ECONOMIC ANALYSIS OF A CAP AND TRADE SYSTEM FOR CARBON DIOXIDE EMISSION REDUCTION IN THE WESTERN STATES

by

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I. INTRODUCTION

A "Cap and Trade" system has many desirable features for implementing pollution emission reductions. The cap limits emissions. The trading ensures that the reduction will be achieved at the lowest possible cost (economic efficiency). The initial allocation of permits can be used to address issues of fairness (equity).

The model used in this study has been previously developed and successfully applied to simulate the workings of interregional (and international) cap and trade (C&T) systems. It is based on established economic principles (equilibrium and optimization). The model can be solved either as a system of simultaneous equations or as a non-linear programming model. It has been applied to the analysis of C&T associated with the Kyoto Protocol, emissions trading within the European Union, the Regional Greenhouse Gas Initiative (RGGI), and emissions trading among ten EPA regions covering all states of the U.S. (see Rose et al., 1998; Zhang, 2000; Loeschel and Zhang, 2002; Rose and Stevens, 2002; Rose and Zhang, 2004; Rose et al., 2006).

II. THE MODEL

The model yields the following general results:

- Carbon dioxide emission reductions for each state before and after permit trading
- Cost of CO_2 emission reductions for each state before and after trading
- Number of permits traded (bought and sold) by each state
- Equilibrium permit price

The model uses as inputs:

- Projections of baseline CO_2 emissions for each state
- Caps on CO_2 emissions for each state (permit allocations are equal to emission levels that meet the cap)
- Marginal cost of CO_2 emission reduction for each state

The model is presented in more detail in Appendix A to this report.

III. SIMULATIONS

A. Simulation cases

The following policy goals were simulated:

- CAP A: Year 2000 CO_2 emission levels

- CAP B: 10% below Year 2000 CO_2 emission levels in Year 2020 (ramped up from baseline in 10% increments starting in Year 2011 to meet the cap in 2020)

For each of the two caps, simulations were run for two geographic configurations:

- 11-state configuration

AZ	NV
CA	OR
CO	UT
ID	WA
MT	WY
NM	

- 4-state configuration

AZ
CA
NM
OR

For each of the two caps, simulations were run with the following coverage:

- Analysis of statewide CO_2 emissions

- Analysis of CO_2 emissions only from the power sector

All the simulations were performed using emissions on a "production" basis. Analogous simulations will be run on a "consumption" basis when data become available.

B. Key Assumptions

- Statewide emission projections based on EPA (2006) data for the year 2000 and growth rates equal to fifty percent of economic growth rates for each state based on 2006 data.

- Power sector emission projections based on EPA (2006) data for the year 2000 and growth rates equal to fifty percent of economic growth rates for each state based on 2006 data.

- Cost-saving conservation up to a 5% level and a 15% level (linear functions beginning at -$10 per ton CO_2 for each state, see Appendix B).

- Marginal cost curves for mitigation measures other than conservation follow an exponential shape (see Appendix B).

- Marginal cost curves for each state are based on relative carbon intensities (see Appendix D).

- Annual permit trade only (no banking or offsets)

- Annual economic growth rate for each state is projected using the Bureau of Labor Statistics (BLS, 2006) employment growth projection and the historical relationship between economic growth and employment growth in each state.

IV. RESULTS

Results for each set of simulations are presented in the tables below (basic data on which each set of simulations is based are presented immediately below each table of results). Results are presented for two key years--2012 and 2020, as well as for the cumulative period 2010 to 2020. Intermediate year results will be presented later for a select number of cases in Appendix C.

The results of the analysis are presented for the following simulations in the corresponding tables below:

Symbol designations for the tables are as follows:

A: Cap is Year 2000 emissions (used for simulation of Year 2012)

B: Cap is 10% below Year 2000 emissions to be achieved in Year 2020

S: Statewide coverage of emissions

P: Power sector emissions only

5%: Cost-saving conservation up to 5% of baseline emissions

15%: Cost-saving conservation up to 15% of baseline emissions

2012: Results for Year 2012

2020: Results for Year 2020

Distinctions are made between the caps and the years to avoid confusion when simulations for interim years are run.

Notation above pertains to the 11-state configuration. For the 4-state configuration a “prime”, or apostrophe, is added after the cap designation, i.e., A’ or B’.

A. Statewide CO_2 Emission Reductions (11-State Area)

We summarize the results for Table BS/5%/2020 in particular, but the column descriptions pertain to all of the tables. We include specific values for New Mexico in brackets. For example, with respect to Table BS/5%/2020, the first column refers to the cost of meeting the cap unilaterally, i.e., as a "fixed quota" [NM = $155.85 million]. After trading, the mitigation cost goes up for permit sellers like CA, relative to the mitigation cost before trading, as they increase mitigation in order to sell permits (in the range where their mitigation cost is lower than the permit price, so they can make a profit on these sales) and goes down for permit buyers like NM [$58.37 million] as they reduce their own mitigation and substitute permits for it (the purchases cover the range where their mitigation costs exceed the permit price of $20.33/ton CO_2, so they can reap cost-savings from these transactions).

Column 3 lists the dollar values of permit purchases (positive costs) [NM = $76.56 million] or sales (negative costs). Note that the column sum equals zero, since permit purchases will just equal permit sales for the region as a whole.

Column 4 is the sum of the first two columns under the "After Trading" heading. The numbers in the column are lower than the corresponding "Before Trading" counterparts for each state, thereby indicating the extent of gains from permit trading [for NM, compare $155.85 million to $134.93 million]. Note that the costs are negative in some tables of results (e.g., AS/15%/2012) because of the existence of cost-saving conservation. Permit trading can in fact enhance this result, as cost saving is achieved and additional gains are reaped by selling permits covered by the increased conservation at a negative cost. An astute reader might note that, if conservation is cost-saving, emitters would have an incentive to mitigate up to the total level of cost saving mitigation on their own volition, without being prompted by a cap, or let alone by a cap and trade system. We assume, however, the standard inertia on the part of emitters (e.g., myopia, intransigence with respect to regulation, competing uses of capital that would need to be devoted to conservation).

