Workshop on Carbon Sequestration Science

Modeling and Integrated Assessment

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Economic Assessments

- Engineering analysis of CO_2 separation and capture
- Economic modeling/ integrated assessment of carbon capture and sequestration
- Comparison on equal basis of the major sequestration options

Economic Modeling Motivation

- When might carbon capture and sequestration (CCS) become competitive?
- What is its potential scale?
- Which technologies look most promising?

  . . . . And when?

- How to see the potential in a general market context?

Detailed Reference

- Sean Biggs Thesis:
  - Biggs, S. D., "Sequestering Carbon from Power Plants: The Jury is Still Out," M.I.T. Masters Thesis, (2000).
  - http://sequestration.mit.edu/pdf/SeanBiggs.pdf

What Determines Competitiveness?

- Relative cost of technologies
- Prices of coal, natural gas
- Prices of capital, labor, materials
- Structure of conventional generation
- Regulatory regime for electric power
- Mitigation policy & resulting carbon price
- [Public acceptance of sequestration]

Emphasize: A Work in Process

- Results for U.S. only so far
- Aggregate national electricity market
  - New NGCC technology explicitly represented
- Simplified approx. of possible technical change
- Ignores possible scale effects (±)
  - Generation with capture
  - Sequestration
- Ignores potential differences in reliability
- No secondary benefits
- No consideration of uncertainty

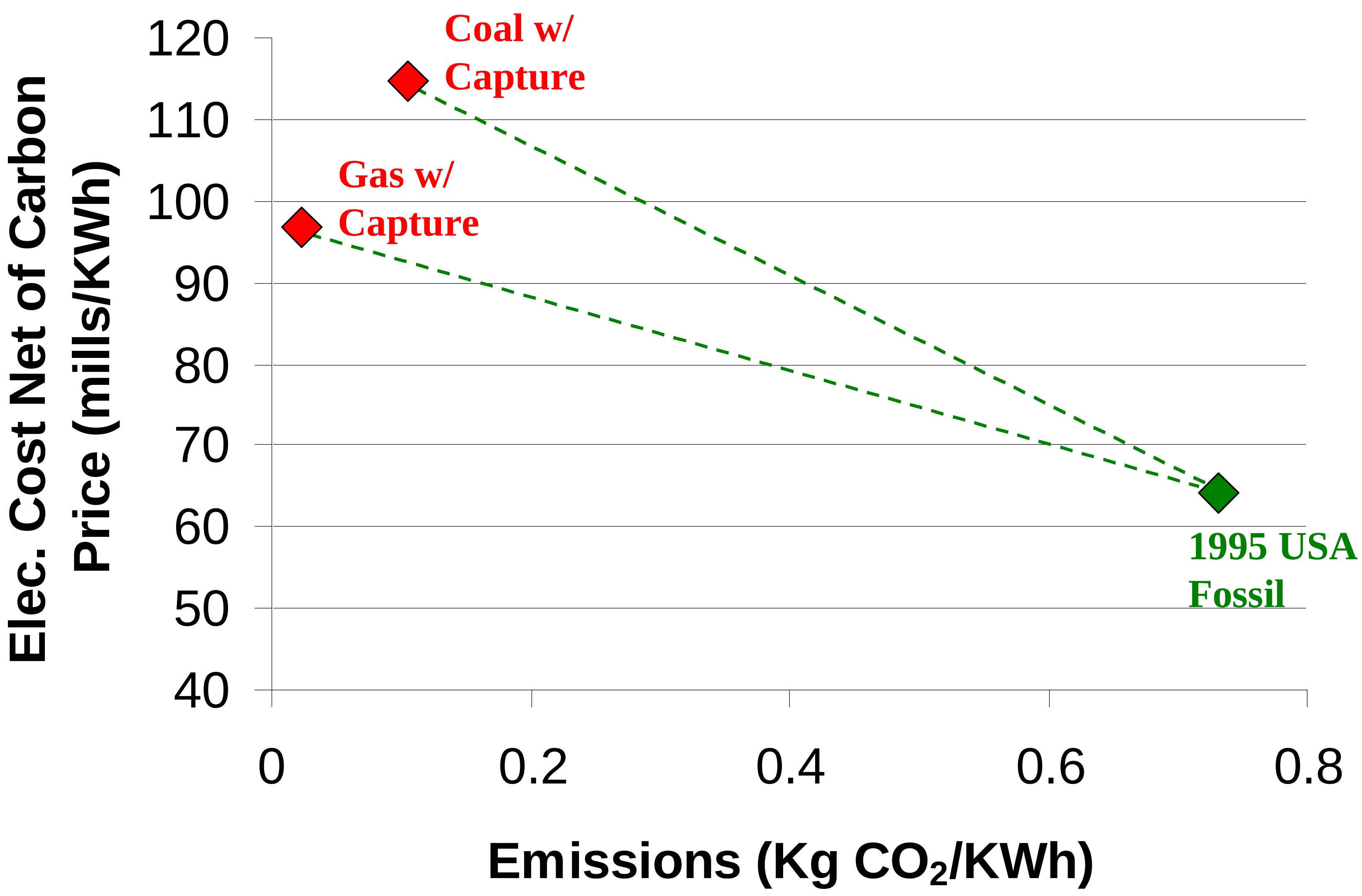
Take Away . . . And NOT!

