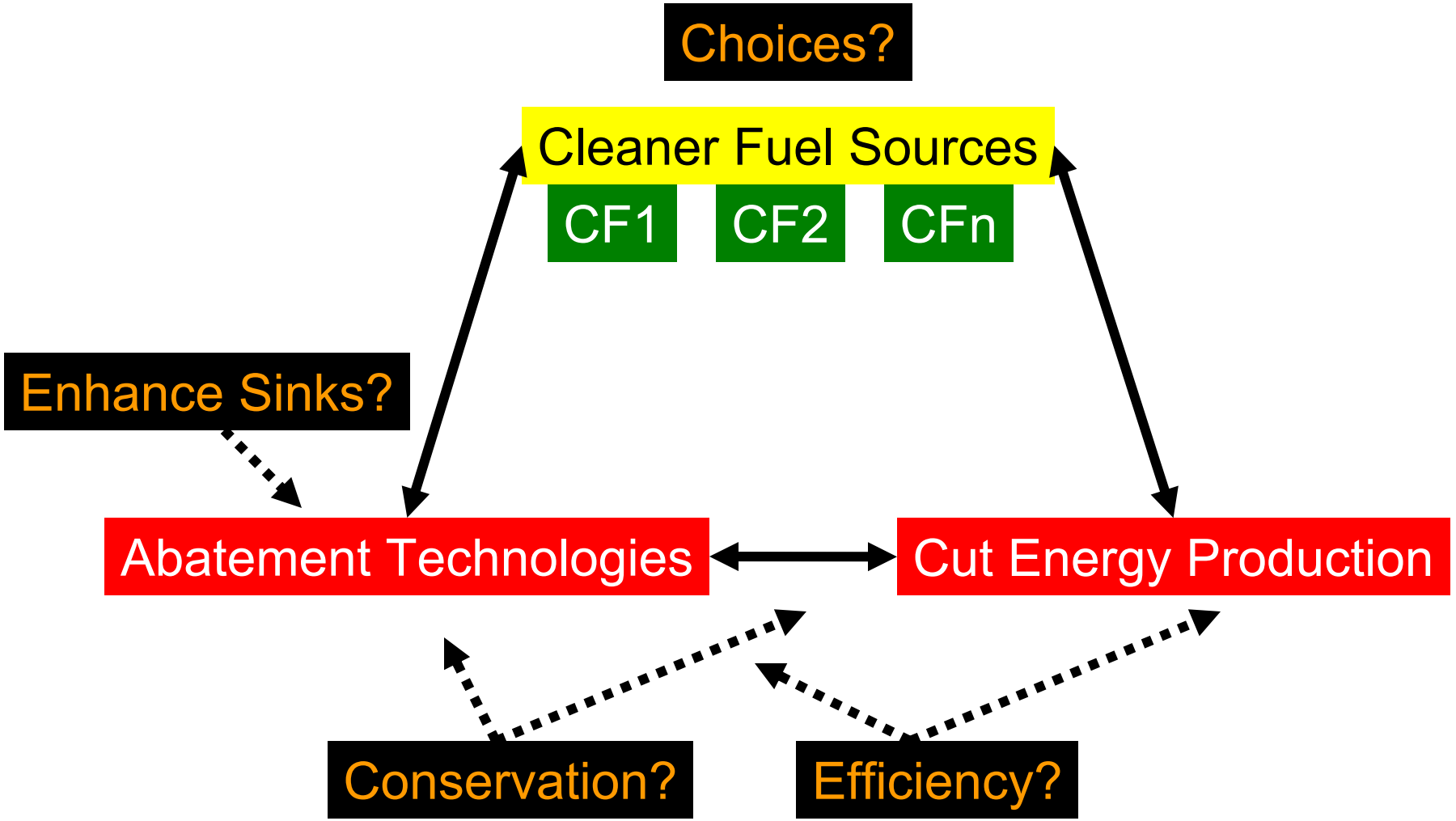
Where is sulfur efficiency?

Sulfur market



Sulfur allowance gives value to “sulfur efficiency.”

Carbon market



Choices of fuel

- Fossil fuels, oil, natural gas, coal, all have CO_2 as a primary product of combustion. One is not exactly clean relative to the other.
  - Yes, there is some spread relative to oil, coal is worst. Looking at factors of two, not factors of 10.
- Alternative fuels
  - Some, like ethanol, do not matter much to the carbon budget. Might contribute to energy security
  - Some, like wind and solar, are relatively high cost per [w]att of energy. Good for carbon. Need technological development.
  - Some, like nuclear, have high resistance for reasons of disposal and security
    - Threat of nuclear waste versus carbon waste?
  - Hydrogen economy?
- Diversity of energy needs
  - Centralized, like electric generation
  - Portable, like transportation

Abatement technologies

- Abatement has to include in it the idea of disposal of the waste.
  - Carbon dioxide is a gas; hence, hard to manage. It's difficult to pile up and cover with a plastic tarp.