Column 5 lists the volume of trading in physical units (million tons CO_2). Columns 6 and 7 list post-trading emission reductions levels [NM = 10.85 million tons CO_2] and percent emission reductions from baseline [NM = 16.35%], respectively.

The equilibrium permit price (in dollars per ton CO_2) is listed just below the main body of each table for any single geographic configuration ($20.33/ton CO_2 for each state). The permit prices increase over time as emissions increase, and hence mitigation requirements increase to meet a fixed cap.

Major implications and insights of the simulation for Table BS/5%/2020 are:

- 4 states sell permits and 7 buy permits
- permit price is $20.33/ton CO_2
- CA is the largest seller (54.6 million tons; total sales $1.1 billion)
- UT is the largest buyer (22.4 million tons; total purchases $455 million)
- NM buys 3.8 million tons of permits at a cost of $76.6 million
- total value of permit trading transactions is $1,294.4 billion (in 2000 dollars)

TABLE AS/5%/2012. COST, PERMITS TRADED, AND EMISSION REDUCTION OF ACHIEVING 2000 EMISSIONS CAPS IN YEAR 2012, ASSUMING 5% COST-SAVING CONSERVATION: STATEWIDE EMISSIONS
(million $2000 or otherwise specified)

State	Before Trading	After Trading			Permits Traded	Emission Reduction	Emission Reduction
	Mitigation Cost	Mitigation Cost	Trading Cost	Net Cost	(million tCO_2)	(million tCO_2)	(percent from baseline)
AZ	82.73	25.58	46.27	71.85	5.08	17.09	15.95
CA	152.89	307.60	-173.48	134.12	-19.04	121.72	25.40
CO	119.39	34.73	65.87	100.60	7.23	19.54	17.69
ID	1.48	6.19	-5.42	0.77	-0.59	3.33	18.28
MT	-5.81	-2.59	-3.88	-6.47	-0.43	2.95	8.81
NM	-9.68	-1.55	-9.88	-11.43	-1.08	6.25	9.98
NV	-1.77	8.51	-12.03	-3.52	-1.32	7.25	14.34
OR	-7.93	19.84	-42.34	-22.50	-4.65	9.39	20.40
UT	212.67	5.90	102.23	108.13	11.22	10.26	12.10
WA	44.57	45.34	-0.77	44.57	-0.08	21.33	20.53
WY	71.99	-11.85	33.42	21.57	3.67	4.77	6.78
Total	660.52	437.70	0.00	437.70	0.00	223.90	19.19

Permit Price = 9.11$/ton$CO_2$

APPENDIX TABLE AS/5%/2012. BASIC DATA

State	Cap: CO_2 Emissions in 2000 (million tCO_2)	Unabated CO_2 Emissions in 2012 (million tCO_2)	Autarkic Marginal Mitigation Cost (dollars per tCO_2)	Gross State Product in 2000 (million dollars)
AZ	85.03	107.21	13.42	153,469
CA	376.48	479.16	7.15	1,330,025
CO	83.70	110.48	14.37	169,341
ID	15.48	18.21	6.74	36,755
MT	30.99	33.52	6.02	21,702
NM	57.47	62.64	5.88	52,592
NV	44.61	50.54	6.46	75,533
OR	41.31	46.05	2.96	121,383
UT	63.31	84.80	28.24	68,430
WA	82.62	103.86	9.05	218,095
WY	61.99	70.44	36.82	19,113
Total	942.99	1,166.89		2,266,438

TABLE AS/15%/2012. COST, PERMITS TRADED, AND EMISSION REDUCTION OF ACHIEVING 2000 EMISSIONS CAPS IN YEAR 2012, ASSUMING 15% COST-SAVING CONSERVATION: STATEWIDE EMISSIONS
(million $2000 or otherwise specified)

State	Before Trading	After Trading			Permits Traded	Emission Reduction	Emission Reduction
	Mitigation Cost	Mitigation Cost	Trading Cost	Net Cost	(million tCO_2)	(million tCO_2)	(percent from baseline)
AZ	-64.89	-75.69	7.64	-68.05	2.72	19.46	18.15
CA	-314.35	-318.76	4.29	-314.47	1.53	101.15	21.11
CO	-46.29	-77.19	17.25	-59.94	6.14	20.63	18.68
ID	-13.66	-12.68	-1.97	-14.65	-0.70	3.44	18.86
MT	-18.91	-24.64	-8.03	-32.67	-2.86	5.38	16.07
NM	-37.46	-45.75	-14.34	-60.09	-5.10	10.27	16.40
NV	-36.10	-36.02	-8.44	-44.46	-3.00	8.93	17.67
OR	-31.15	-31.65	-11.92	-43.57	-4.24	8.99	19.51
UT	1.61	-61.21	19.83	-41.38	7.06	14.43	17.01
WA	-68.43	-71.31	2.62	-68.69	0.93	20.31	19.55
WY	-50.70	-52.34	-6.93	-59.27	-2.47	10.91	15.49
Total	-680.33	-807.23	0.00	-807.23	0.00	223.90	19.19