- These economic/market issues are important
- The farther into the future, the foggier
- To understand them, need specialized tools
- Take the insight about what matters

  . . . not the specific numbers
- Much remains to be done

Conditions for Entry

(Enter When Carbon Price Equates Cost)



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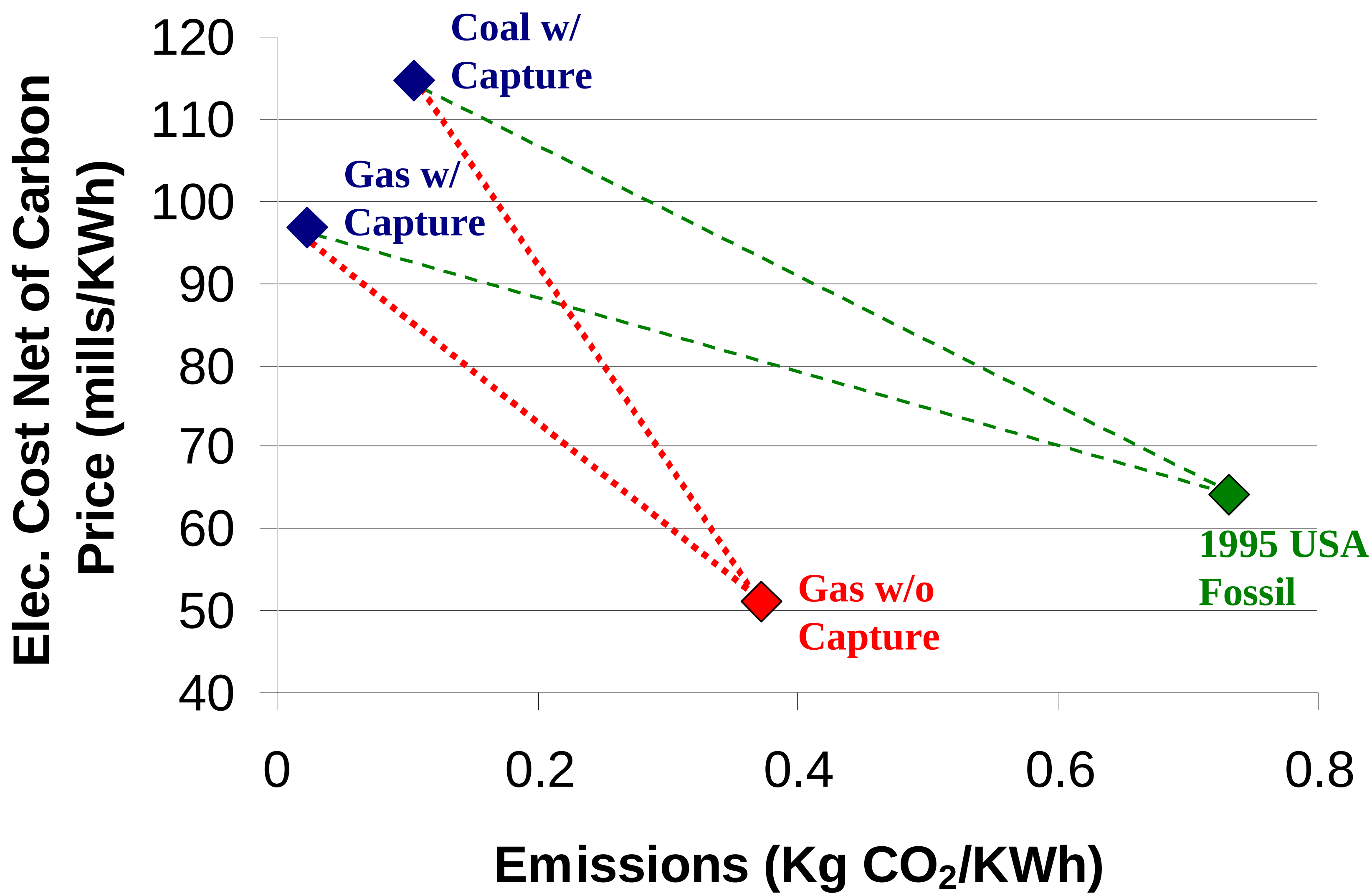
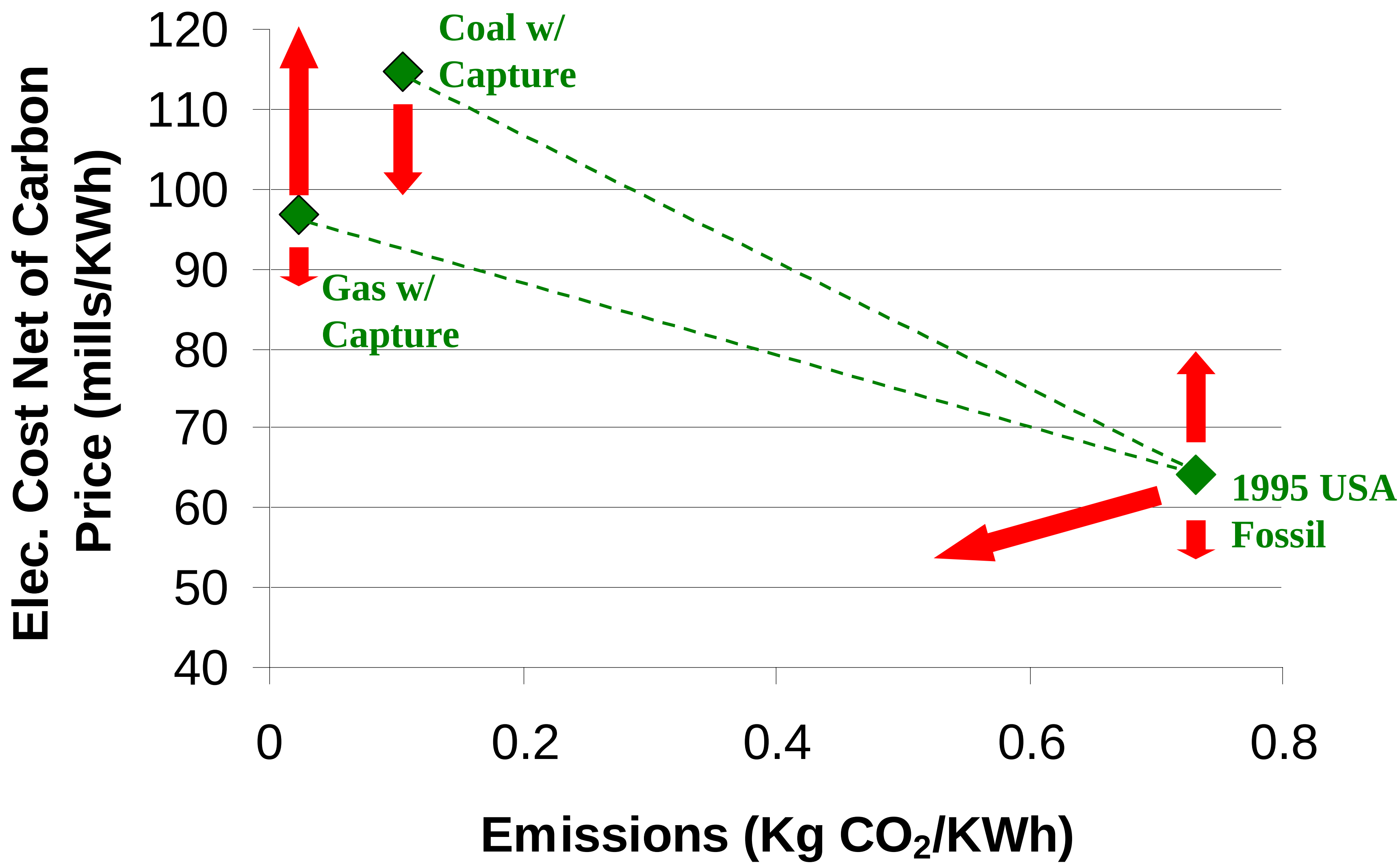