Conservation principle for CO_2

$$\frac{\Delta CO_2}{\Delta t} = \text{Production} - \text{Loss}$$

For exampled, we considered the conservation of energy and CO_2 in the ice core data

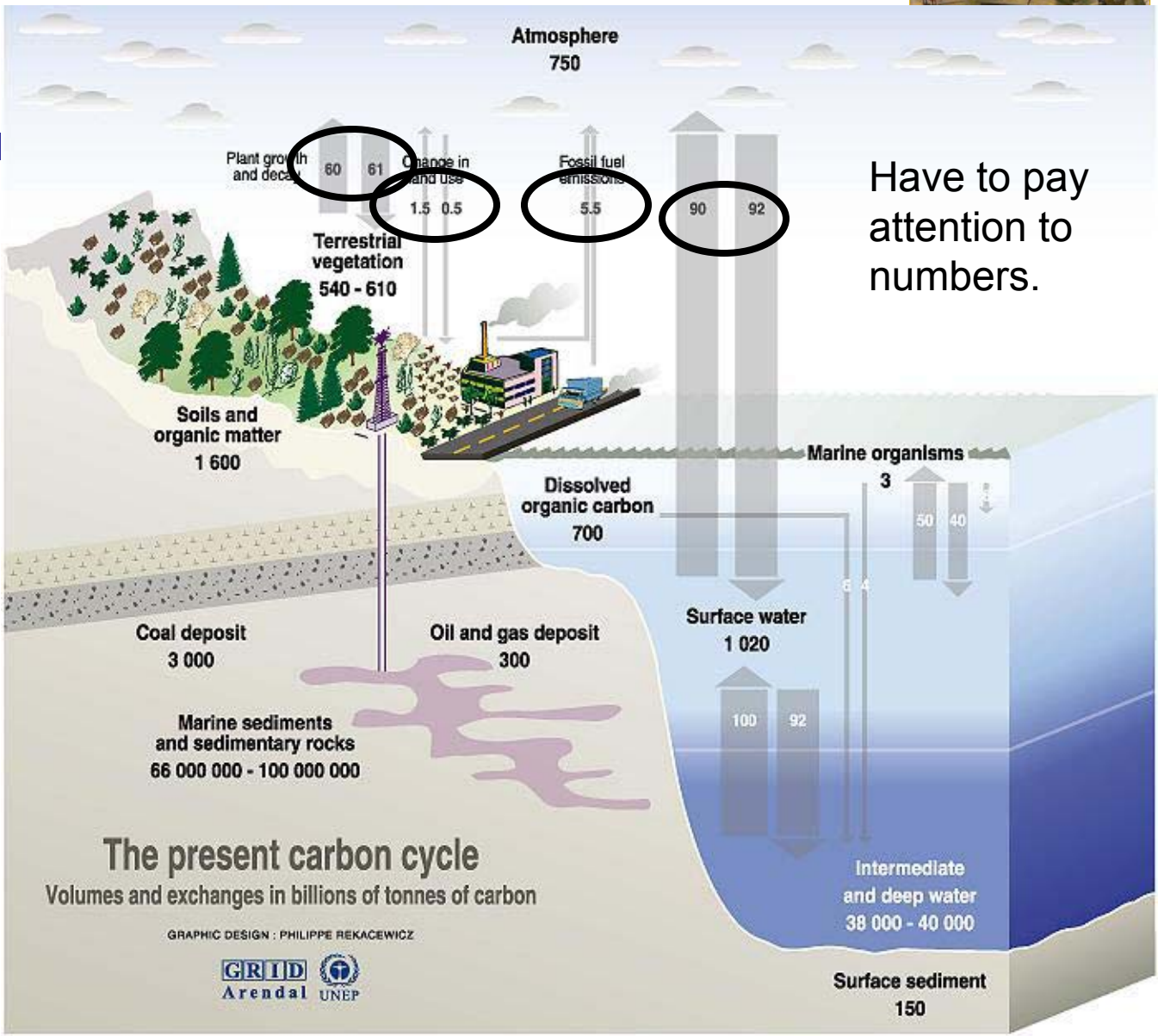
CHANGES IN SOLAR HEATING

$$\frac{\Delta T}{\Delta t} = Heating - Cooling = H - \lambda T$$