Permit Price = 2.81$/ton$CO_2$

APPENDIX TABLE AS/15%/2012. BASIC DATA

State	Cap: CO_2 Emissions in 2000 (million tCO_2)	Unabated CO_2 Emissions in 2012 (million tCO_2)	Autarkic Marginal Mitigation Cost (dollars per tCO_2)	Gross State Product in 2000 (million dollars)
AZ	85.03	107.21	5.15	153,469
CA	376.48	479.16	2.96	1,330,025
CO	83.70	110.48	7.31	169,341
ID	15.48	18.21	0.01	36,755
MT	30.99	33.52	-4.98	21,702
NM	57.47	62.64	-4.50	52,592
NV	44.61	50.54	-3.32	75,533
OR	41.31	46.05	-2.77	121,383
UT	63.31	84.80	15.20	68,430
WA	82.62	103.86	3.38	218,095
WY	61.99	70.44	-2.01	19,113
Total	942.99	1,166.89		2,266,438

TABLE BS/5%/2020. COST, PERMITS TRADED, AND EMISSION REDUCTION OF ACHIEVING EMISSION CAPS 10% BELOW 2000 LEVELS IN YEAR 2020, ASSUMING 5% COST-SAVING CONSERVATION: STATEWIDE EMISSIONS
(million \$2000 or otherwise specified)

State	Before Trading	After Trading			Permits Traded	Emission Reduction	Emission Reduction
	Mitigation Cost	Mitigation Cost	Trading Cost	Net Cost	(million tCO_2)	(million tCO_2)	(percent from baseline)
AZ	521.06	280.37	202.50	482.87	9.96	38.63	30.87
CA	1,186.74	2,137.88	-1,110.02	1,027.86	-54.61	278.51	49.49
CO	604.79	349.54	218.18	567.72	10.73	46.87	35.26
ID	39.68	52.31	-13.52	38.79	-0.67	7.04	34.65
MT	98.21	21.95	52.45	74.40	2.58	4.84	13.71
NM	155.85	58.37	76.56	134.93	3.77	10.85	16.35
NV	108.37	99.02	9.15	108.17	0.45	14.32	26.08
OR	41.05	141.22	-130.00	11.22	-6.40	18.73	37.83
UT	950.78	155.91	455.04	610.95	22.39	23.67	22.97
WA	329.64	369.27	-40.83	328.44	-2.01	48.63	40.20
WY	945.11	13.88	280.50	294.38	13.80	7.10	9.26
Total	4,981.28	3,679.72	0.00	3,679.72	0.00	499.18	37.03

Permit Price = 20.33\$/tonCO_2

APPENDIX TABLE BS/5%/2020. BASIC DATA

State	Cap: CO_2 Emissions 10% below 2000 (million tCO_2)	Unabated CO_2 Emissions in 2020 (million tCO_2)	Autarkic Marginal Mitigation Cost (dollars per tCO_2)	Gross State Product in 2000 (million dollars)
AZ	76.53	125.12	28.15	153,469
CA	338.83	562.73	14.67	1,330,025
CO	75.33	132.93	27.39	169,341
ID	13.93	20.30	17.67	36,755
MT	27.89	35.31	39.03	21,702
NM	51.72	66.34	31.55	52,592
NV	40.15	54.92	21.23	75,533
OR	37.17	49.52	11.28	121,383
UT	56.98	103.04	52.45	68,430
WA	74.36	120.98	19.12	218,095
WY	55.79	76.70	118.20	19,113
Total	848.69	1,347.87		2,266,438

TABLE BS/15%/2020. COST, PERMITS TRADED, AND EMISSION REDUCTION OF ACHIEVING EMISSION CAPS 10% BELOW 2000 LEVELS IN YEAR 2020, ASSUMING 15% COST-SAVING CONSERVATION: STATEWIDE EMISSIONS
(million \$2000 or otherwise specified)

State	Before Trading	After Trading			Permits Traded	Emission Reduction	Emission Reduction
	Mitigation Cost	Mitigation Cost	Trading Cost	Net Cost	(million tCO_2)	(million tCO_2)	(percent from baseline)
AZ	202.70	59.11	118.11	177.22	8.08	40.51	32.38
CA	307.20	759.03	-515.18	243.85	-35.24	259.13	46.05
CO	277.73	90.36	152.37	242.73	10.42	47.18	35.49
ID	3.41	13.22	-10.94	2.28	-0.75	7.12	35.06
MT	-10.20	-11.98	1.73	-10.25	0.12	7.30	20.68
NM	-18.07	-14.23	-3.95	-18.18	-0.27	14.88	22.44
NV	-2.29	13.48	-17.19	-3.71	-1.18	15.95	29.04
OR	-22.85	39.68	-90.05	-50.37	-6.16	18.49	37.35
UT	514.70	10.15	268.14	278.29	18.34	27.72	26.90
WA	101.02	110.42	-9.53	100.89	-0.65	47.27	39.07
WY	258.13	-42.12	106.49	64.37	7.28	13.62	17.76
Total	1,611.49	1,027.12	0.00	1,027.12	0.00	499.18	37.03

Permit Price = 14.62\$/tonCO_2

APPENDIX TABLE BS/15%/2020. BASIC DATA

State	Cap: CO_2 Emissions 10% below 2000 (million tCO_2)	Unabated CO_2 Emissions in 2020 (million tCO_2)	Autarkic Marginal Mitigation Cost (dollars per tCO_2)	Gross State Product in 2000 (million dollars)
AZ	76.53	125.12	21.04	153,469
CA	338.83	562.73	11.09	1,330,025
CO	75.33	132.93	21.49	169,341
ID	13.93	20.30	11.62	36,755
MT	27.89	35.31	15.52	21,702
NM	51.72	66.34	13.79	52,592
NV	40.15	54.92	12.22	75,533
OR	37.17	49.52	5.94	121,383
UT	56.98	103.04	41.67	68,430
WA	74.36	120.98	14.24	218,095
WY	55.79	76.70	68.95	19,113
Total	848.69	1,347.87		2,266,438

- total cost savings after trading is $1,301.6 billion, or 26%
- greatest gainer in absolute term is WY--$650.7 million per year
- greatest gainer in percentage terms is WY--69%
- NM gains $21 million (overall cost reduction), or 13%

Some general insights from a comparison of statewide emission reductions for the 11-state configuration are:

- NM would actually be a permit seller in the Year 2012, under both levels of cost-saving conservation, and would incur negative net costs of achieving a Year 2000 emission cap. In fact, in absolute terms, it would be the second highest gainer under the 15% cost-saving conservation level.
- NM would even be able to meet the cap in Year 2020 at a negative cost under the 15% cost-saving level.
- The permit price does not exceed $20.33/ton CO_2 in any of the compliance years.

