Representation of Industrial Energy Efficiency Improvement in Integrated Assessment Models

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Presented at the Workshop on

Energy and Economic Policy Models:

A Reexamination of Some Fundamental Issues

Washington DC, November 16-17, 2006

With inputs from Ernst Worrell and Amol Phadke

Work supported by US Department of Energy, Office of Science, Biological and Environmental Research Program.

Presentation Contents

- Integrated assessment (IA) models
- Demand-side cost curves
- Updated cost curves for US steel and cement sectors (preliminary results)
- Representing US cost curves in a IA model (preliminary results)
- Conclusions

Climate change mitigation models

- **Long term perspective**
  - **— Cost-effective implementation strategies**
  - **— Least-cost emissions reduction pathway**
- **Emissions baseline is critically important to determining costs**
  - **— Defines the size of the reduction required to meet a target**

Climate change mitigation bottom-up models: Cost estimates differ widely

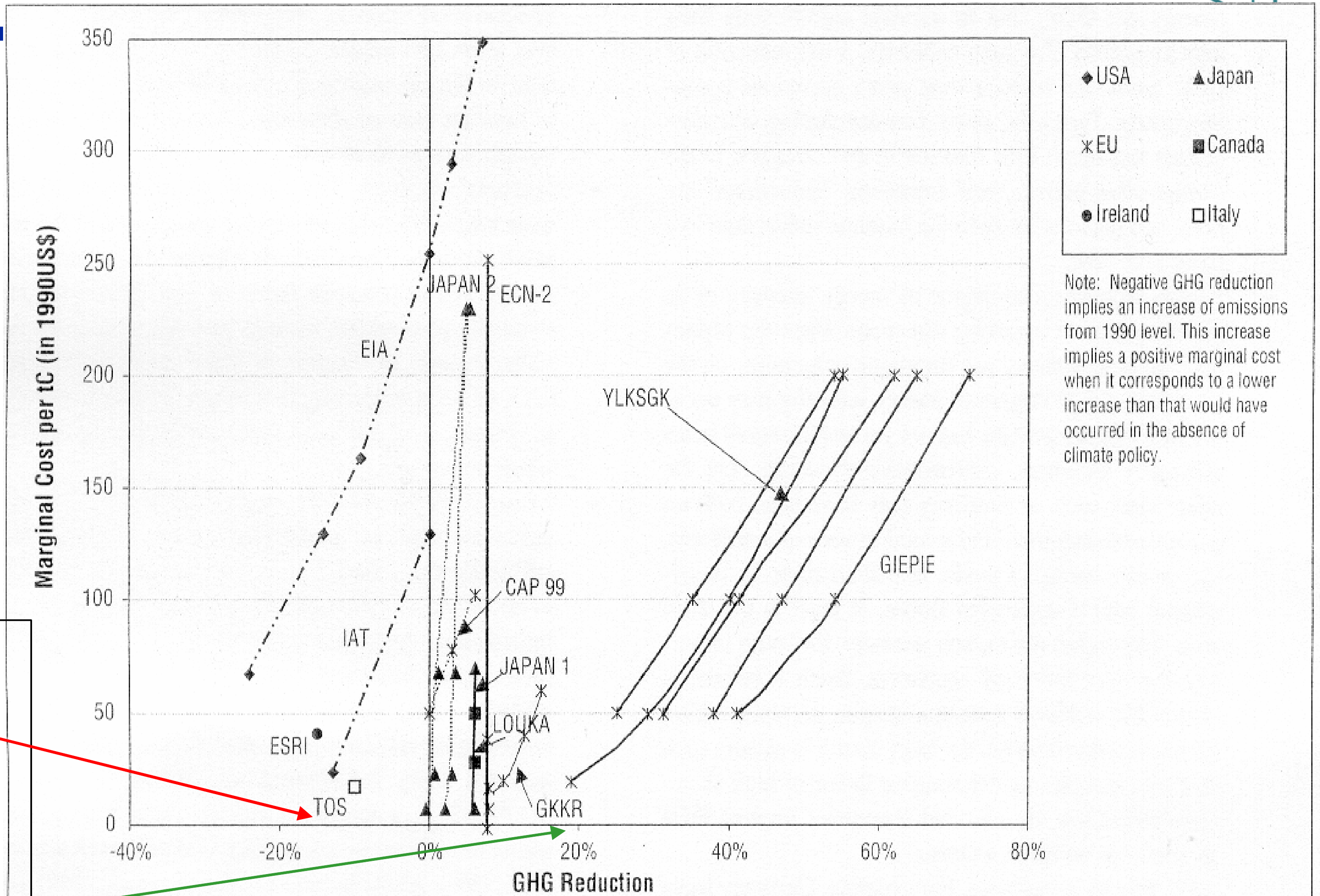
- Differences can be traced to assumptions about
  - — economic growth
  - — resource endowments
  - — choice of policy instruments
  - — extent of no-regrets options
  - — cost and availability of new supply- and <u>demand</u>-side technologies
    - technological change
- This presentation will focus on the last two items and reflects work in progress and preliminary results

B-U Results: Marginal costs of reducing emissions relative to 1990, single region, no trading

- Energy endowment
- Economic growth
- Energy intensity
- Other country-specific conditions

Negative values: Future emissions higher than 1990

Positive values: Future emissions lower than 1990



[EIA]: Energy Information Administration, 1998.
[ESRI]: Conniffe, *et al.*, 1997.
[IAT]: Interagency Analytical Team, 1997.
[TOS]: Contaldi and Tosato, 1999.
[CAP-99]: Capros, *et al.*, 1999a
[JAPAN-2]: Kainuma *et al.*, 1999.
[JAPAN-1]: Kainuma *et al.*, 2000.
[ECN-2]: Gielen *et al.*, 1998.
[LOUKA]: Loulou *et al.*, 1998.
[GKKR]: Gielen et al., 1999a
[YLKSGK]: Ybema *et al.*, 1999.
[GIEPIE]: Gielen and Pieters, 1999.

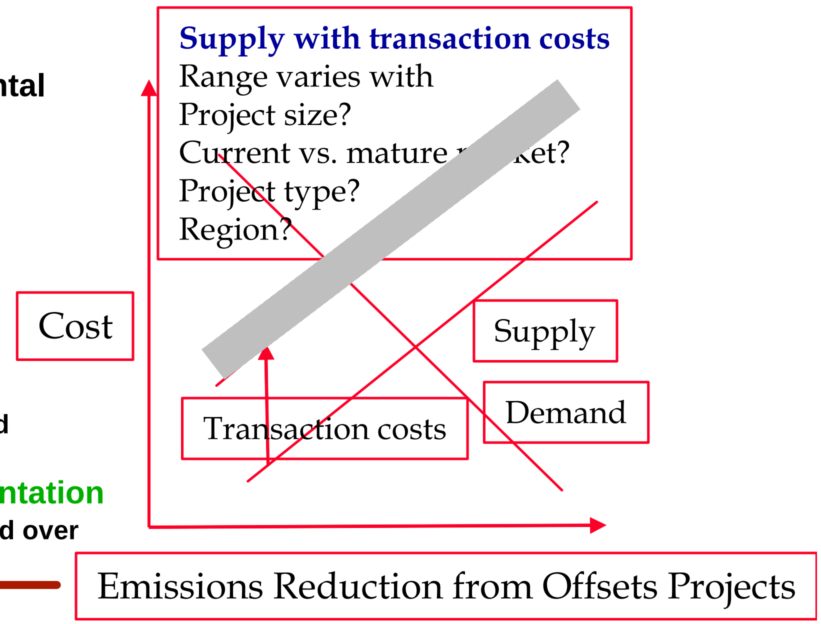
Source: Hourcade and Shukla (2001)

Bottom-up Models: How to explain the cost results?

- Factors that could increase costs:
  - Transaction costs
  - Hidden costs, such as the risks of using a new technology
  - Rebound effect
  - Real preferences of consumers
- Factors that could reduce costs:
  - Technological change over time
  - Complete accounting of benefits
  - Policies that remove costlier barriers

Transaction Costs Influence Supply of Traded Carbon

- **<u>Project search costs</u> – Identification and stakeholder consultation**
  - **May be spread over many projects**
- **<u>Feasibility studies costs</u> – engineering, economic, and environmental assessments**
  - **GHG Baseline estimation and establishing additionality**
- **<u>Negotiations costs</u> – obtaining permits, negotiating and enforcing contracts for fuel supply, arranging financing**
  - **Marketing GHG credits, carbon contracting and enforcement**
- **<u>Insurance costs</u> – project risk insurance**
  - **GHG credit insurance (Difficult to get or too expensive today)**
- **<u>Regulatory approval costs (GHG)</u>**
  - **Project validation and government review (May include both domestic and international validation costs)**
- **<u>Monitoring and verification costs (GHG)</u> – During project implementation**
  - **Monitoring including equipment cost, verification and certification (Spread over many years of project life)**



- **<u>Data Set 1: (26 projects)</u>**
  - **The Nature Conservancy (Forestry) -- Bolivia, and Brazil**
  - **Indian Institute of Science (Forestry) , LBNL (Household woodstoves)**
  - **Oregon Climate Trust (Forestry, energy efficiency, renewable energy)**
  - **Natural Resources Canada (Forestry)**
  - **Trexler and Associates (Methane, large power plants, energy efficiency, carbon capture)**
- **<u>Data Set 2:</u> (13 projects)**
  - **Ecofys (renewable energy)**
  - **Ecoenergy (bagasse cogeneration)**
- **<u>Data Set 3:</u> (50 projects) –**
  - **Swedish AIJ Programme (Energy efficiency and renewable energy)**
- **<u>Data Set 4:</u> (10 projects)**
  - **Global Environmental Facility**
  - **Transportation, energy efficiency, renewable energy**

Key Findings of Regression Analysis of Transaction Costs of Multiple Types of Projects