CHANGES IN CO_2, WHICH CHANGE THE RATE OF COOLING

$$\frac{\Delta CO_2}{\Delta t} = P_{CO_2} - L_{CO_2}$$

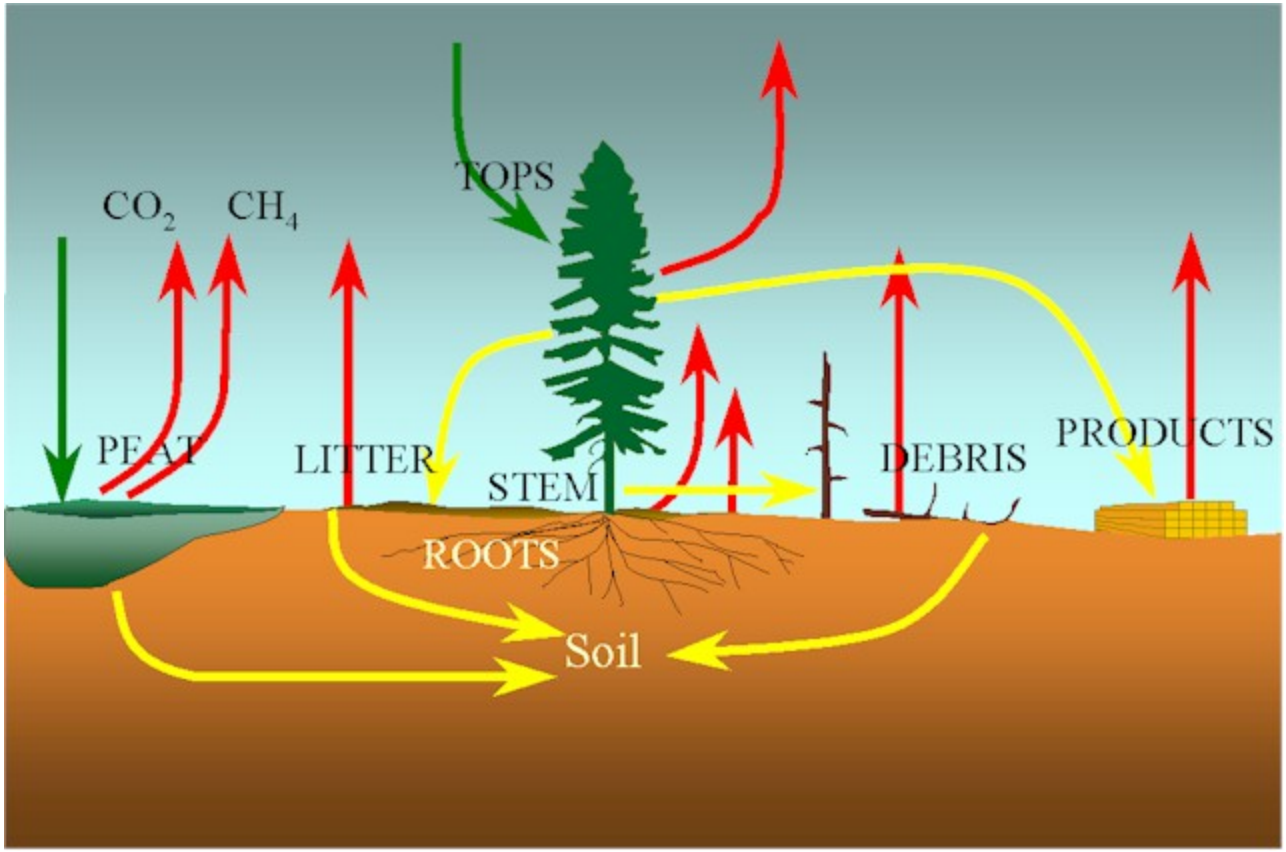
What are the mechanisms for production and loss of CO_2?



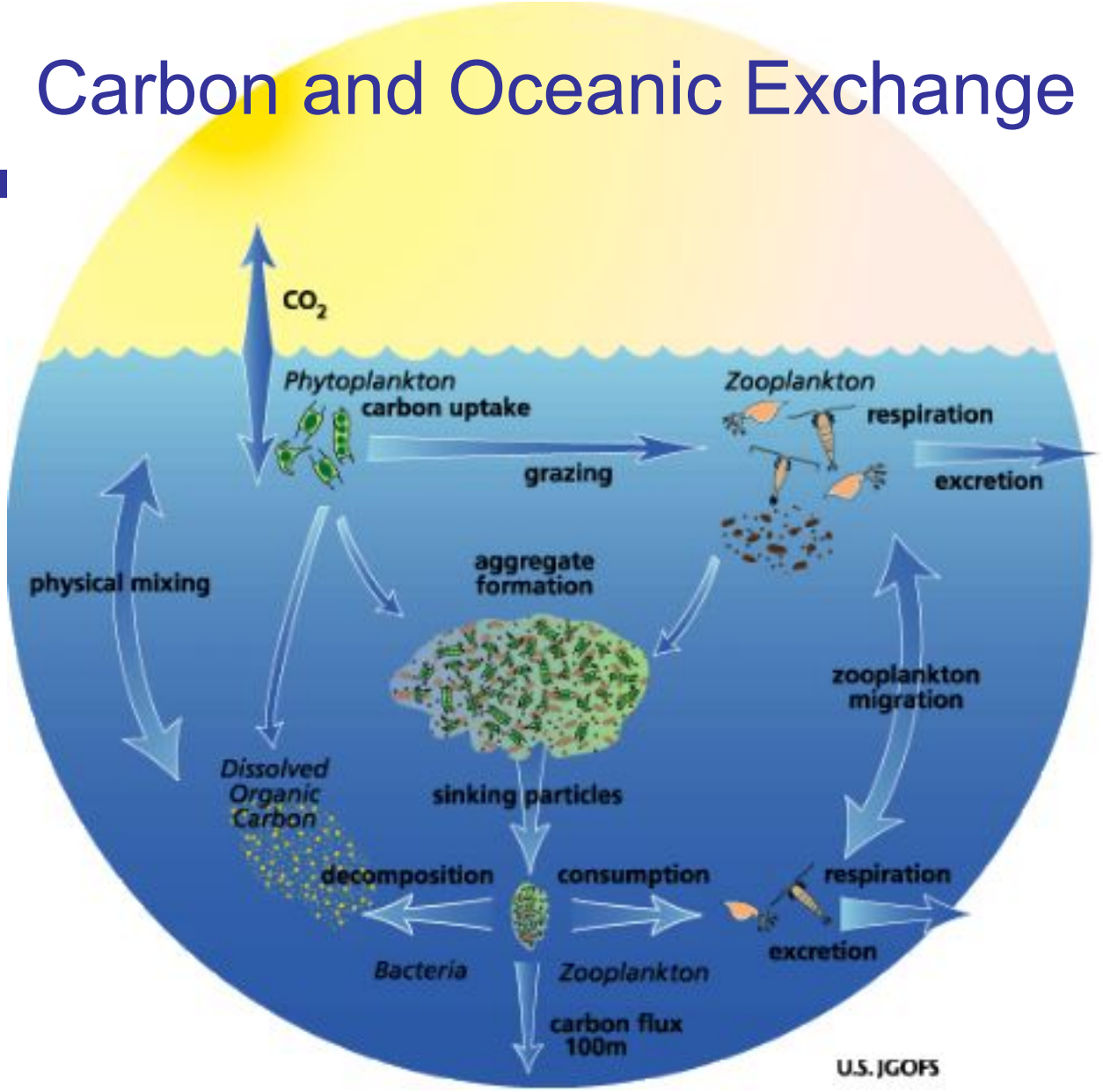
Have to pay attention to numbers.