B. Power Sector CO_2 Emission Reductions (11-State Area)

Results of simulations for the caps on emission from the power sector only are presented in the following two tables for the case of a 5% level of cost-saving conservation. Major implications for NM are:

- With respect to achieving the cap in the Year 2012, NM is able to do so at a negative overall cost, in part because it is a permit buyer.
- With respect to achieving the cap in the Year 2020, NM incurs a positive cost of $j87 million, in part because it purchases $54 million of permits.
- The permit price reaches a maximum of $23.15 in 2020.

C. Statewide CO_2 Emission Reductions (4-State Area)

Results of simulations for caps on statewide emissions for a 4-state trading area are presented in the following tables for the case of a 5% level of cost-saving emissions. Major implications for NM are:

- For the cap applicable to the Year 2012, NM can achieve the target at negative overall cost, in part because it is a permit seller.
- For the cap applicable to the Year 2020, NM can achieve this target a a total cost of $117 million. This is actually a reduction of $28.7 million over what NM would incur in the absence of participation in trading. This 25% reduction in costs is the highest for any of the four states.
- The permit price reaches a maximum of $16.33 in 2020.

TABLE AP/5%/2012. COST, PERMITS TRADED, AND EMISSION REDUCTION OF ACHIEVING 2000 EMISSIONS CAPS IN YEAR 2012, ASSUMING 5% COST-SAVING CONSERVATION: POWER SECTOR ONLY EMISSIONS
(million \$2000 or otherwise specified)

State	Before Trading	After Trading			Permits Traded	Emission Reduction	Emission Reduction
	Mitigation Cost	Mitigation Cost	Trading Cost	Net Cost	(million tCO_2)	(million tCO_2)	(percent from baseline)
AZ	41.84	10.04	24.89	34.93	2.94	8.50	15.37
CA	-0.46	80.87	-122.85	-41.98	-14.49	28.28	43.95
CO	101.01	2.63	51.50	54.13	6.07	6.17	12.21
ID	-0.03	0.06	-0.85	-0.79	-0.10	0.12	100.00
MT	-3.32	-1.54	-2.18	-3.72	-0.26	1.64	8.93
NM	-4.36	-3.06	-1.39	-4.45	-0.16	2.91	8.74
NV	1.02	0.77	0.25	1.02	0.03	3.22	11.62
OR	-1.73	6.92	-15.33	-8.41	-1.81	2.65	32.55
UT	192.55	-3.62	59.97	56.35	7.07	3.85	8.93
WA	1.37	14.91	-18.00	-3.09	-2.12	5.69	32.62
WY	72.91	-9.67	23.99	14.32	2.83	3.05	6.22
Total	400.79	98.31	0.00	98.31	0.00	66.07	17.99

Permit Price = 8.48\$/tonCO_2

APPENDIX TABLE AP/5%/2012. BASIC DATA

State	Cap: CO_2 Emissions in 2000 (million tCO_2)	Unabated CO_2 Emissions in 2012 (million tCO_2)	Autarkic Marginal Mitigation Cost (dollars per tCO_2)	Gross State Product in 2000 (million dollars)
AZ	43.84	55.27	13.23	153,469
CA	50.55	64.34	3.05	1,330,025
CO	38.27	50.51	24.30	169,341
ID	0.10	0.12	0.09	36,755
MT	16.98	18.36	5.42	21,702
NM	30.57	33.32	7.35	52,592
NV	24.47	27.72	8.62	75,533
OR	7.29	8.13	1.42	121,383
UT	32.19	43.11	48.30	68,430
WA	13.88	17.45	4.38	218,095
WY	43.12	48.99	50.31	19,113
Total	301.26	367.32		2,266,438

TABLE BP/5%/2020. COST, PERMITS TRADED, AND EMISSION REDUCTION OF ACHIEVING EMISSION CAPS 10% BELOW 2000 LEVELS IN YEAR 2020, ASSUMING 5% COST-SAVING CONSERVATION: POWER SECTOR ONLY EMISSIONS
(million $2000 or otherwise specified)

State	Before Trading	After Trading			Permits Traded	Emission Reduction	Emission Reduction
	Mitigation Cost	Mitigation Cost	Trading Cost	Net Cost	(million tCO_2)	(million tCO_2)	(percent from baseline)
AZ	264.56	188.75	69.04	257.79	2.98	22.07	34.21
CA	57.15	476.39	-745.75	-269.36	-32.21	62.27	82.42
CO	478.01	130.50	235.05	365.55	10.15	16.19	26.63
ID	-0.03	0.06	-2.08	-2.02	-0.09	0.12	100.00
MT	47.98	19.06	23.02	42.08	0.99	3.07	15.88
NM	105.71	32.93	54.06	86.99	2.34	5.44	15.41
NV	81.81	54.11	24.93	79.04	1.08	7.03	23.32
OR	2.35	48.72	-81.56	-32.84	-3.52	5.70	65.23
UT	836.03	60.31	331.32	391.63	14.31	9.11	17.38
WA	24.17	116.82	-138.87	-22.05	-6.00	13.83	68.05
WY	903.21	8.63	230.85	239.48	9.97	4.57	8.57
Total	2,800.96	1,136.27	0.01	1,136.28	0.00	149.39	35.52