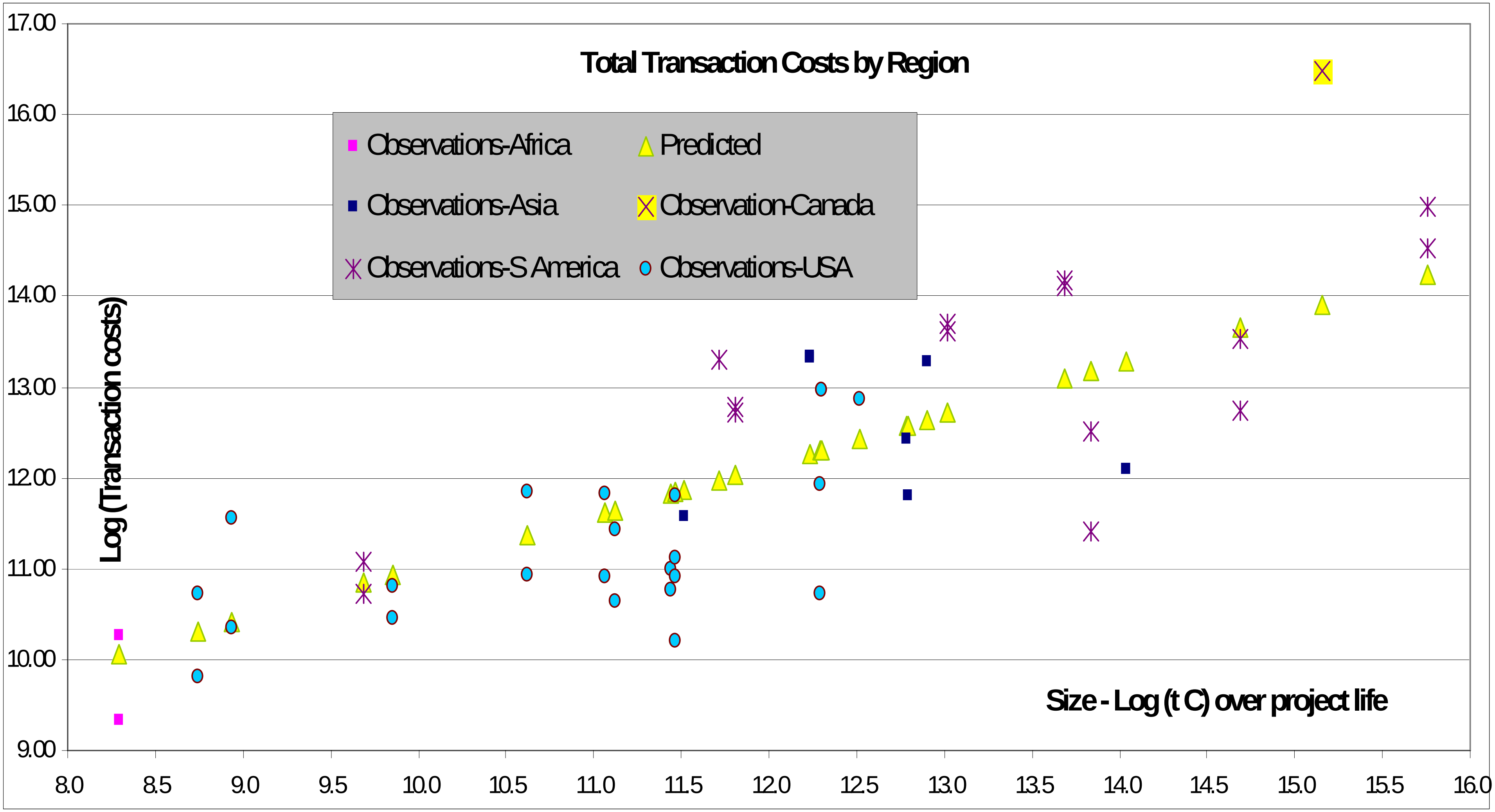
Dependent variable:

	Log (Total Transaction Costs (USD))
Independent variables:	
t C (log)	.56** (.08)
Forestry	-1.04** (.40)
Energy Efficiency	-59 (.36)
Multiple objectives	-.34 (.30)
S. America	.75* (.45)
Asia	-.24 (.41)
Mature	-.49* .27
Constant	6.08** (1.00)
R2	.69
N	48

*Statistical significance at the 10% level

**Statistical significance at the 5% level or better

- **Statistical analysis to determine significant influence on costs of**
  - **Project Size**
  - **Multiple benefits**
  - **Technology demonstration, social development, other environmental benefits**
  - **Forestry, energy efficiency, and renewable energy dummies**
  - **Regional dummies – Asia and Latin America**
  - **Mature vs. nascent markets**


Total Transaction Costs by Region
Observations-Africa
Predicted
Observations-Asia
Observation-Canada
Observations-S America
Observations-USA
Log (Transaction costs)
Size - Log (t C) over project life
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0

. Effect of Barriers on CFL Sales in California in 2005 (18W CFL vs. 75W Incandescent Bulb Used 2.5 Hours per Day)

Barrier	Parameter Affected	CCE Effect	Total CCE	Penetration Reduction Effect	Total Red'n	Adopting Stock in 2005	Lifetime GWh Savings from 2005 Purchases	Explanation	Policies & Programs	Xenergy Variable
1. Initial Stock	N/A	N/A	$0.031	N/A	N/A	132,770,314	60,543	These are the initial values before barriers are applied.	N/A	N/A
2. Baseline Share	ES	N/A	$0.031	5%	5%	126,131,798	57,516	The estimated California market share of CFLs in 2005.	N/A	Not Complete Factor
3. Split Incentive	ES	N/A	$0.031	1%	6%	124,870,481	56,941	Assumes a small number of HH pay a flat fee for electricity.	N/A	Applicability Factor
4. Lock-In (lights do not fit fixture)	ES	N/A	$0.031	20%	25%	99,896,384	45,553	The number of fixtures that do not accommodate CFLs.	N/A	Feasibility Factor
5. Product Availability	ES	N/A	$0.031	20%	40%	79,917,108	36,442	Assumes some rural population and some lower income urban population do not have nearby stores selling CFLs.	Utility-run purchase by mail programs	N/A
6. Lifetime Uncertainty	LT	$0.007	$0.038	16%	49%	67,316,135	23,022	Lifetime reduced by two thousand hours to reflect uncertainty over product lifetime.	Consumer education on CFL testing and reliability	N/A
7. Product Information Cost	K	$0.048	$0.086	72%	86%	18,970,889	6,488	Assumes one-half hour needed (at $20 time value per hour) for consumers to educate themselves about CFLs.	Consumer awareness campaign on benefits of CFLs	Awareness Function
8. Vendor Information Cost	K	$0.024	$0.110	44%	92%	10,696,434	3,658	Assumes one quarter hour needed to find nearby vendors with CFLs.	Product and vendor lists for consumers	Awareness Function
9. Consumer Preference, Light Quality & Bulb Shape	K	$0.024	$0.134	40%	95%	6,459,449	2,209	Assigns a $5 penalty to CFLs to reflect consumer preference for familiar incandescent light and shape.	Consumer awareness about CFL improvements	N/A

Notes: HH = households; ES = eligible stock; LT = lifetime; S = (cost) savings; K = capital cost

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Cost of Conserved Energy: Accounting for Changes in Capital Costs and Reduction in Energy due to an Energy Efficiency Measure

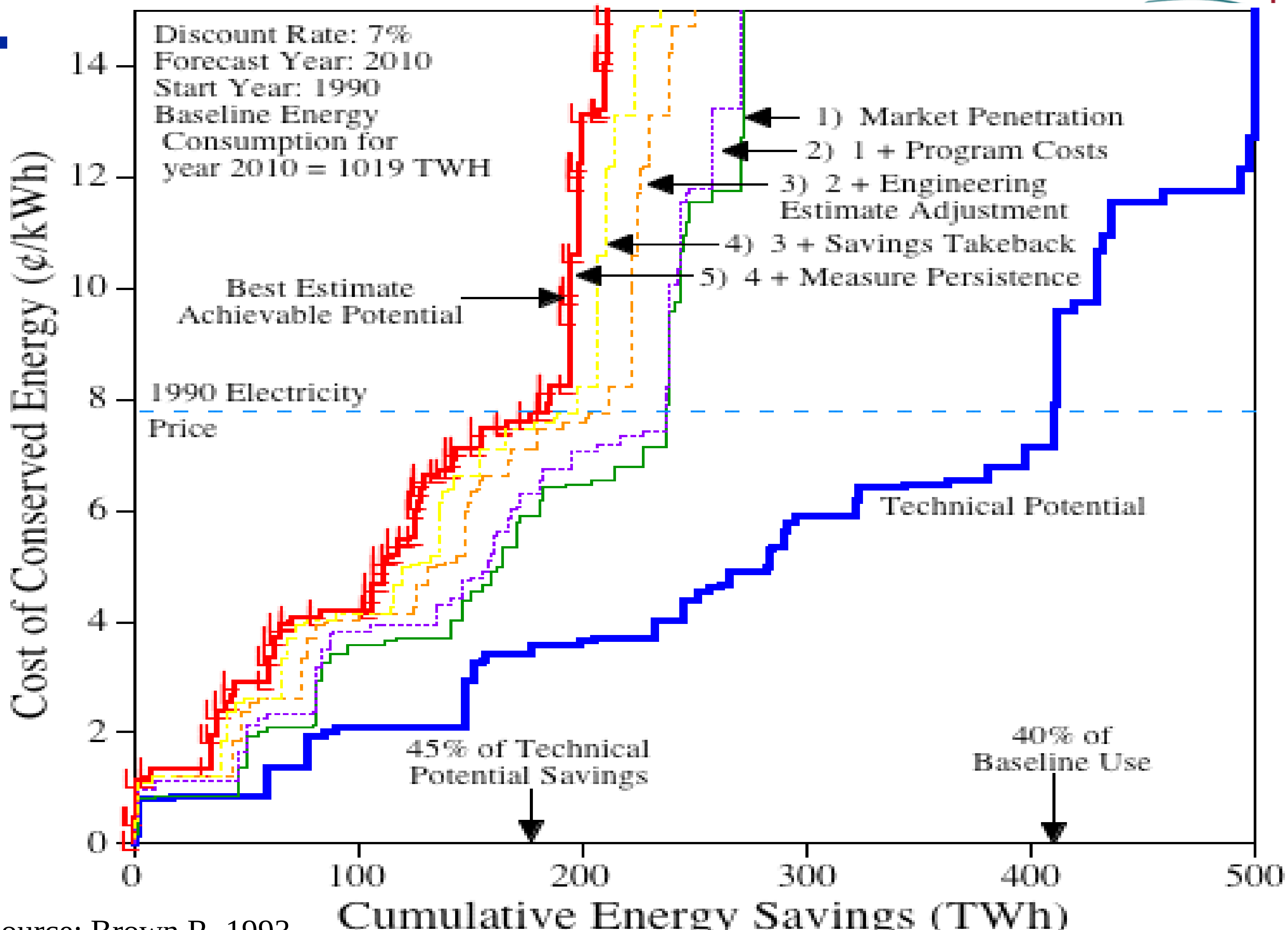
$$CCE = \frac{I \cdot q}{S}$$

$$q = \frac{d}{(1-(1+d)^{-n})}$$

where:

CCE = Cost of Conserved Energy for the energy efficiency measure, in \$/GJ
I = Capital cost (\$)
q = Capital recovery factor
S = Annual energy savings (GJ)
d = discount rate
n = lifetime of the conservation measure (years)

Estimates of the achievable potential for electricity efficiency improvements in US residences



Source: Brown R. 1993

Cost of Conserved Energy: Accounting for Changes in Capital, Labor and Material Costs

$$CCE = \frac{I \cdot q + M}{S}$$

$$q = \frac{d}{(1-(1+d)^{-n})}$$

where:

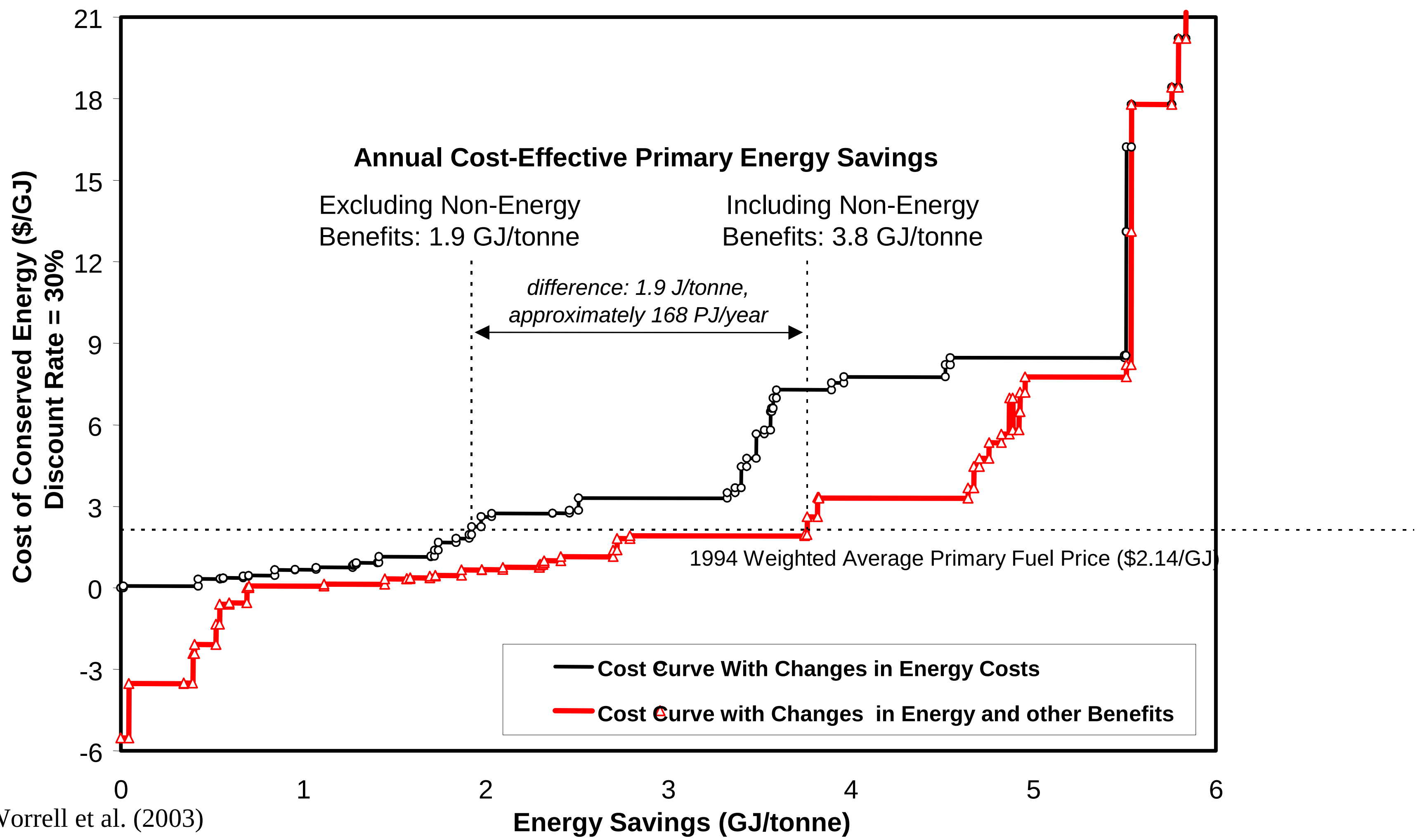
CCE = Cost of Conserved Energy for the energy efficiency measure, in \$/GJ
I = Capital cost (\$)
q = Capital recovery factor
M = Annual change in labor and material costs (\$)
S = Annual energy savings (GJ)
d = discount rate
n = lifetime of the conservation measure (years)

US Steel Industry Cost of Conserved Energy: Other Benefits

Waste	Emissions	Operation & Maintenance
Use of waste fuels, heat, gas	Reduced dust emissions	Reduced need for engineering controls
Reduced product waste	Reduced CO, CO2, NOx, SOx emissions	Lowered cooling requirements
Reduced waste water		Increased facility reliability
Reduced hazardous waste		Reduced wear and tear on equipment/machinery
Materials reduction		Reductions in labor requirements
Production	**Working Environment**	**Other**
Increased product output/yields	Reduced need for personal protective equipment	Decreased liability
Improved equipment performance	Improved lighting	Improved public image
Shorter process cycle times	Reduced noise levels	Delaying or Reducing capital expenditures
Improved product quality/purity	Improved temperature control	Additional space
Increased Reliability in Production	Improved air quality	Improved worker morale

US Steel Industry Supply Curves: Accounting for Changes four categories of benefits (previous slide)

Benefits double cost effective energy efficiency potential to 19%



Source: Worrell et al. (2003)

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Baseline Changes 1. Structural Changes in the US Cement Industry

- **Cement: amount of raw materials input; clinker produced (clinker to cement ratio); wet and dry cement produced; types and ages of kilns)**

		1994		2004	
		(Mt)	**(%)**	**(Mt)**	**(%)**
Raw materials input		**123**		**165**	
Total Clinker Production		**68.5**		**88.2**	
Wet Clinker production		19.5	29%	16.9	19%
Dry Clinker production		49.0	71%	71.3	81%
Total Cement		**74.3**		**99.0**	
Wet cement production		21.2	29%	20.2	20%
Dry cement production		53.1	71%	78.8	80%
# Kilns	Wet	71		52	
	Dry (preheater, precalciner, long)	132		134	
	Average age (years)	27		36	

Sources: USGS and PCA, various years for throughputs; PCA and Major Industrial Plant Database (MIPD) for kiln technologies

2. Energy intensity changes at each stage of cement production

	1994		2004	
Process Stage	**Primary Energy PJ**	**Primary Intensity GJ/t**	**Primary Energy PJ**	**Primary Intensity GJ/t**
Wet Cement Production				
Raw Materials Preparation	11	0.3	7	0.2
Clinker Production	124	6.3	100	5.9
Finish Grinding	13	0.6	12	0.6
Total Wet	***148***	**7.0**	**119**	**5.9**
Dry Cement Production				
Raw Materials Preparation	33	0.4	53	0.4
Clinker Production	230	4.7	349	4.9
Finish Grinding	34	0.6	48	0.6
Total Dry	**296**	**5.6**	**450**	**5.7**
Total All Cement	**444**	**6.0**	**569**	**5.7**

Sources: USGS, MECS, PCA, COWIconsult, CANMET (Canada), Lowes (UK), Folsberg, Ellerbrock, Holnan, ISTUM

3. Changes in fuel mix and energy price – Cement

	1994			2004		
	PJ	Share	Price	PJ	Share	Price
Electricity	37	10%	$ 4.01	48	13%	$ 4.46
Fuel Oil (Dist.+resid)	2	1%	$ 3.56	4	1%	$ 4.58
Gas	25	7%	$ 2.35	15	4%	$ 4.09
LPG	0	0%	$10.19	0	0%	$ 14.82
Coal	211	59%	$ 1.71	173	47%	$ 1.83
Coke	58	16%	$ 2.25	80	22%	$ 0.96
coal coke	9	2%		0	0%	
petroleum coke	49	14%		80	22%	
Other	26	7%	$ 1.07	49	13%	$ 1.07
Tires -waste	3	1%		11	3%	
solid-waste	1	0%		3	1%	
Liquid-waste	21	6%		36	10%	

Sources: MECS, various years

1. Structural Changes in the Steel Industry

	Units	1994	2002
Crude Steel	**Mt**	**91**	**101**
Electric Arc	Mt	36	51
Basic Oxygen	Mt	55	50
Open Hearth	Mt	0	0

Sources: IISI, various years

	1994	**2002**
EAF Steelmaking	36	51
EAF Casting	50	46
EAF Hot Rolling	48	42
EAF Cold Rolling and Finishing	0	0
Total Secondary Steelmaking	36	51

Sources: AISI, various years

2. Energy intensity changes at each stage of steel production

	Throughput (Mtonne)		Primary Intensity (GJ/t product)	
	1994	**2002**	**1994**	**"2002"**
Integrated Steelmaking				
Sintermaking	12.1	8.9	2.6	2.6
Cokemaking	16.6	11.4	4.9	0.9
Ironmaking	49.4	40.2	13.9	11.6
BOF Steelmaking	55.4	50.1	0.7	0.6
BOF Casting	59.1	50.0	0.8	0.6
BOF Hot Rolling	48.3	41.6	5.4	6.5
BOF Cold Rolling and Finishing	31.7	33.4	2.8	2.7
Secondary Steelmaking				
EAF Steelmaking	35.9	50.8	5.5	4.7
EAF Casting	49.5	45.7	0.2	0.3
EAF Hot Rolling	48.3	41.6	3.5	5.2
EAF Cold Rolling and Finishing	0	0	0	0
Total Primary and Secondary Steelmaking	**91.22**	**100.9**	**20.5**	**16.2**

Sources: AISI, various years for throughput; Margolis (for DOE) 1994 and 2000 for intensities

3. Changes in fuel mix and energy price – Steel

	Energy Mix (PJ)		Energy Prices ($/GJ)	
	1994	2002	1994	2002
Residual Fuel Oil	42	*	$ 2.47	$ 4.06
Distillate Fuel Oil	*	12	$ 4.89	$ 2.37
Natural Gas	483	418	$ 2.41	$ 3.69
Coal	901	509	$ 1.69	$ 1.83
Coke	538	538	$ 2.25	$ 2.25
Electricity	148	184	$ 10.40	$ 9.86

* data withheld

Sources: MECS, various years

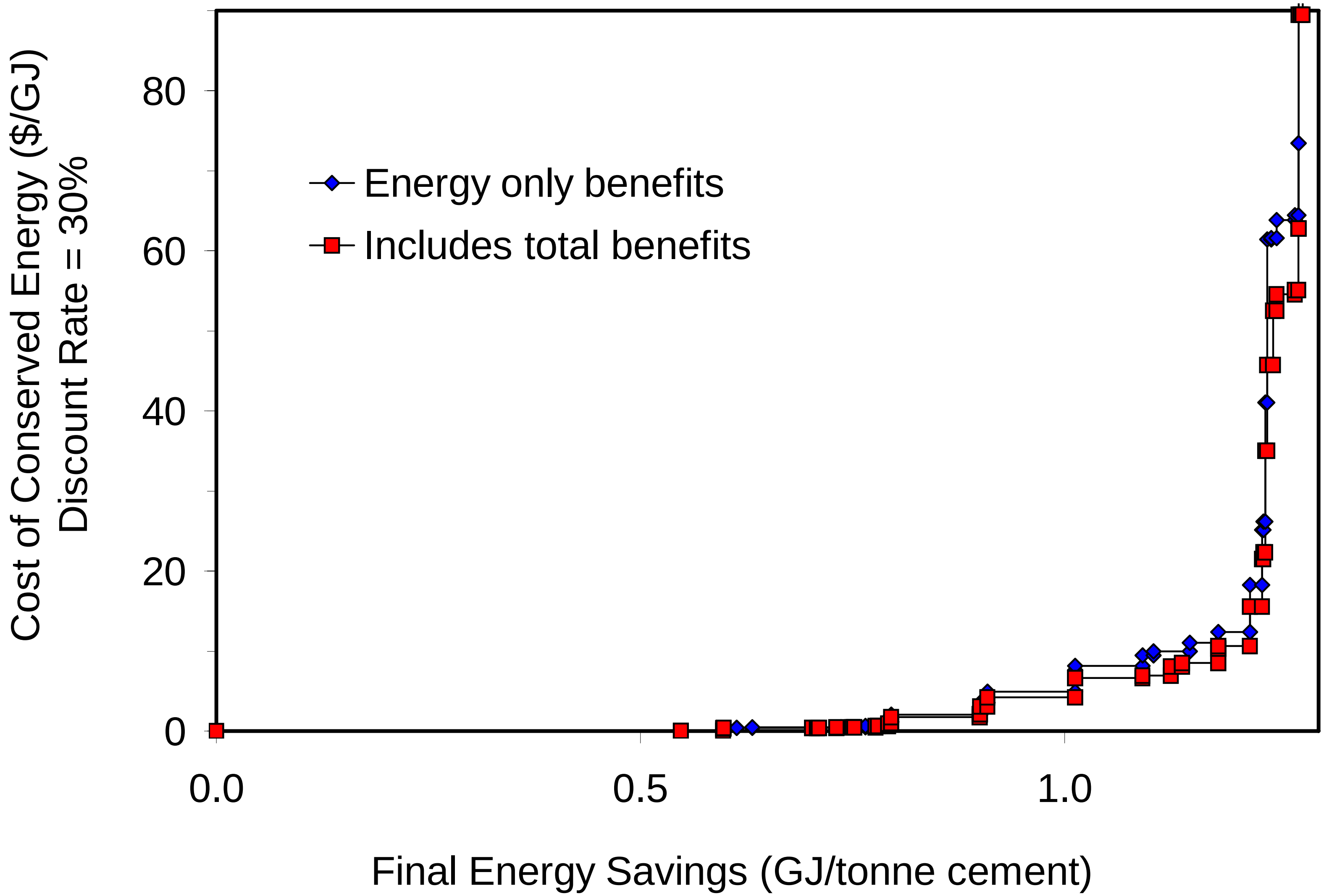
Updating the Cost Curves – critical changes implemented from 1994 to 2004 (cement) or 2002 (steel) in efficiency measures