Sources: Center for climatic research, Institute for environmental studies, university of Wisconsin at Madison; Okanagan university college in Canada, Department of geography; World Watch, November-December 1998; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

Carbon and Terrestrial Exchange



Carbon and Oceanic Exchange



Reliance upon natural CO_2 sinks?

- Consequences to ecosystems and possibly food security
  - Ocean acidification
- How is carbon really stored in the ecosystem?
- Reliance upon natural sinks is not adequate
  - Reduce CO_2 source
  - Increase CO_2 loss

Reduce CO_2 source; Enhance CO_2 loss

- What is the role of a market in that process today?

- Alternatives for reducing CO_2 source?
- Alternatives for increasing CO_2 loss?

- How is a CO_2 allowance related to the Marginal Cost of Abatement?

- Requirement that any solution we seek maintain exponential growth of the economy ...
  - What is the impact of this.

Carbon market

Choices?

Trading of Carbon Allowances

Cleaner Fuel Sources

CF1 CF2 CFn

Enhance Sinks?

Abatement Technologies

Cut Energy Production

Conservation?

Efficiency?

Developing a model of the Carbon Market?

- Fuel mass unit ≡ M_f
- Total fuel units ≡ N
- Cost of fuel per unit mass ≡ C_f
- Total cost of fuel = NC_f
- P ≡ energy produced from unit fuel = εM_f
- Total energy = $N\varepsilon M_f$
- E_0 ≡ Raw emissions from fuel use = $k_{CO2}\, N\varepsilon M_f$
- GDP ≡ Gross Domestic Product = $k_e N\varepsilon M_f$

Developing a model of the Carbon Market?

- $E_0 \equiv$ Raw emissions from fuel use = $k_{CO2}\, N\varepsilon M_f$ (for carbon-based economy)
- GDP ≡ Gross Domestic Product = $k_e N\varepsilon M_f$
- GDP = $k_e\, E_0 / k_{CO2}$

- Need to de-correlate emissions from energy production
  - $k_{CO2} = 0$ ... what if $k_{CO2} < 0$?
- efficiency, ε, is every where.

Backup

- What follows are more detailed expositions of material presented above. It is linked in lecture, with returns in the material below.

Example: DTE Marginal Cost of Abatement

- Monroe Power Plant (Monroe, MI)
  - Owned by Detroit Edison
  - 4th largest coal-fired power plant in country
- 2004 data
  - 95,364 allowances allocated
  - 99,735 tons of emissions
  - 4,371 tons in excess
    - Purchased these on the market
    - Or, banked them from a prior year

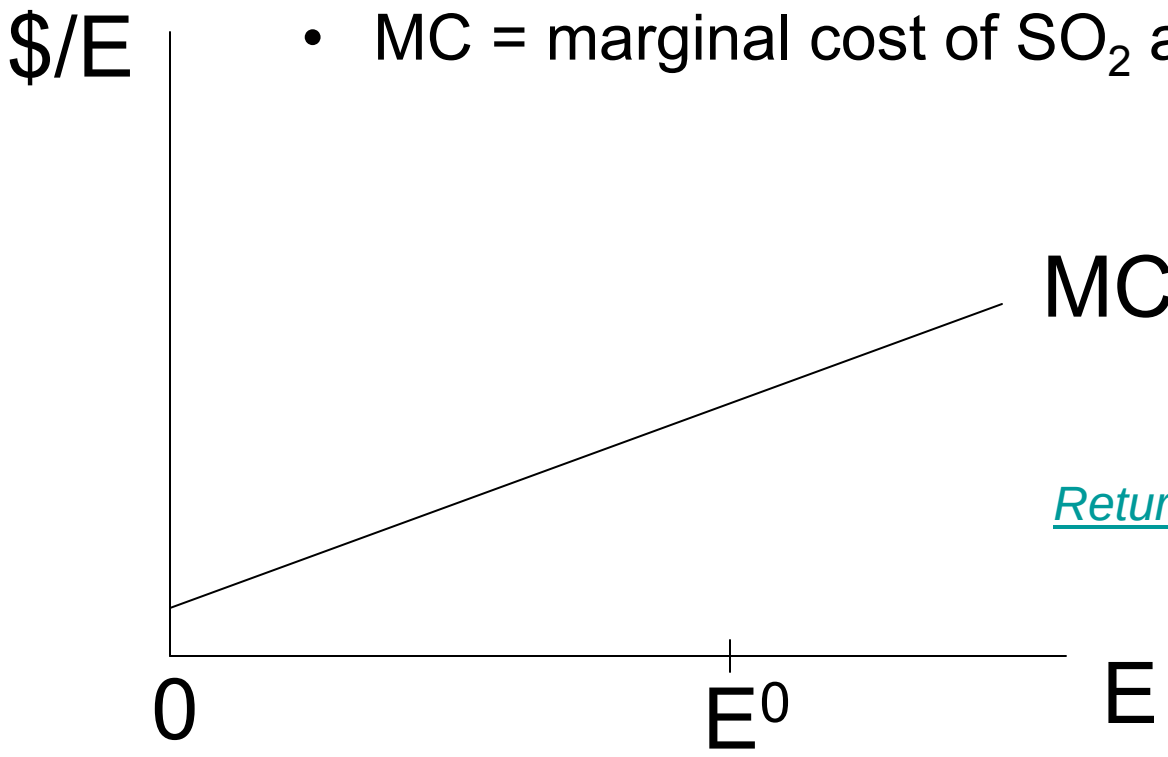
Company compliance decisions (cont.)