Permit Price = 23.15$/ton$CO_2$

APPENDIX TABLE BP/5%/2020. BASIC DATA

State	Cap: CO_2 Emissions 10% below 2000 (million tCO_2)	Unabated CO_2 Emissions in 2020 (million tCO_2)	Autarkic Marginal Mitigation Cost (dollars per tCO_2)	Gross State Product in 2000 (million dollars)
AZ	39.46	64.51	27.74	153,469
CA	45.49	75.56	6.26	1,330,025
CO	34.44	60.78	46.30	169,341
ID	0.09	0.12	0.24	36,755
MT	15.28	19.35	35.15	21,702
NM	27.51	35.29	39.40	52,592
NV	22.02	30.13	28.31	75,533
OR	6.56	8.74	5.42	121,383
UT	28.97	52.39	89.69	68,430
WA	12.49	20.32	9.25	218,095
WY	38.81	53.35	161.52	19,113
Total	271.12	420.54		2,266,438

TABLE A'S/5%/2012. COST, PERMITS TRADED, AND EMISSION REDUCTION OF ACHIEVING 2000 EMISSIONS CAPS IN YEAR 2012, ASSUMING 5% COST-SAVING CONSERVATION: STATEWIDE EMISSIONS
(million \$2000 or otherwise specified)

State	Before Trading	After Trading			Permits Traded	Emission Reduction	Emission Reduction
	Mitigation Cost	Mitigation Cost	Trading Cost	Net Cost	(million tCO_2)	(million tCO_2)	(percent from baseline)
AZ	82.68	8.86	52.95	61.81	7.10	15.08	14.07
CA	152.77	175.43	-23.14	152.29	-3.10	105.78	22.08
NM	-9.71	-6.14	-3.99	-10.13	-0.53	5.70	9.10
OR	-7.94	9.97	-25.82	-15.85	-3.46	8.20	17.81
Total	217.81	188.12	0.00	188.12	0.00	134.76	19.39

Permit Price = 7.46\$/tonCO_2

APPENDIX TABLE A'S/5%/2012. BASIC DATA

State	Cap: CO_2 Emissions in 2000 (million tCO_2)	Unabated CO_2 Emissions in 2012 (million tCO_2)	Autarkic Marginal Mitigation Cost (dollars per tCO_2)	Gross State Product in 2000 (million dollars)
AZ	85.03	107.21	13.42	153,469
CA	376.48	479.16	7.15	1,330,025
NM	57.47	62.64	5.88	52,592
OR	41.31	46.05	2.96	121,383
Total	560.29	695.06		1,657,469

TABLE B'S/5%/2020. COST, PERMITS TRADED, AND EMISSION REDUCTION OF ACHIEVING EMISSION CAPS 10% BELOW 2000 LEVELS IN YEAR 2020, ASSUMING 5% COST-SAVING CONSERVATION: STATEWIDE EMISSIONS
(million $2000 or otherwise specified)

State	Before Trading	After Trading			Permits Traded	Emission Reduction	Emission Reduction
	Mitigation Cost	Mitigation Cost	Trading Cost	Net Cost	(million tCO_2)	(million tCO_2)	(percent from baseline)
AZ	520.98	178.12	253.80	431.92	15.54	33.05	26.41
CA	1186.52	1449.89	-277.56	1172.33	-17.00	240.90	42.81
NM	155.79	32.55	84.47	117.02	5.17	9.44	14.23
OR	41.04	92.20	-60.71	31.49	-3.72	16.06	32.42
Total	1904.34	1752.75	0.00	1752.75	0.00	299.44	37.26

Permit Price = 16.33$/ton$CO_2$

APPENDIX TABLE B'S/5%/2020. BASIC DATA

State	Cap: CO_2 Emissions 10% below 2000 (million tCO_2)	Unabated CO_2 Emissions in 2020 (million tCO_2)	Autarkic Marginal Mitigation Cost (dollars per tCO_2)	Gross State Product in 2000 (million dollars)
AZ	76.53	125.12	28.15	153,469
CA	338.83	562.73	14.67	1,330,025
NM	51.72	66.34	31.55	52,592
OR	37.18	49.52	11.28	121,383
Total	504.26	803.71		1,657,469

D. Comparison of Cases

A brief comparison across the various cases yields the following insights for NM.

- For the Year 2012, for the 5% cost-saving conservation assumption, NM is best off under a statewide CO_2 emission target as part of an 11-state coalition.

- For the Year 2020, for the 5% cost-saving assumption, NM is best off under a power sector only CO_2 emission target as part of an 11-state coalition.

V. FUTURE SIMULATIONS

The simulations represented in this report are intended to provide basic insight. They are based on the best available data at the time of this writing.