Partial Equilibrium Analysis

	TC* **Today's Technology** (mills/kWh)	TC* **Small Technical Improvement** (mills/kWh)	κ **(kg C/kWh)**	**Equalizing PCO_2** ***with Reference Gas*** ($/t C)	
Reference Gas	52.0	51	0.10	Today's Technology	Small Improvement
Gas Capture	76.6	68.6	0.01	273	196
Coal Capture	87.1	79.1	0.025	460	368

Conditions for Entry

(Shifting Competition with Time/Carbon Price)



Sample Policy Cases

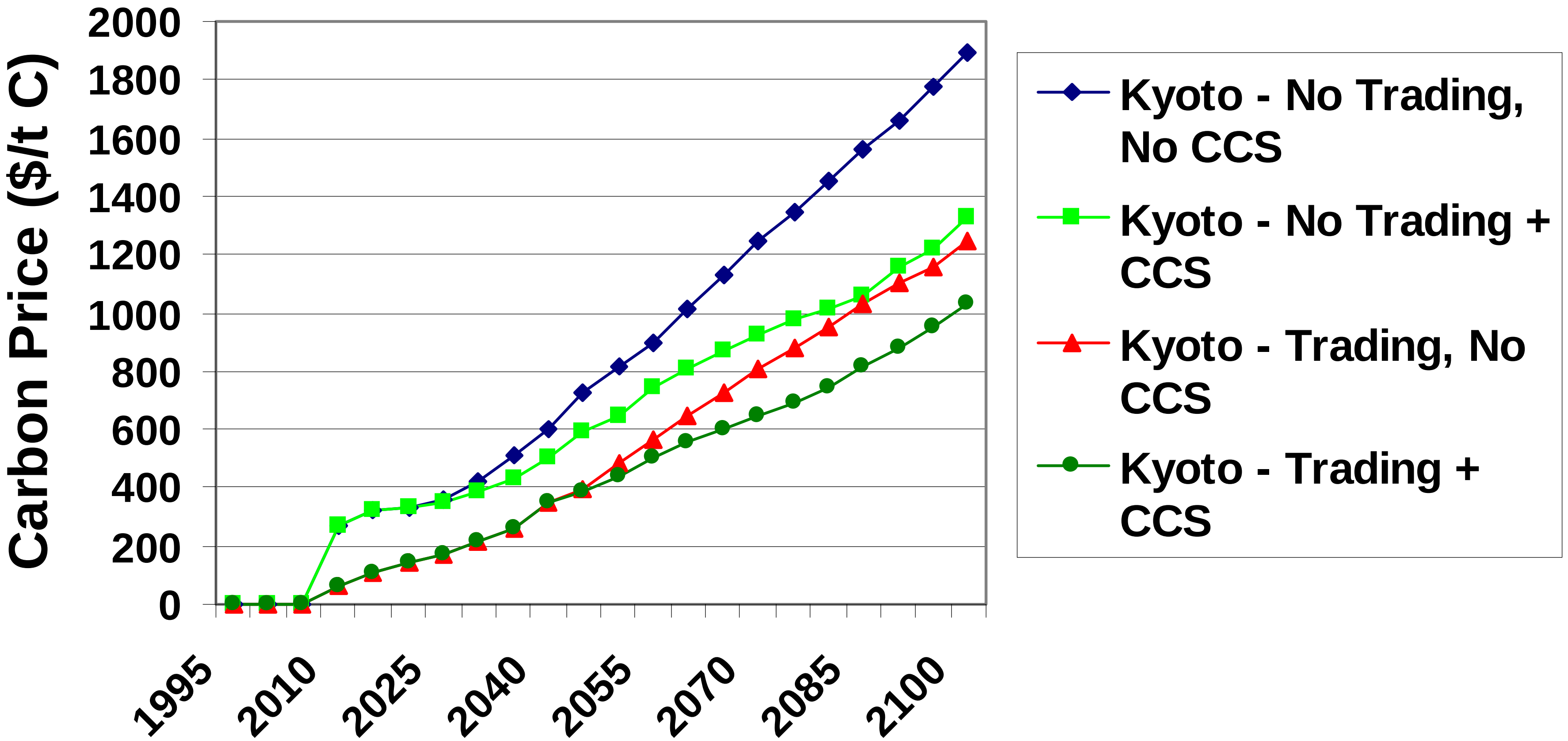
- Kyoto Protocol
  - Annex B achieves Kyoto targets in 2010
  - Maintain to 2100
  - no Non-Annex B control