- Analytical concept: a company's *marginal cost of abatement*
  - a mathematical function: marginal cost increases as the amount of pollution abatement increases.

Return to Main Presentation

Marginal cost of abatement (single company)

- E = SO_2 emissions abatement
- E^0 = required abatement without trading
- $/E = dollars per ton of E
- MC = marginal cost of SO_2 abatement



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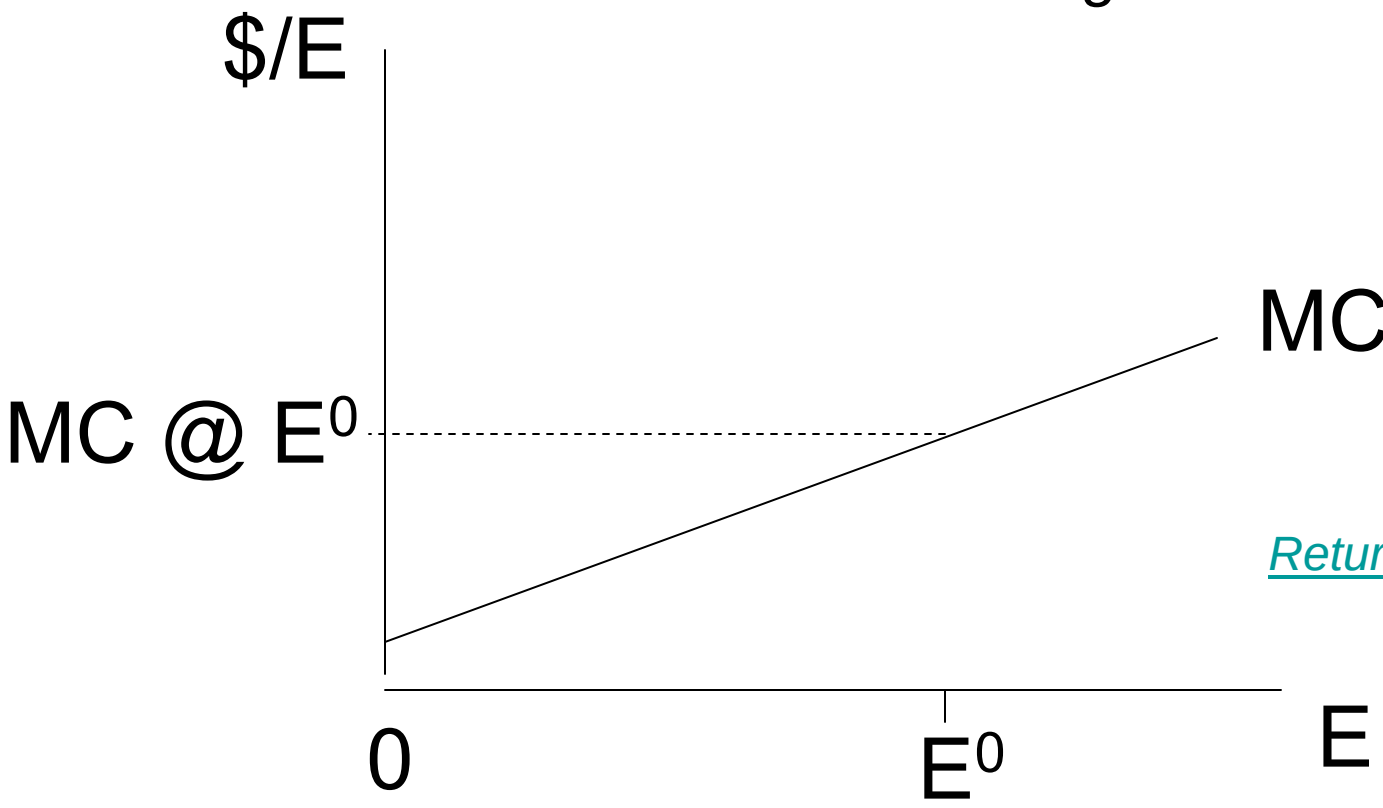
Marginal cost of abatement (cont.)

The area in red is the company's total cost of abating to E^0.