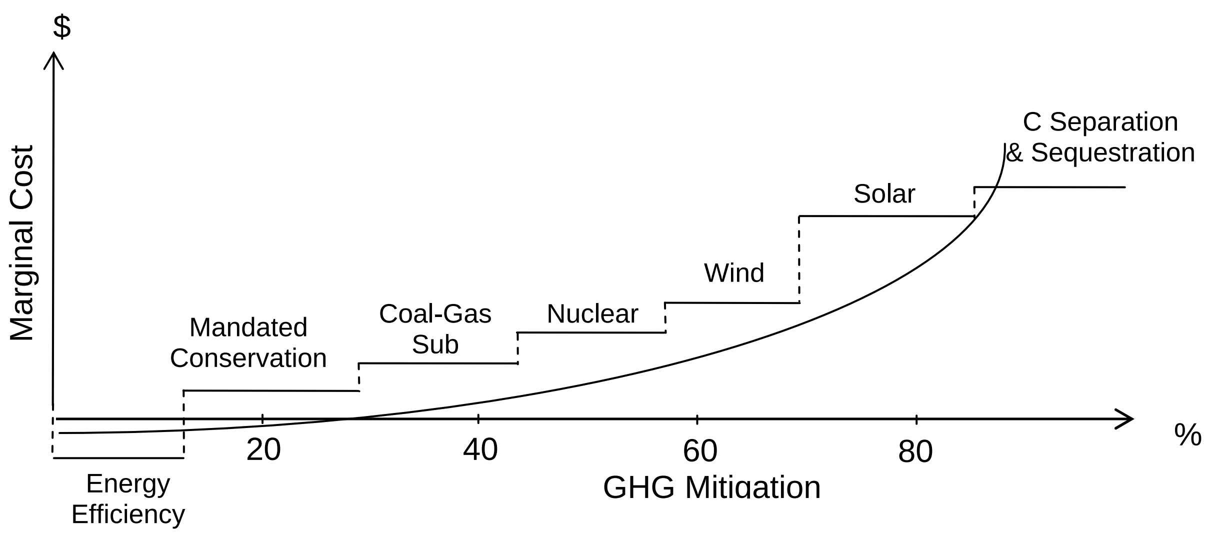
It is our intend to perform one more set of simulations after the Working Group provides us with feedback and improved data. This could include modifications of the level of the emissions cap with the timing of its implementation. Improved data would include state CO_2 emission projections (both statewide and power sector only). We also will need emissions data on a consumption basis, both statewide and power sector (electricity consumption).

The most valuable data improvement would be in the specification of the mitigation cost functions for as many states as possible. The ideal way of transmitting the data would be to list for each mitigation option in each state:

- The range of the mitigation option's application (maximum percentage of total emissions that can be reduced by this option)
- The cost per ton of CO_2 that can be reduced (this could either be specified in terms of a constant cost per unit or a non-constant marginal cost function)

An example of such a cost function is presented below for illustrative purposes.

Figure 1. Marginal Costs of GHG Mitigation (Curve)



APPENDIX A. THE CAP AND TRADE MODEL

Our model is based on well-established principles of the ability of unrestricted permit trading to achieve a cost-effective allocation of resources in the presence of externalities (see, e.g., Tietenberg, 1985). Where a strict cap implies unique GHG emission reduction requirements, the individual state and overall regional optimization can be accomplished without explicit consideration of the benefits side of the ledger (i.e., it yields "efficiency without optimality"). Therefore, the model simply requires equalization of marginal costs of all entities with the equilibrium permit price (see, Zhang, 2000; Loeschel and Zhang, 2002; Rose and Zhang, 2004). This ensures minimization of total net compliance costs for each region and minimization of total abatement costs for the nation as a whole (see also Rose et al., 1998; Stevens and Rose, 2002, for a formal optimization approach to the problem). For purchasing states, compliance costs are equal to own abatement cost plus the cost of permits, whereas for selling regions, compliance costs are equal to own abatement cost minus the revenues from selling permits. For the region as a whole, permit sales and purchases cancel out, simplifying the overall objective functions.

We assume that the marginal abatement cost function for state *i* is of the logarithmic form, similar to Nordhaus (1994):[1]

$$MCA_i = -\ln\left(1 - R_i\right)/\alpha_i \qquad i = 1, \ldots, n \qquad (1)$$

where MCA_i is the marginal cost of abatement for state *i*, R_i is the percentage of greenhouse gas abatement undertaken by state *i* in million tons of carbon, and α_i is a cost parameter. This functional form has the desired property of positive and increasing marginal cost for $\alpha_i > 0$. This cost parameter also captures technological and other distinctions that cause mitigation costs to differ across regions. By integration, the total cost of abatement for region *i*, TCA_i, is:

$$TCA_i = \int_0^{R_i} \left[\left(-\ln\left(1 - r_i\right)/\alpha_i \right) dr_i E_i \right] = \left[\frac{\left(1 - R_i\right) \cdot \ln\left(1 - R_i\right) + R_i}{\alpha_i} \right] \cdot E_i \qquad i = 1, \ldots, n \qquad (2)$$

where E_i is each state's gross (unabated) emissions in million tons of carbon. Denoting the total required percentage reduction of emissions in region *i* in the absence of emissions trading as $\overline{R}_i$, the total abatement cost for each state in the absence of trading, $TC\overline{R}_i$, is calculated as:

$$TC\overline{R}_i = \int_0^{\overline{R}_i} \left[\left(-\ln\left(1 - r_i\right)/\alpha_i \right) dr_i E_i \right] = \left[\frac{\left(1 - \overline{R}_i\right) \cdot \ln\left(1 - \overline{R}_i\right) + \overline{R}_i}{\alpha_i} \right] \cdot E_i \qquad i = 1, \ldots, n \qquad (3)$$

Emissions trading helps a region with relatively high marginal abatement cost to lower its compliance cost by avoiding the undertaking of autarkic actions. To minimize compliance costs, a purchasing state undertakes only some of its abatement requirement itself, $R_i E_i$, $\left(R_i E_i < \overline{R}_i E_i\right)$, up to the point where the marginal cost of doing so is equal to the endogenously determined permit price, *P*:

$$-\ln\left(1 - R_i\right)/\alpha = MCA_i = P \qquad i \in N \qquad (4)$$

where *N* is the set of all states.