- **Technology changes – for each individual existing technology**
  - — **Updating costs of technology**
  - — **Updating energy savings relative to current industry practices**
  - — **Applicable share of production for the technology in new year**

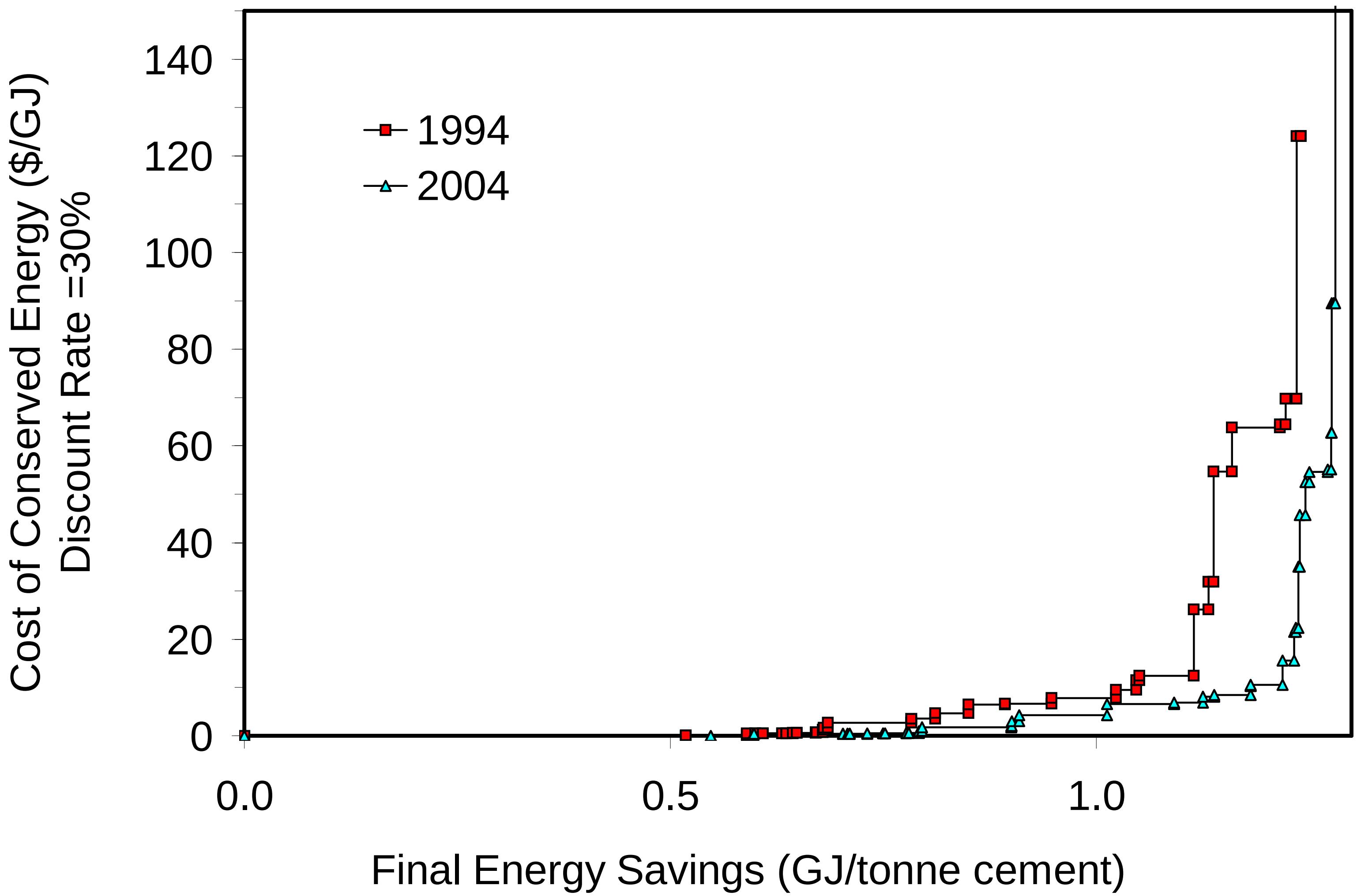
- **Technology changes –new technology additions which came onto the market (cement only)**
  - — **Requires cost, energy and applicable share of production data for each new technology**

- **Comparison of inclusion of energy-only and total benefits**

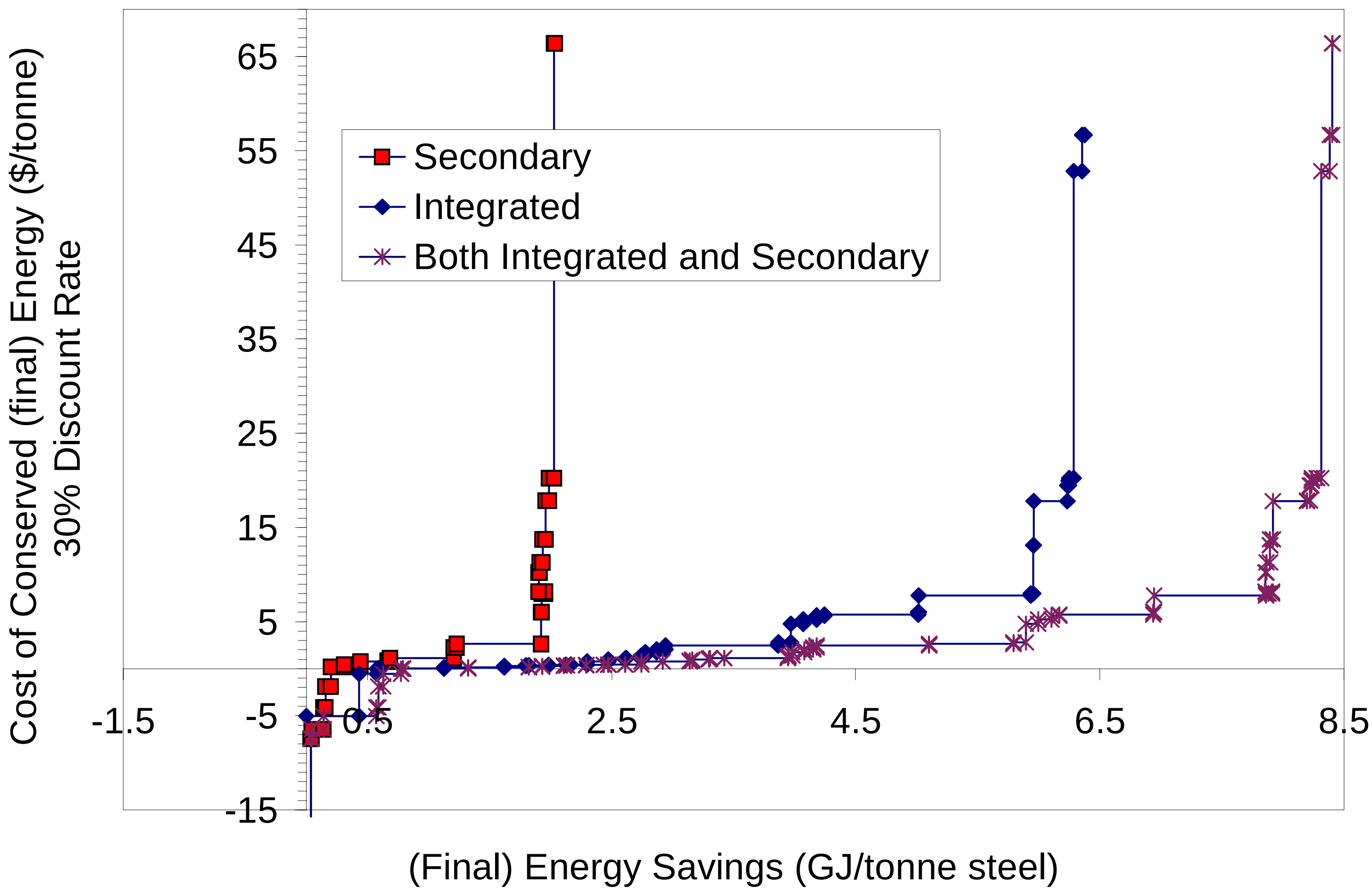
Comparison of Cement Cost Curves for 2004 including total versus only energy benefits