Return to Main Presentation

Company compliance options (with trading as an option)

- Compliance options:
  - Without trading: Reduce SO_2 emissions to comply with their quota (scrubbers, low-sulfur coal)
  - With trading: *Same options as above* ***plus***
    - Purchase allowances at the market price (P)

Return to Main Presentation

Simple intuition of market incentive

Consider the following example:

-- \$300 to abate a ton of SO_2

compared to

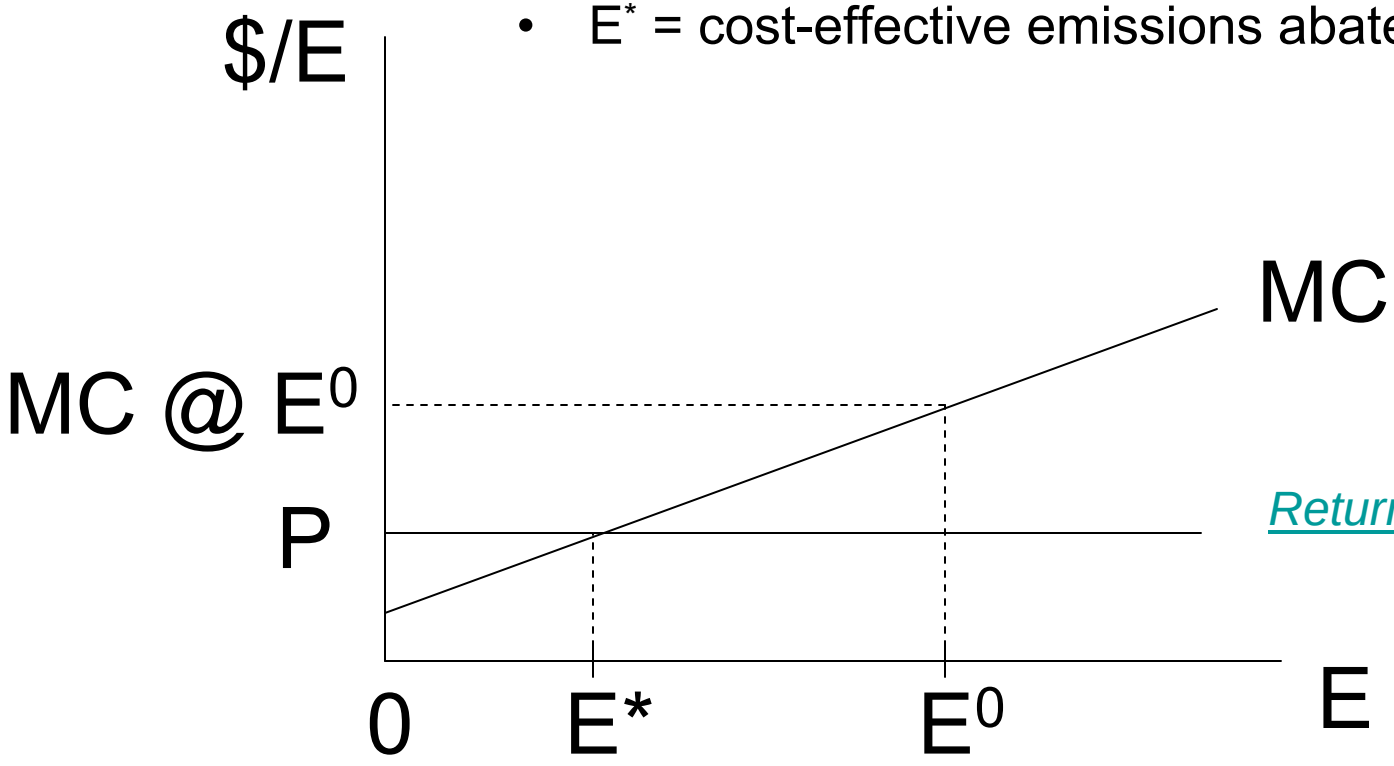
-- \$170 to purchase an SO_2 allowance.

The company saves \$130 by using an allowance to cover its emission

Return to Main Presentation

Marginal cost *versus* allowance price

- E = SO_2 emissions abatement
- $/E = dollars per ton of E
- P = market price of SO_2 allowances
- E^* = cost-effective emissions abatement