The state meets the remaining demand, $\left(\bar{R}_i E_i \; - \; R_i E_i\right)$, via purchasing the "right to emit" at the national market price, *P*. So, the total remaining demand for emission permits of all purchasing states, *TD*, is:

$$TD = \sum_i \left(\bar{R}_i E_i - R_i E_i\right) \qquad i \in N \qquad (5)$$

On the other hand, for state *j*, with relatively low marginal cost, emissions trading provides it an incentive to undertake abatement and sell permits to those higher-cost states at the equilibrium permit price, *P*:

$$-\ln\left(1 - R_i\right)/\alpha_i = MCA_i = P \qquad i \in N \qquad (6)$$

Thus, the total amount of emissions permits available for sale in a given regional trading coalition *TS*, is:

$$TS = \sum_j \left(R_j E_j - \bar{R}_j E_j\right) \qquad j \in N \qquad (7)$$

The sum of total number of purchasing states *i* and total number of selling states *j* will be equal to *n*. At the equilibrium, the total demand for emissions permits in the region is equal to the total supply:

$$TS = TD \qquad (8)$$

Substituting Eq. (5) and Eq. (7) into Eq. (8) and rearranging terms yields the condition that the total emissions actually abated equal the total emission abatement requirement:

$$\sum_i R_i E_i = \sum_i \bar{R}_i E_i \qquad i = 1, \ldots, n \qquad (9)$$

We solve the model by minimizing total abatement costs of all states $\sum_i TCA_i$ subject to Eq. (4) through Eq. (8), using GAMS, an algebraic modeling system for linear, nonlinear, and integer programming problems (Brooke et al., 1996).[2] The solution yields the equilibrium permit price (*P*), each state's own abatement after trading $\left(R_i E_i\right)$, and each state's marginal abatement cost (MCA_i). Because we focus on unrestricted emissions trading, in equilibrium the marginal cost of abatement for each region is the same and is equal to the permit price, indicated in Eq. (4) and Eq. (6).

This completes the description of the general model by which the permit price, MCA_i, and $R_i E_i$ are determined endogenously in a competitive market.[3] In the case of monopsony, where the sheer volume of a purchasing state's transactions enables it to exercise market power, the model is modified. In this case, one state, *m*, has market power on the buying side, while all other states denoted as the "fringe," *f*, behave as price takers, whether buyers or sellers.

The monopsonist sets its own permit demand to minimize abatement cost plus expenses for permit purchases:

$$\min = TCA_m + P(\bar{R}_m - R_m)E_m \qquad m \neq f,\; m \in N \qquad (10)$$

The first-order condition of the cost minimization problem indicates that the monopsonist sets its marginal expense curve, MEC_m (which is above its marginal cost curve), equal to its marginal revenue, which is equal to the competitive market price, to identify its optimal quantity of permit purchases:

$$MEC_m = P \qquad m \neq f,\ m \in N \tag{11}$$

The monopsonist then establishes the monopsonist price, P_m, equal to its marginal abatement cost associated with its optimal quantity of permit purchases, where P_m is lower than:

$$MCA_m = P_m \qquad m \neq f,\ m \in N \tag{12}$$

The fringe states minimize their compliance costs given the permit price set by the monopsonist. They each emit carbon until the marginal abatement cost equals the permit price:

$$MCA_f = P_m \qquad f \neq m,\ f \in N \tag{13}$$

The aggregate permit supply of all the fringe states, which is in total a net sale of permits for all fringe states, $q_f(P)$, is:

$$Q_F(P) = \sum_f q_f(P_m) \qquad f \neq m,\ f \in N \tag{14}$$

The inefficiency arises because, even though marginal costs are equalized across all states, this is done at a restricted volume of transactions, and at a price lower than the competitive market price, resulting in an overall efficiency loss due to market power.

ENDNOTES FOR APPENDIX A

[1] The shape of the cost function for mitigating carbon emissions has been studied extensively. For example, Nordhaus (1994) found that the logarithmic functional form provided the best fit for the estimates of the marginal costs of mitigating a specific amount of carbon emissions among a number of economic modeling studies that he surveyed (a type of meta-analysis). Nordhaus (1994) used an analytical model to further derive a logarithmic relationship between the marginal costs and the percentage reduction. We adjust the explicit parameter values of Nordhaus cost functions as indicated later in this Appendix.

[2] The market equilibrium solution of our model is unique, so the same solution could be obtained without optimizing. The reason why we specify an objective function is that we use GAMS/MINOS, a solver mainly for optimization problems. The minimization of the total cost is a logical choice for an objective in the case of “cost-effectiveness” analysis here (i.e., when a policy target is set and decision units seek to attain it at least cost). Had we used a software package that is specifically designed to solve a simultaneous equation system, then there would have been no need for an objective function.

[3] In the case where the permit price is set exogenously, the situation becomes much simpler because MCA_i and hence R_iE_i follows suit. There is no need for Eqs. (5), (7), (8), and (9) because the total sales of selling states to purchasing states are not equal to the total purchases, except by chance (when the specified permit price equals the equilibrium price).

APPENDIX B. MITIGATION COST CURVE

Below is the marginal cost (MC) curve for CO_2 emission reduction of New Mexico in 2010. This cost curve includes cost-saving conservation up to 15% of mitigation in the state. The formal specification of the MC function is:

$$\begin{cases} MC = -10 + \frac{200}{3} \times R & \text{when } R \le 15\% \\ MC = -\frac{\ln\left[\frac{1}{0.85} - \frac{1}{0.85} \times R\right]}{\alpha} & \text{when } R \ge 15\% \end{cases}$$