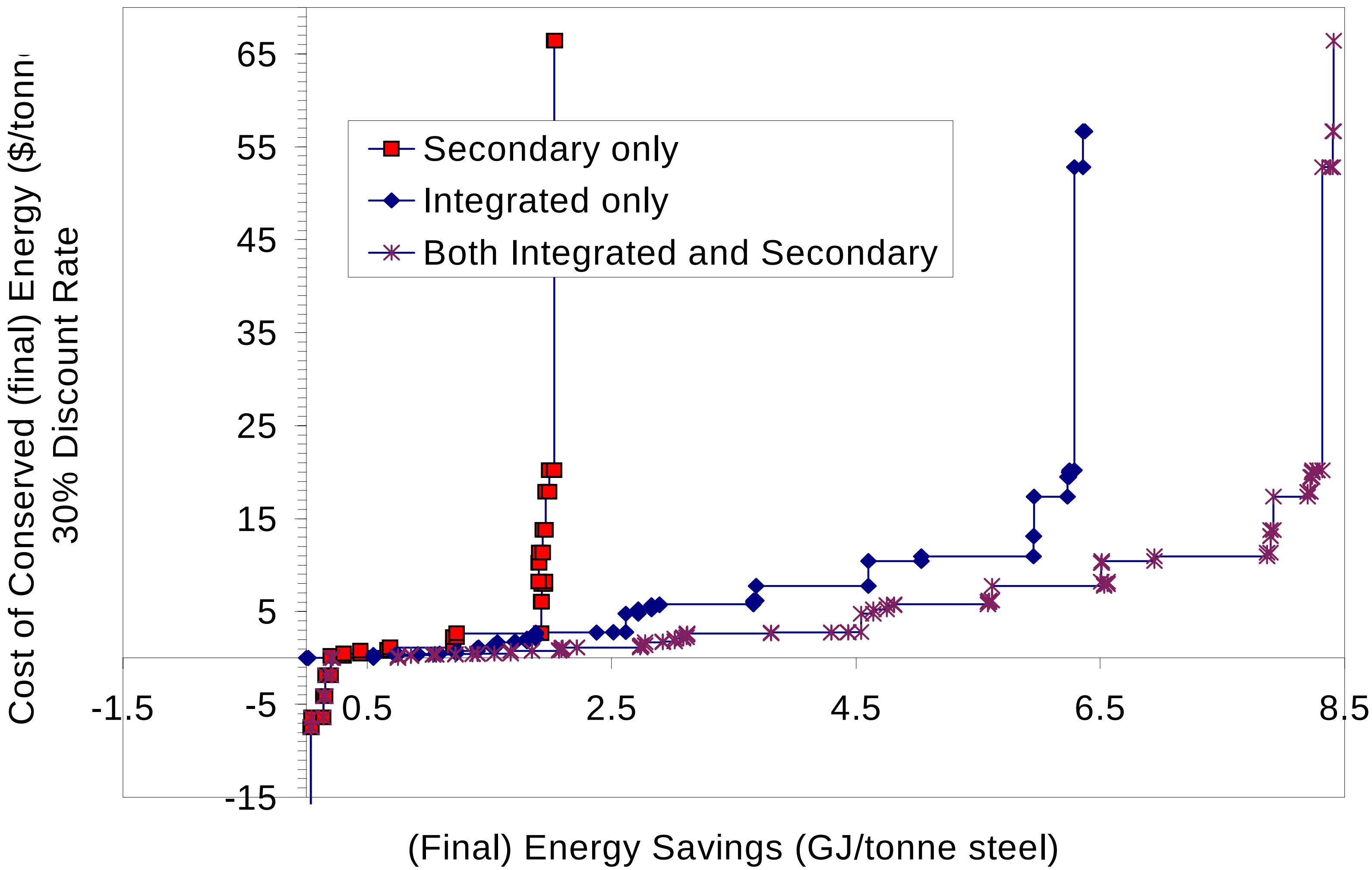
Cement Cost Curves – comparison of curves for 2004 and 1994 (30% discount rate)



Iron and Steel Cost Curves –2002 total benefits - integrated, secondary and combined (30% discount rate)



Iron and Steel Cost Curves –2002 energy only benefits - integrated, secondary and combined (30% discount rate)



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Global Atmospheric Stabilization Analysis Using COBRA: A Linear Programming Model

- COBRA was developed using
  - — LBNL data and expertise on bottom-up country-specific models of energy sector mitigation costs and potential,
  - — combined with global IEA, WEA, and SRES data
  - — assumes perfect foresight
- Includes 10 global regions, tracks carbon emissions decadally for 16 energy sources and demand sectors, including five industrial sectors, under a stabilization constraint and/or carbon price

Source: Wagner and Sathaye, 2006

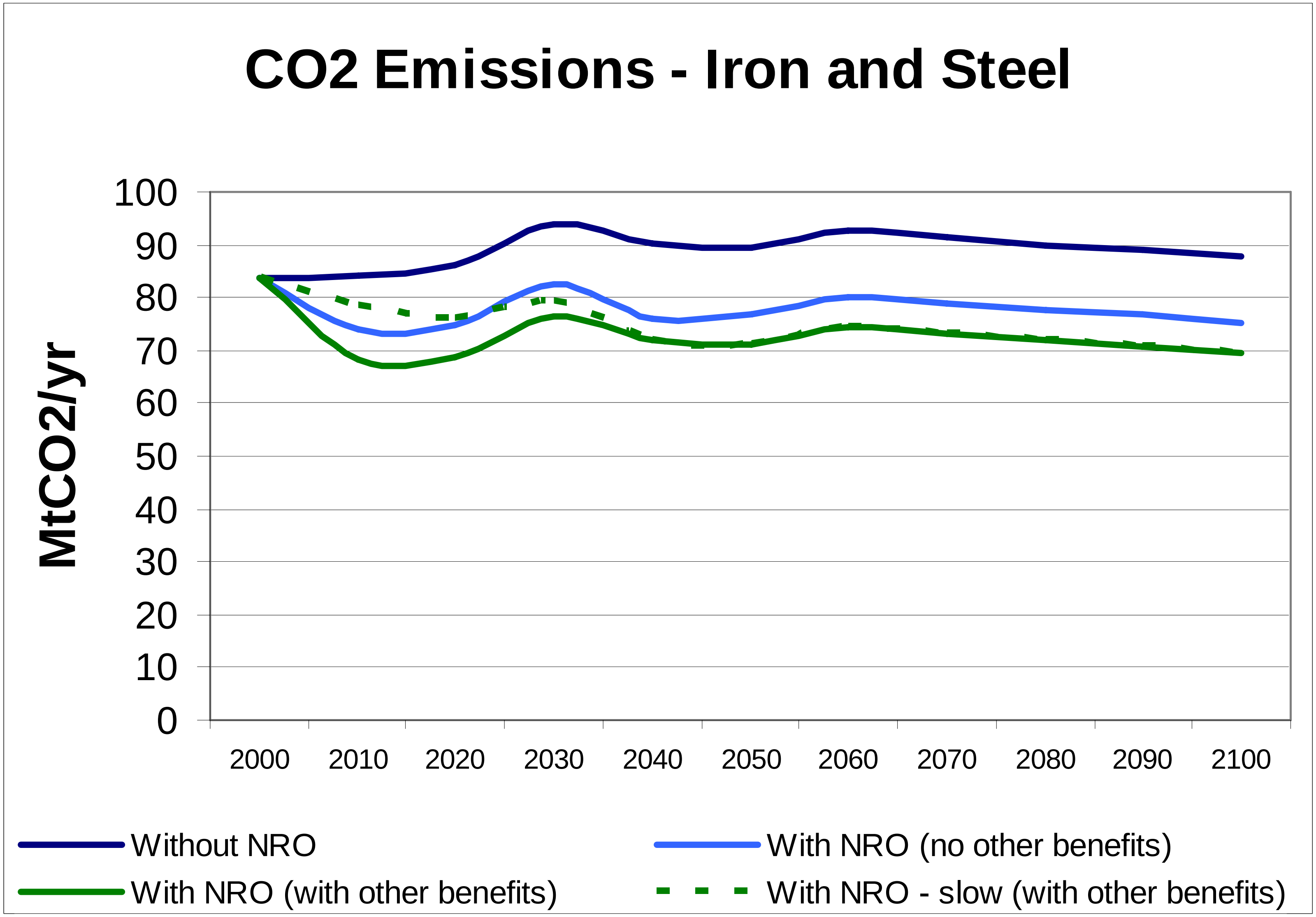
Global Atmospheric Stabilization Analysis Using COBRA: A Linear Programming Model

- Small and fast, appropriate for sensitivity analysis
  - — treatment of no regrets options
  - — energy and total costs of industrial options
  - — technological change
  - — discount rates
  - — alternative stabilization levels and/or carbon prices
- Model discount rate is 4%
  - — Steel and cement cost curves were derived at 15% discount rate

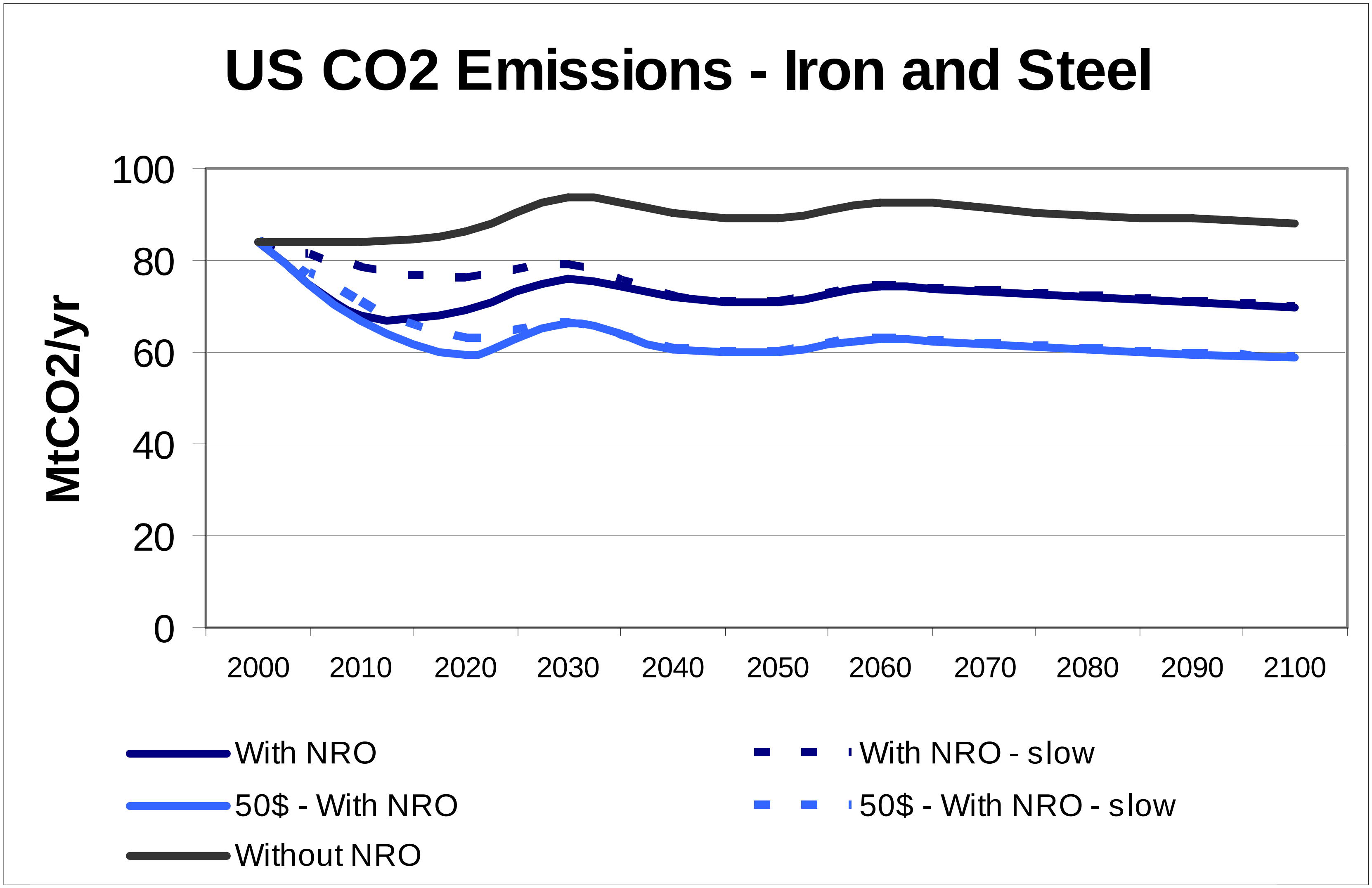
Key Cases Analyzed Using COBRA

- Model is calibrated to SRES A1B scenario
- Baseline with and without no-regrets options (NROs)
  - — instantaneous penetration of NROs
  - — slowed penetration of NROs
- Baselines vs. mitigation at alternative carbon prices
- Energy cost vs. all benefits cost curve
- Technological change vs. no technological change