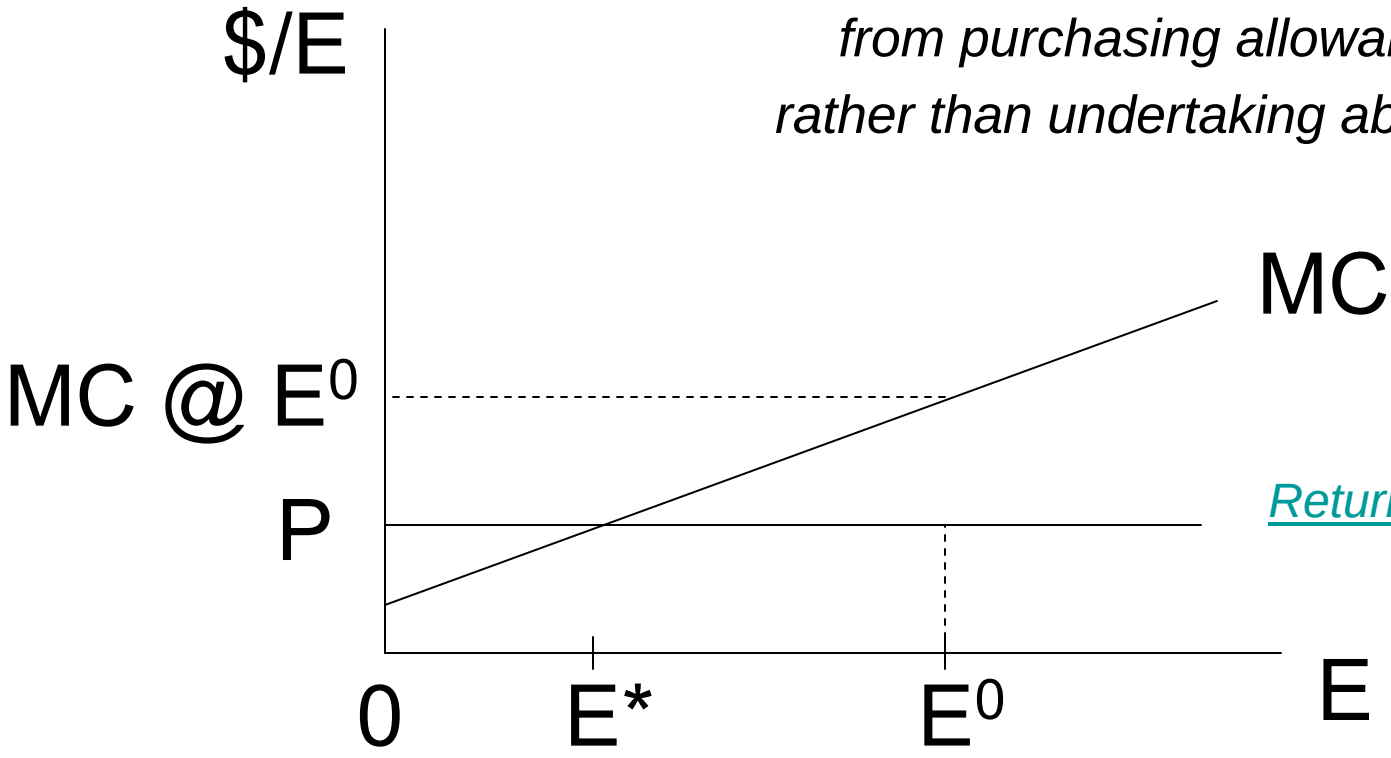


Return to Main Presentation

Purchasing allowances as a compliance option

At price P, the company purchases ($E^0 - E^*$)

The area in red is the cost savings from purchasing allowances rather than undertaking abatement



Return to Main Presentation

General results

- **P < MC** implies a *buyer* on the market
  - A buyer saves money by purchasing allowances to cover its emissions.
- **P > MC** implies a *seller* on the market
  - A seller makes money by undertaking extra abatement and selling its excess allowances.
- These incentives give rise to least-cost abatement.
  - We achieve cost-effective regulation!!!

Return to Main Presentation

Cost-effective regulation (*repeat*)

Estimates for the SO_2 market:

Abatement cost without trading = $1.82 billion/yr

Abatement cost with trading = $1.04 billion/yr

(least-cost abatement)

Cost savings = $0.78 billion/yr

43% reduction in abatement cost!!!

Return to Main Presentation

Does this seem like a conservation equation?

- What is conserved?
- What is different from a physical continuity equation?
- Minimization?

Return to Main Presentation

The model is simple, but there is an issue of complexity

Imagine that you have a savings account and a checking account $\mathbf{M = M^s + M^c}$

Savings: $\mathbf{(M^s}_{\text{tomorrow}} - \mathbf{M^s}_{\text{yesterday}}\mathbf{)}/N = I^s - e^s\mathbf{M^s}$

Checking: $\mathbf{(M^c}_{\text{tomorrow}} - \mathbf{M^c}_{\text{yesterday}}\mathbf{)}/N = I^c - e^c\mathbf{M^c}$

And we can transfer money from

Checking to savings – $T^{c\rightarrow s}$

Savings to checking - $T^{s\rightarrow c}$

Savings: $\mathbf{(M^s}_{\text{tomorrow}} - \mathbf{M^s}_{\text{yesterday}}\mathbf{)}/N = I^s - e^s\mathbf{M^s} + T^{c\rightarrow s} - T^{s\rightarrow c}$

Checking: $\mathbf{(M^c}_{\text{tomorrow}} - \mathbf{M^c}_{\text{yesterday}}\mathbf{)}/N = I^c - e^c\mathbf{M^c} - T^{c\rightarrow s} + T^{s\rightarrow c}$

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- Through carbon could we couple a cap and trade market with a climate model or an emissions model?

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Some details of European CO2 Market

Warning: C or CO_2; ton or tonne; $ or euros?

- Commonly \$/ CO_2; sometimes \$/C
- To convert: \$/CO_2 * CO_2/C = \$/C
- CO_2 = atomic weight of 44
- C = atomic weight of 12

- tonne = metric ton = 2,204.6 pounds
- tonne, not ton, is the standard measure

- 1.00 euro (€) = \$1.3094 (exchange rate varies!)
- Euro – currency used on European Union market

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EU's Emission Trading System

"The European Union is establishing a greenhouse gas emissions trading scheme for the cost-effective reduction of such emissions in the Community."

- EU ETS birth: January 1, 2005
- EUA = European Union allowance
- One allowance = one tonne of CO_2 emission
- EU's cap: about 2.2 billion allowances/yr
- 11,500-12,000 regulated facilities
- Sectors covered: energy (electricity; cogeneration); iron and steel; mineral; pulp and paper.