- With and without emissions trading
  - Annex B only

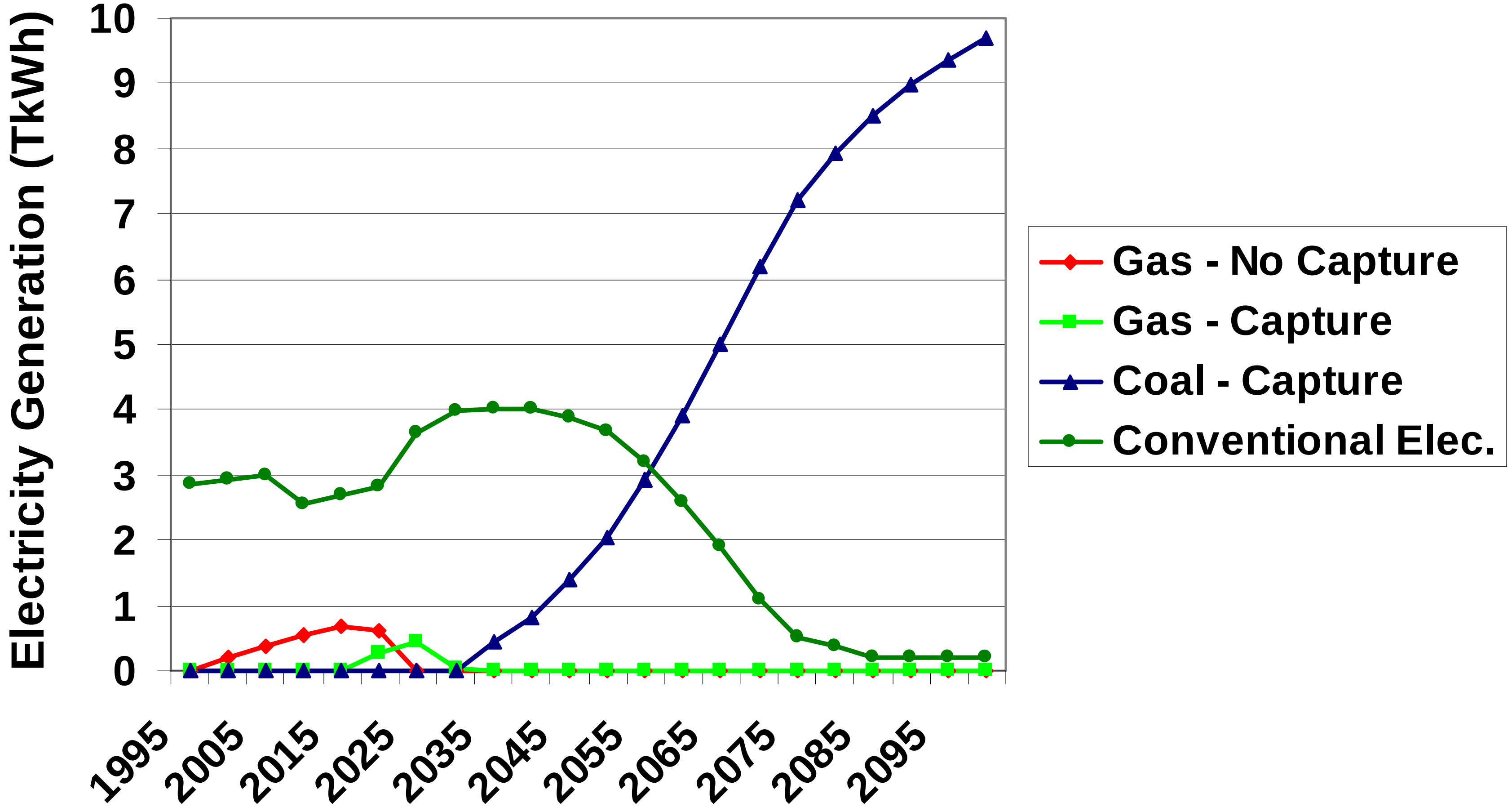
Some Key Assumptions

- U.S. imposes carbon policy by price incentives
  - Cap-and-trade
  - Carbon tax
- CCS will enter when it breaks even with the lowest cost generation at the margin
- After entry, penetration rates are limited (a judgment about max. growth in market share)