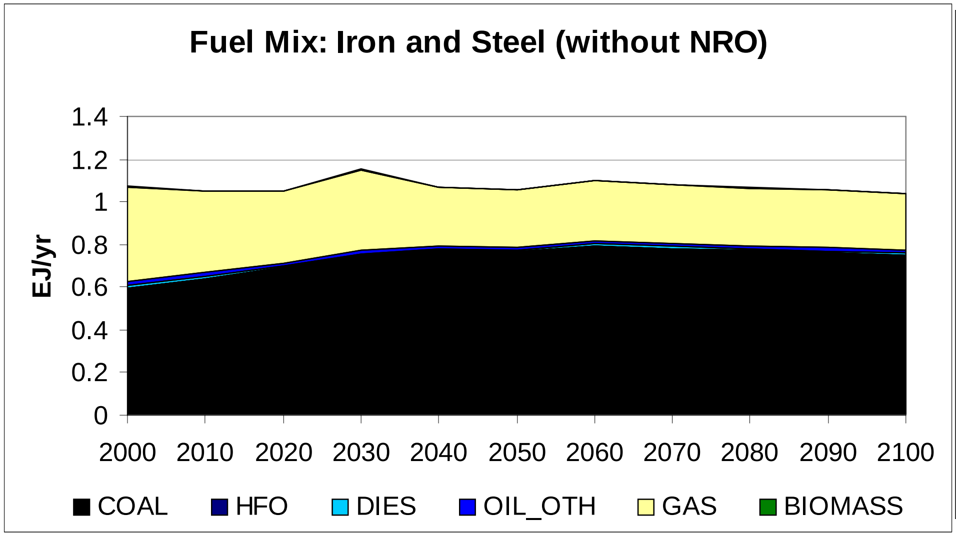
US Iron and Steel

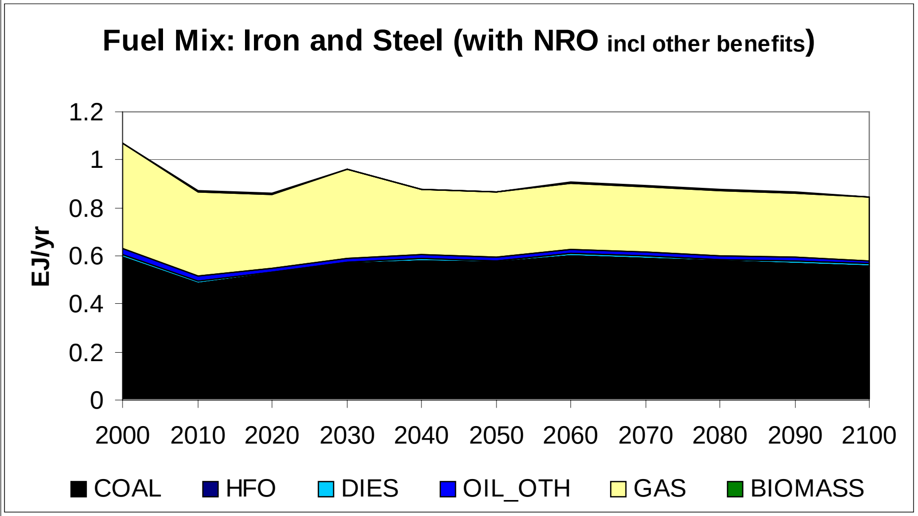


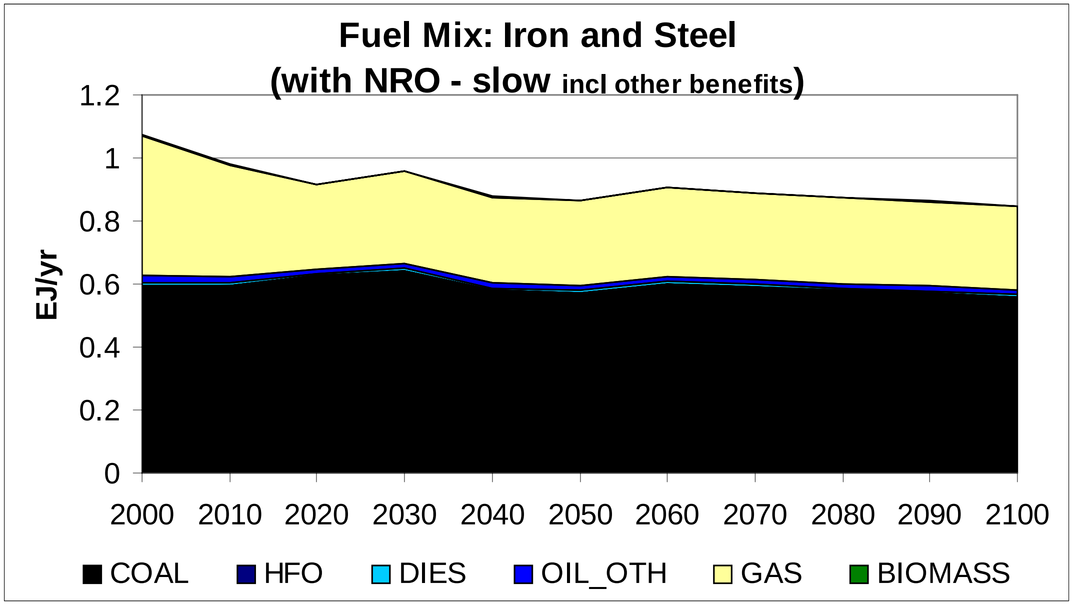
The effect of carbon prices: Options include energy and non-energy benefits