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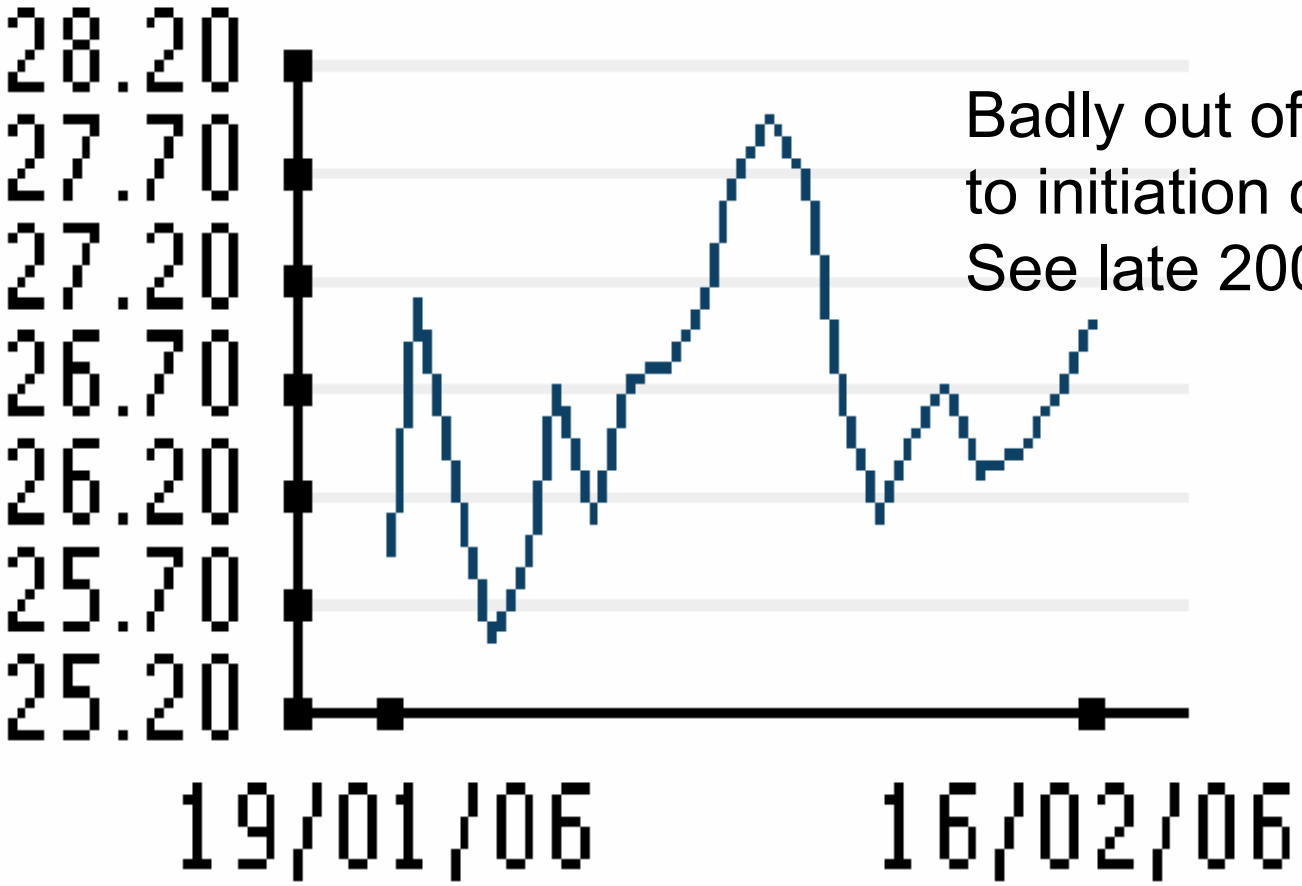
Market Prices in 2006 – EU ETS

(euros per ton of CO_2)
(26 euros = 31.2 dollars)



Badly out of date: Close to initiation of market. See late 2006.

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EU ETS (cont).

- Penalty for excess emissions:
  - € 40 per tonne
  - rising to €100 in 2008
- Impressive volume of trading activity
  - 2005: global volume = 800 million tonnes CO_2
  - Jan. 2006: EU volume = 262 million tonnes
- Brokers competing to be the “marketplace”

  (like SO_2: Evolution Markets/Natsource/Cantor-Fitzgerald)
  - Powernext Carbon
  - European Climate Exchange

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EU ETS (cont).

- Companies and traders “get it”

  “Carbon is now being used as a commodity on the same lines as other energy commodities.”

- US SO_2 market: widely hailed as very successful
- EU CO_2 market – the next important experiment in cap-and-trade. Too soon for rigorous evaluation.

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Action in the United States

- McCain-Lieberman Climate Stewardship Act
  - 2001. U.S. withdraws from Kyoto.
  - 2003. McCain-Lieberman proposed.
    - Cap emissions at 2000 levels
    - Implement in 2010
    - Market provision – “cap and trade” system
- 2005 - U.S. Senate passes non-binding resolution
  - “national program of mandatory, market-based limits and incentives on greenhouse gases…”
- Future federal policy
  - Will companies push for consistent approach?

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Action in the U.S. (cont.)

- Regional Greenhouse Gas Initiative (2005)
  - Multi-state coalition (CT, DE, ME, NH, NJ, NY, VT)
  - MA and RI pulled out at 11th hour
- California GHG emission reductions (2005)
  - Reduce emissions to 2000 levels by 2010 and to 1990 levels by 2020.
- Chicago Climate Exchange (2003)
  - Voluntary participation by companies, cities, NGOs
  - Tradable quotas
  - Baseline: average emissions over 1998-2001
  - 2006 quota: 4% below baseline
  - Market price about $2 per tonne CO_2

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