where

MC is the marginal cost of CO_2 reduction

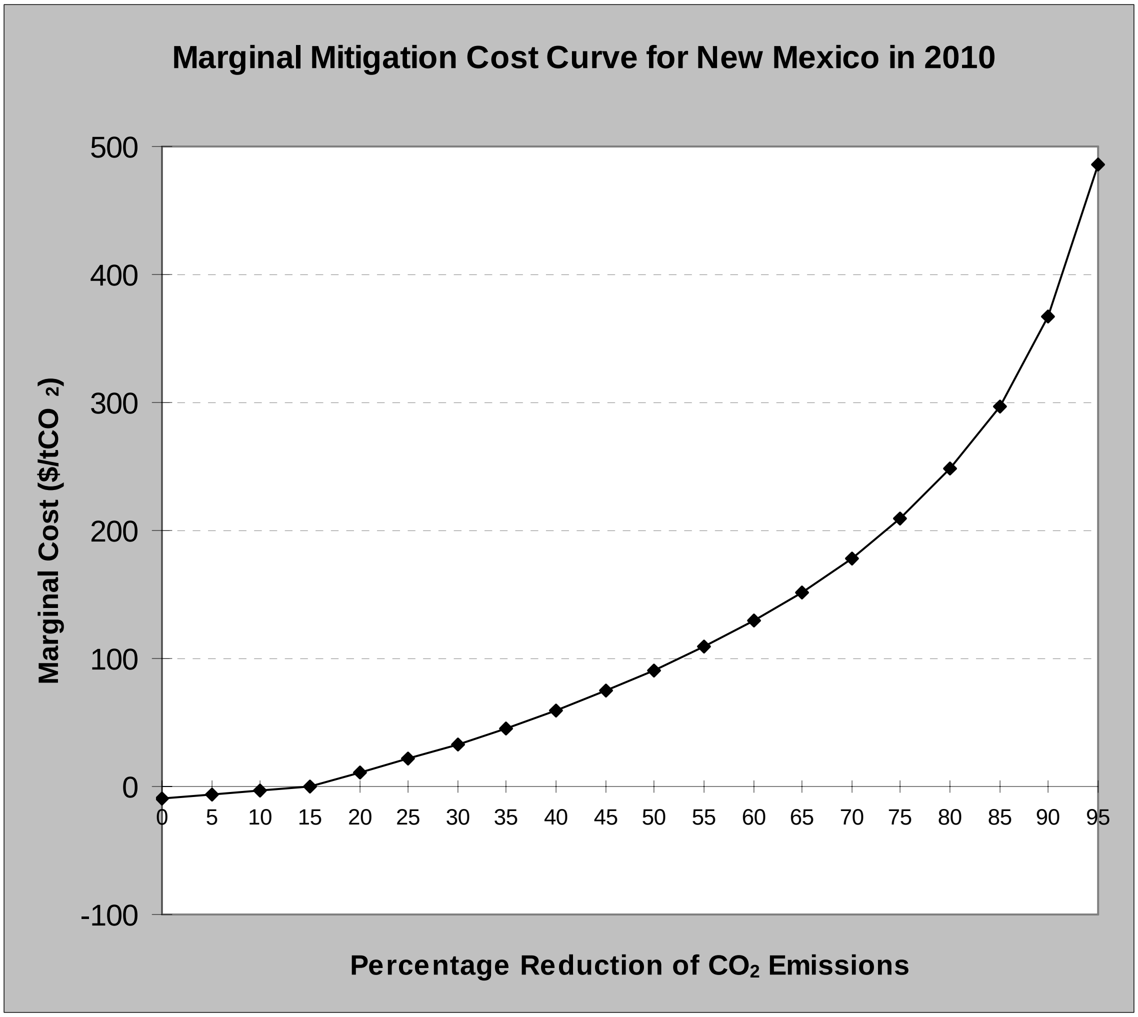
R is the percentage emission reduction

α is the slope parameter

The marginal cost function is a piecewise function: the negative segment has a linear form beginning at MC = -\$10 and then increasing at a constant rate to MC = 0 at the 15% reduction level; the positive segment has the logarithmic functional form, which is consistent with theoretical expectations and empirical findings on diminishing returns of emission control. The value of α for NM is 0.00583038 tCO_2/\$.

The marginal cost function adopted in this study was first developed by Nordhaus (1994). We have updated Nordhaus' specific parameter values to the level specified in the latest Intergovernmental Panel on Climate Change Report (IPCC, 2001). Generally, Nordhaus' original mitigation cost estimates are reduced by about two-thirds of their value for several reasons, the most prominent one being technological improvements in mitigation. We also incorporate a cost-saving range of conservation.

In this study, we modify it to allow for cost-saving conservation up to 5% or 15% mitigation levels. We specify a marginal cost function for each of the eleven Western states based on the Nordhaus' marginal cost function which was developed for the United States as a whole. Individual state MC curves are specified by parametric shifts from the U.S. reference curve for each of the eleven states in direct proportion to their energy intensity weighted by the relative carbon content of the three major fossil fuels. The shift is accomplished by altering the alpha parameter value in the marginal cost function. The basic value is 0.01071 for the U.S. as a whole. The energy intensity and the alpha parameter value have an inverse relationship. Thus, a state with an emission weighted fossil energy intensity half as large as the U.S. average would have a parameter value twice as large (0.02142). The relative weighted fossil fuel intensity value of a state is proportional to the carbon intensity value (ratio of CO_2 emission and gross state product) of this state. For example, in 2010 Arizona has a CO_2/GSP ratio of 0.000649, while New Mexico has a ratio of 0.00128. Thus, the alpha parameter value of Arizona is 1.972 times that of the New Mexico. The alpha parameter of each state utilized in the power-sector-only simulations is calculated based on the power sector carbon intensity value (ratio of CO_2 emissions from power sector and the gross output of power sector) of the state.


Marginal Mitigation Cost Curve for New Mexico in 2010
Marginal Cost ($/tCO 2)
500
400
300
200
100
0
-100
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Percentage Reduction of CO2 Emissions

APPENDIX C. ADDITIONAL RESULTS

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