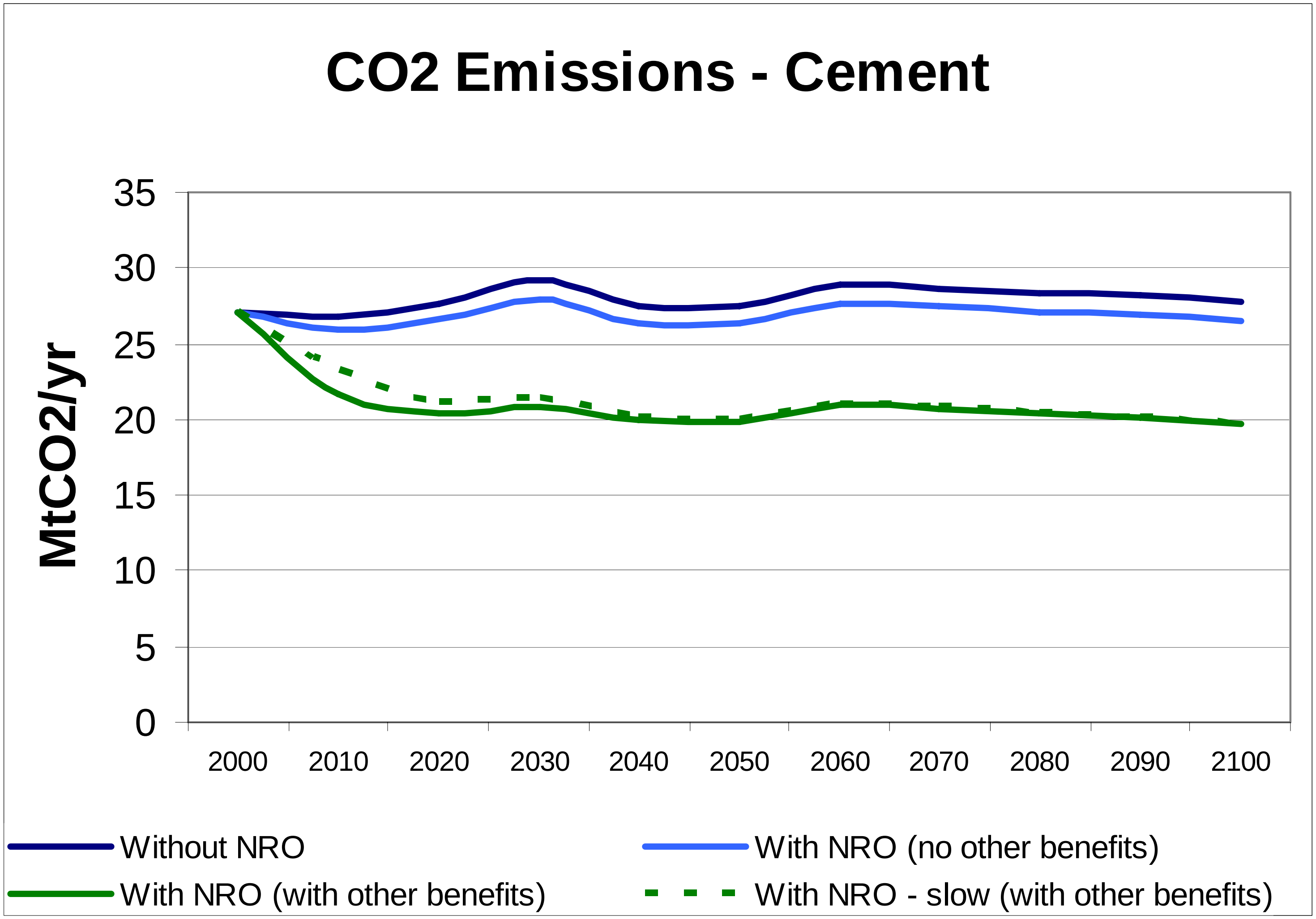
Fuel Mixes: US Iron & Steel



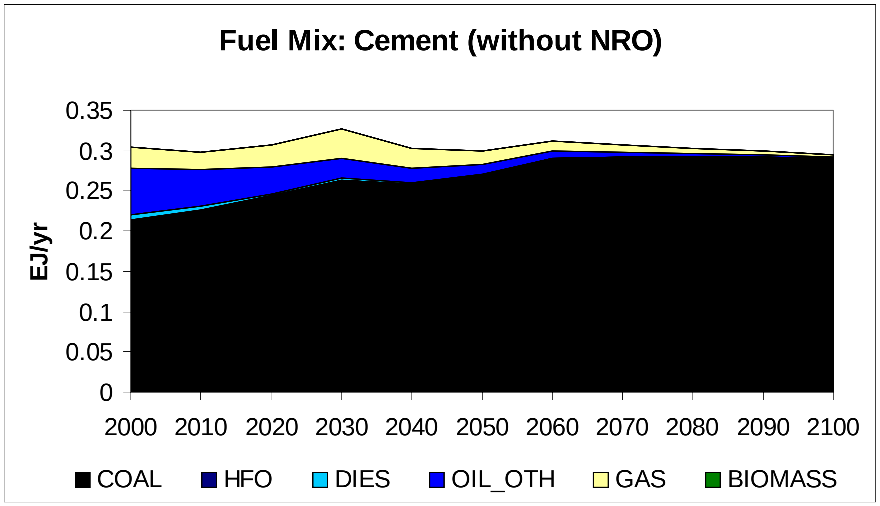




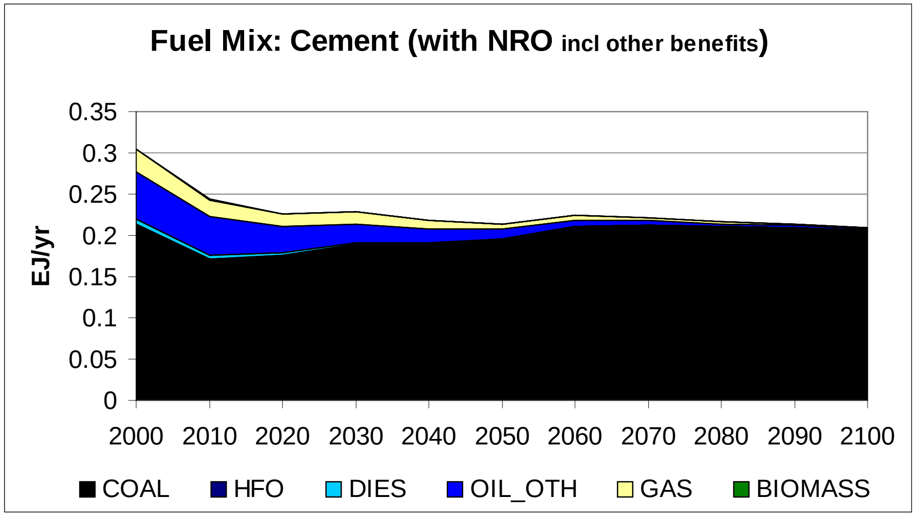
US Cement


CO2 Emissions - Cement
MtCO2/yr
35
30
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Without NRO
With NRO (no other benefits)
With NRO (with other benefits)
With NRO - slow (with other benefits)

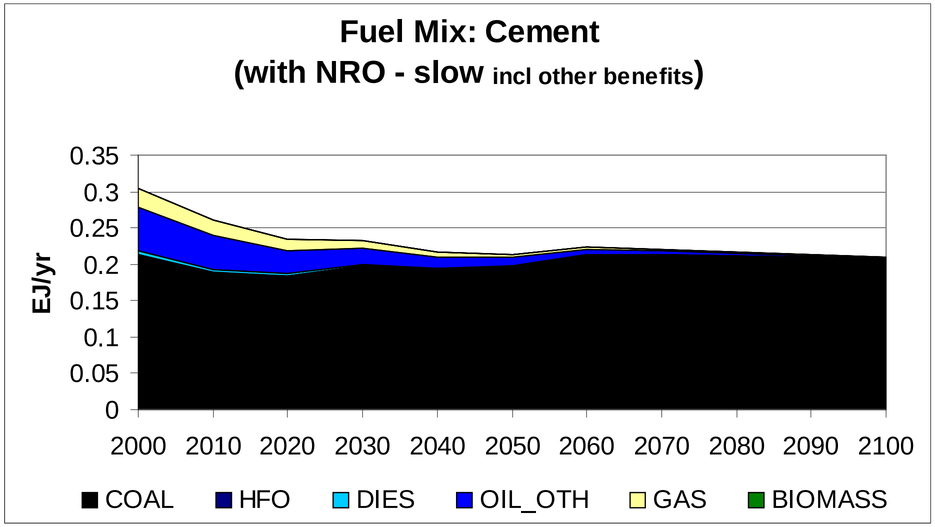
US Cement



Fuel Mix: Cement (without NRO)
EJ/yr
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2000 2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
COAL HFO DIES OIL_OTH GAS BIOMASS

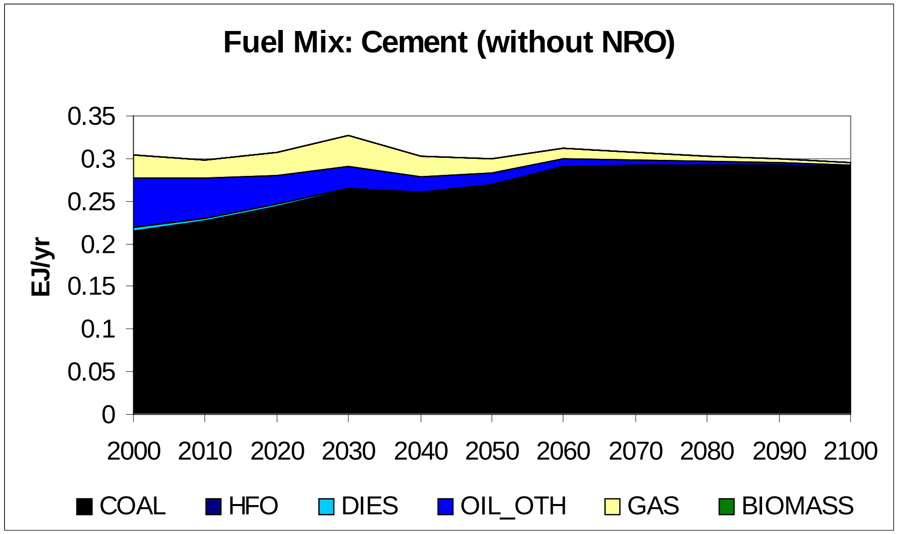


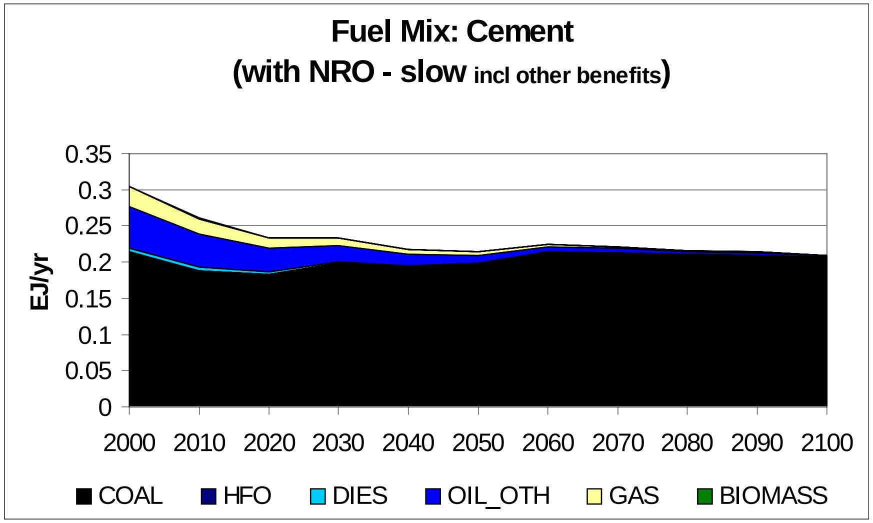
Fuel Mix: Cement (with NRO incl other benefits)
EJ/yr
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2000 2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
COAL HFO DIES OIL_OTH GAS BIOMASS

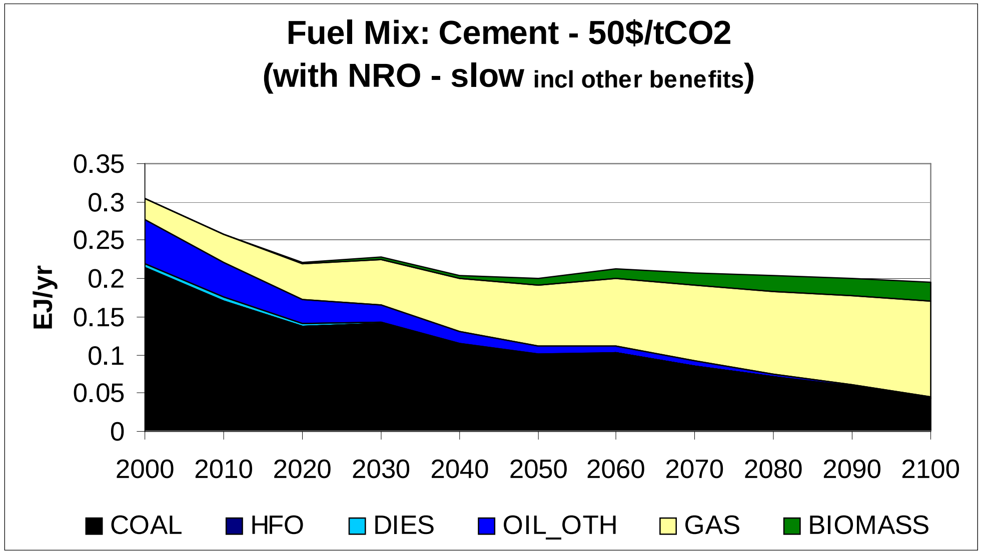


Fuel Mix: Cement
(with NRO - slow incl other benefits)
EJ/yr
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2000 2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
COAL HFO DIES OIL_OTH GAS BIOMASS

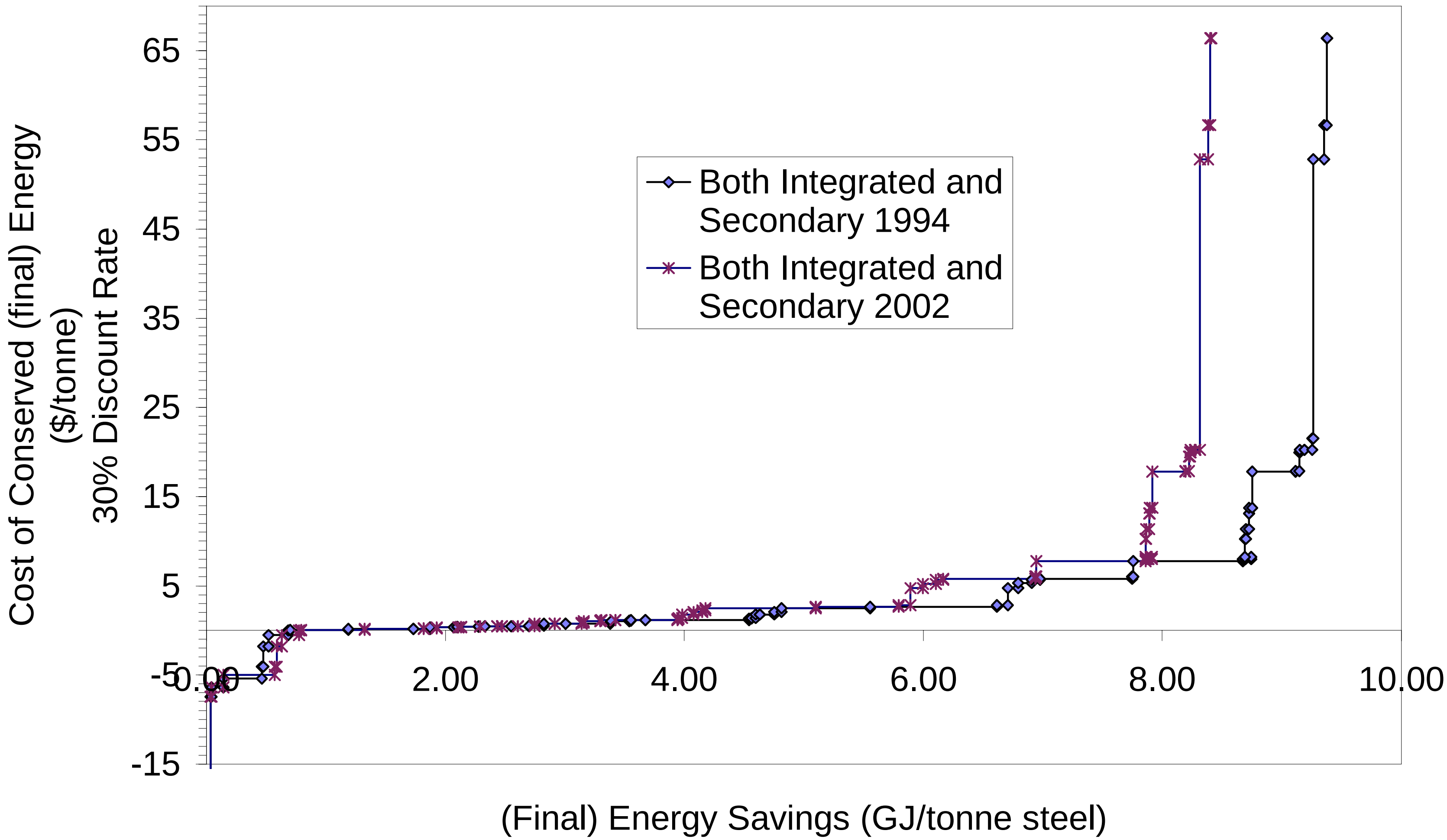
The effect of carbon prices: US fuel mix for cement sector