Effect on US CO_2 Prices - Kyoto

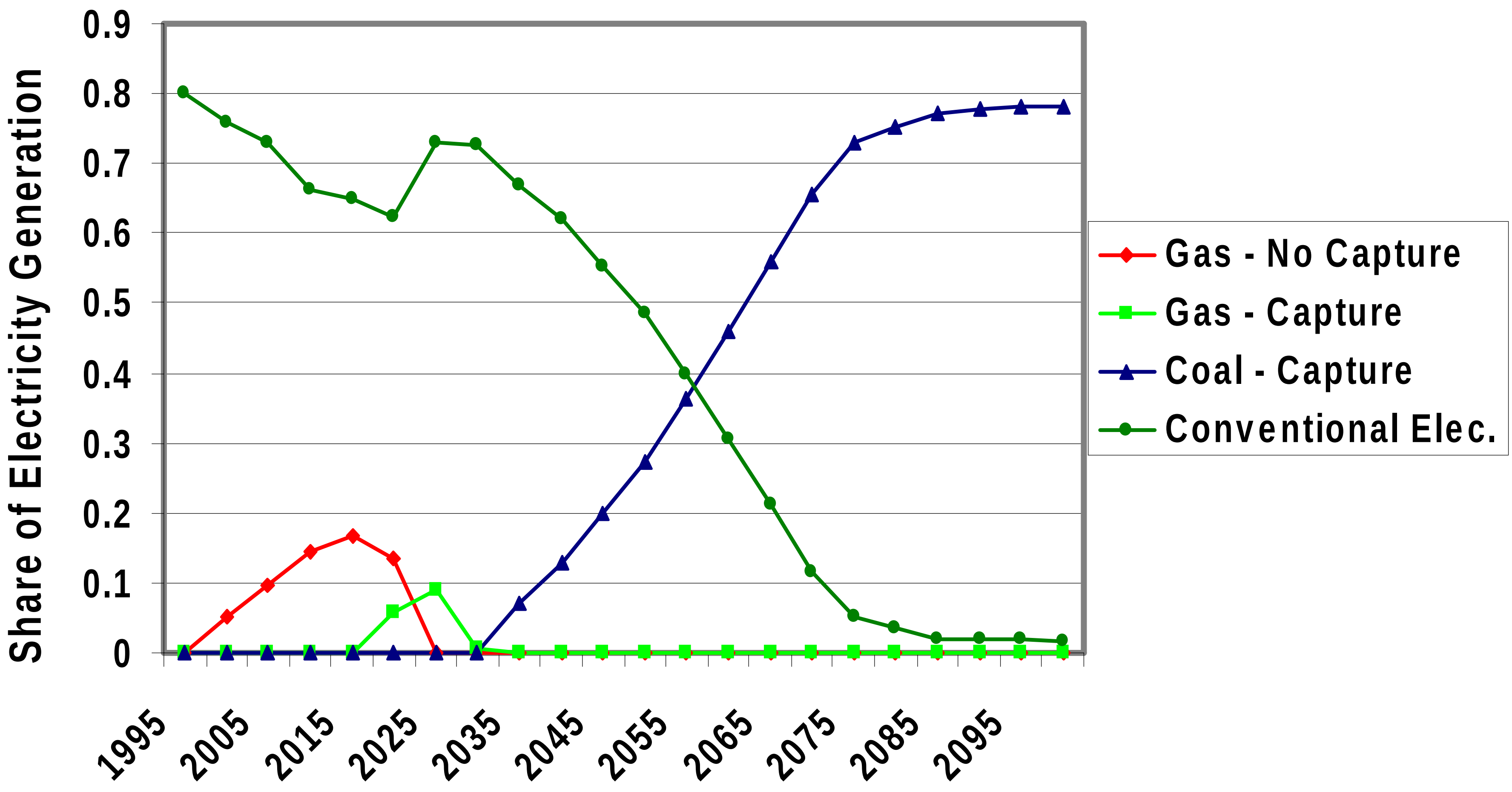


US Electricity Generation
by source, Kyoto – no trading



Share of US Electricity Generation

Kyoto, no trading



Penetration Under Kyoto
(Current Technology)

	Gas Capture		***Coal Capture***	
	Time of Entry	*Max Share*	Time of Entry	Max Share
No - Trading	2020	*9%*	2035	78%
Trading	-	*0%*	2045	80%

Penetration Under Kyoto

(Moderate Autonomous Technical Change)

	Gas Capture		Coal Capture	
	Time of Entry	*Max Share*	Time of Entry	*Max Share*
No - Trading	2020	*12%*	***2020***	*80%*
Trading	-	*0%*	***2035***	*81%*

Uncertainties

- Potential for technological improvements in carbon capture and sequestration technologies
- Level of economic growth and reference emissions
- Economic viability of low-carbon energy sources (e.g., solar and nuclear)

Economic Assessments

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Net Present Value of Abatement

$$\text{NPV} = \int_{0}^{T} \big(p(t)A(t) - C(t)\big)e^{-rt}\,dt$$

Where:

NPV = net present value

p(t) = carbon price ($/tonne)

A(t) = abatement (avoided emissions, tonnes/yr)

C(t) = abatement cost ($/yr)

r = discount rate

t = time (years)

T = planning horizon (e.g., 100 years or infinity)