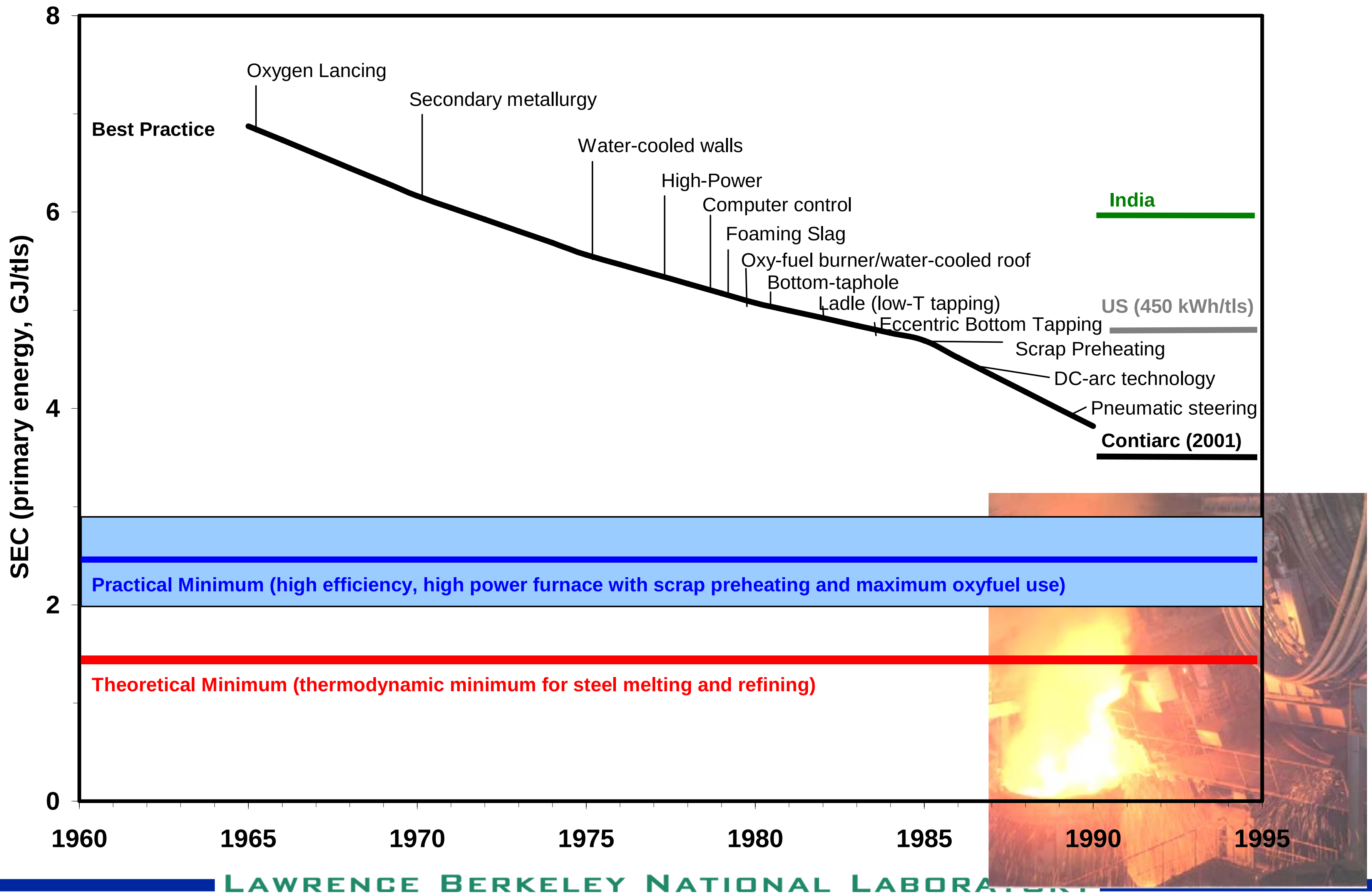




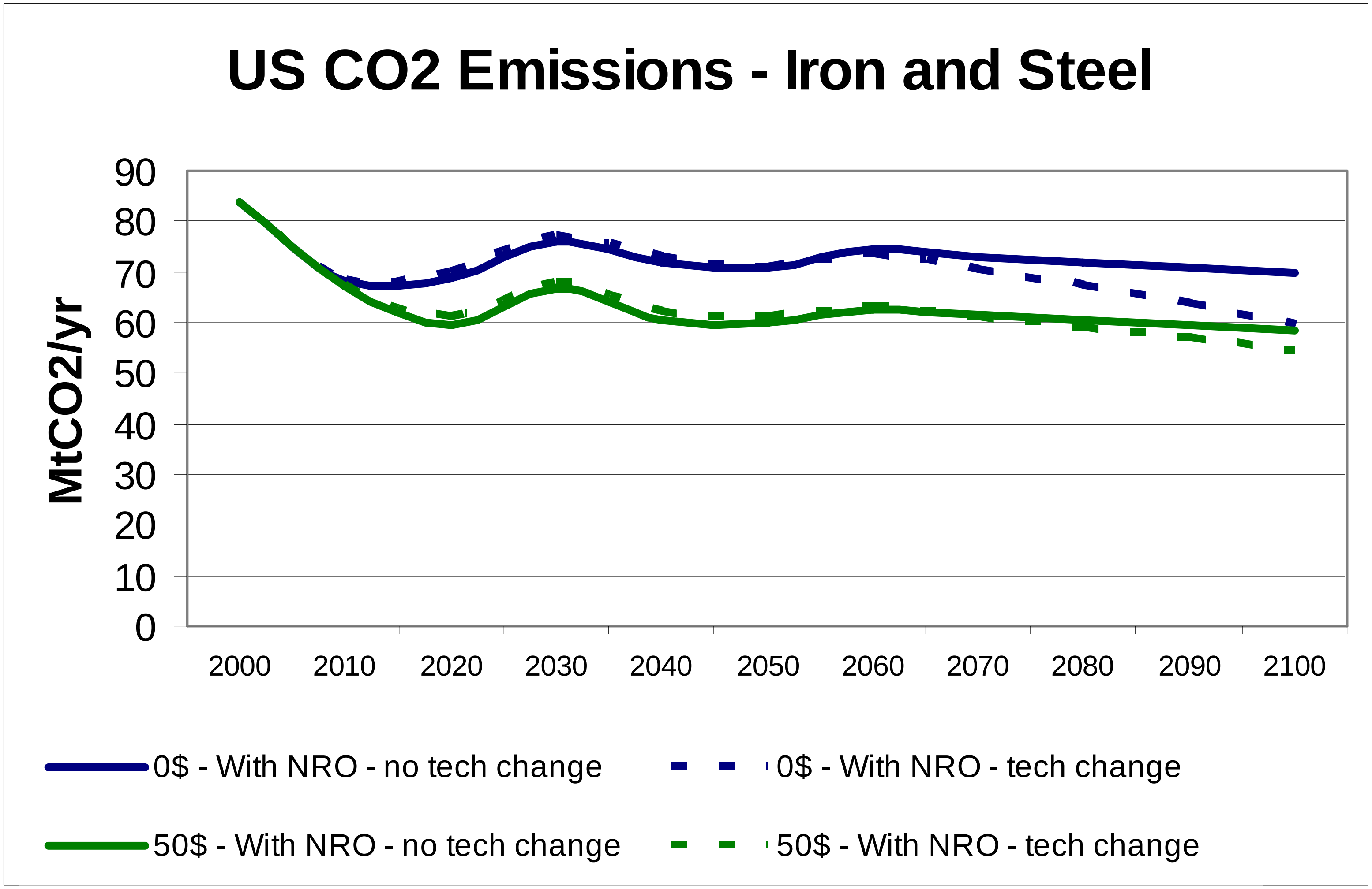
US Steel: Comparison of 1994 and 2002 Supply Curves (Include both energy and other benefits)



Energy Efficiency in the Steel Industry – Electric Arc Furnace



Technological Change: impact on emissions



Conclusions

- Detailed technology representation provides insight and understanding of technology anf fuel mix choices
- Inclusion of non-energy benefits increases emissions reductions
- Bottom-up cost curves provide another approach for modeling technological change
  - — Technological change increases emissions reduction
  - — With a carbon price, potential is lower compared to only price-induced emissions

Effect of Accounting for Changes in Other Benefits on Cost-Effectiveness and Ranking of Measures

Measure	*With Energy (E)* Benefit Only: CCE ($/GJ)	Rank (of 47)	Cost-Effective?	*With Other* Benefits: CCE ($/GJ)	Rank (of 47)	Cost-Effective?
Inj. of NG – 140	3.1	19	NO	-0.5	8	YES
Coal inj. – 225	3.9	22	NO	1	23	YES
Coal inj. – 130	4.4	23	NO	0.1	11	YES
DC-Arc furnace	5	26	NO	-1.3	6	YES
Process control	5.6	27	NO	-2.1	5	YES
Scrap preheating	6.7	31	NO	-0.6	7	YES
Thin slab casting	8.5	35	NO	1.9	27	YES
Hot charging	8.9	36	NO	5.3	35	NO
FUCHS furnace	12.7	37	NO	-3.5	3	YES
Adopt cont. cast	14.3	39	NO	-3.5	2	YES
Twin shell	16.6	40	NO	3.3	30	NO
Oxy-fuel burners	17.4	41	NO	-5.5	1	YES
Bottom stirring	20.5	45	NO	-2.4	4	YES
Foamy slag	30.1	46	NO	7.2	40	NO

NOTE: These cost of conserved energy (CCE) and cost-effectiveness calculations are based on a discount rate of 30% and an average primary energy price of $2.14/GJ.