Calculating Avoided Cost

$$p = \frac{\int_0^T C(t)e^{-rt}\,dt}{\int_0^T A(t)e^{-rt}\,dt}$$

Assumes breakdown condition (NPV = 0)

Assumes p(t) is constant over time

Discretize

$$p = \frac{\sum_{0}^{T} C(t)\,(l+r)^{-t}}{\sum_{0}^{T} A(t)\,(l+r)^{-t}}$$

Reduced Tillage Example

- Sequester 1 unit/yr for 20 years at a cost of 1 unit/yr
- Discount rate = 4%
- Timeframe = 100 years
- Case 1 – Release all in years 21-23
- Case 2 – Pay to assure no release
- Case 3 – Farmers change practices so no release

Reduced Tillage Example

	Case 1	Case 2	Case 3
C(t)	1, t=1,20	1, t=1,100	1, t=1,20
A(t)	1, t=1,20 -6.67, t=21,23	1, t=1,20	1, t=1,20
p	2.64	1.80	1.0

Leaky Reservoir Example

- Cost of capture and sequestration is $31.93 million/yr for 20 years
- 2.16 million tonnes CO_2/yr captured
- 1.82 million tonnes CO_2/yr avoided
- Case 1 – No leaks, r=4%, T is infinity
- Case 2 – 0.5%/yr leaks starting in year 51, r=4%, T is infinity
- Case 3 – Case 2 leaks, r=0%, T=100 years

Leaky Reservoir Example

	Case 1	Case 2	Case 3
C(t)	31.93, t=1,20	31.93, t=1,20	31.93, t=1,20
A(t)	1.82, t=1,20	1.82, t=1,20 .216, t=51,250	1.82, t=1,20 .216, t=51,100
p	17.55	18.15	25.51

C(t) in millions of dollars, A(t) in millions of tonnes CO_2