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ESTIMATION OF COSTS TO MEET
CO_2 EMISSION TARGETS IN THE ENERGY SECTOR

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INTRODUCTION

This paper summarizes an approach to estimating the costs of meeting different CO_2 emission targets in the energy sector by using the U.S. EPA Atmospheric Stabilization Framework (ASF), detailed country studies of energy use developed by the EPA and by the Energy and Industry Subgroup (EIS) of the Intergovernmental Panel on Climate Change (IPCC), and energy supply assumptions from the Energy Modeling Forum Study Number 12 (EMF 12). This approach explicitly addresses the impact of estimated zero or low cost energy use reduction potential.

REFERENCE SCENARIO

The intent of the analysis was to use information gathered by the EIS, supplemented with data from EPA sponsored country studies, to estimate the cost of meeting the different EMF 12 CO_2 emission targets. The first step was to use the EIS analysis and create a reference scenario of future energy use that conformed with the EMF 12 population, economic, and supply cost assumptions. The ASF was used to estimate future energy use with input assumptions of population and economic growth from the EMF 12; with assumptions concerning changes in energy intensity, and energy supply mix through 2025 from the EIS (IPCC, 1991); and with assumptions concerning energy resources and backstop technologies from the EMF 12. One major difference between the energy supply assumptions used in this analysis and the EMF 12 assumptions is in the availability of biofuels at prices less than the backstop price. These scenarios assume that up to 205 exajoules of biofuels will be available at prices less than the EMF 12 non-carbon non-electric backstop price.

Table 1 summarizes energy use and CO_2 emissions for this reference scenario. Primary energy use (excluding non-commercial biofuels) grows from 345 EJ in 1990 to 672 EJ in 2025 and nearly doubles again by 2100. Through 2025, fossil fuels continue to dominate primary energy supply, but coal and natural gas take a larger share of the market over time. Other non-conventional energy sources, such as synfuels from biomass and coal, start to appear before 2025. The share of primary energy provided by non-carbon electric sources increases from 12% in 1990 to 20% by 2025.

After 2025, primary energy use continues to grow due to increased reliance on synthetic fuels and rapid population and economic growth in the developing economies. Primary energy use increases from 672 EJ in 2025 to 1283 EJ in 2100, while the share of primary energy use in the developing economies grows from 37%in 2025 to 62% in 2100. This increase in energy use yields an increase in CO_2 emissions from 6.0 Billion metric tons of carbon (Bt C) in 1990 to 11.1 Bt C in 2025 and 19.8 Bt C in 2100.

The share of primary energy consumption by energy type in the reference scenario changes dramatically over time. The share of primary energy provided by fossil fuels declines from 88% in 1990 to 80% in 2025 and to 66% by 2100 despite the increased reliance on coal synfuels. Energy losses from coal synfuel production are 10% of primary energy use in 2100. The share of primary energy provided by nuclear, solar, and biofuels increases from 5% in 1990 to 28% in 2100, while the share provided by hydro declines from 7% to 6% (despite tripling the total amount of hydro).

Table 1. Reference Scenario

	1990	2010	2025	2100	2010	2025	2050	2100
Primary Energy Use (EJ) by Energy Type								
Oil	122	144	135	38				
Gas	77	114	125	52				
Coal	103	170	275	761				
Biomass	0	0	8	103				
Hydro	24	37	49	73				
Other	19	40	80	256				
Total	345	506	672	1283				
Primary Energy Use by Region (EJ)					CO_2 Emissions (Bt C)			
USA	80	98	112	123	1.4	1.6	1.9	1.9
Other OECD	92	122	143	179	1.4	1.8	2.1	2.5
USSR/E.Europe*	91	128	155	188	1.7	2.3	2.7	3.0
China**	28	52	79	315	0.6	1.0	1.4	5.2
ROW	54	106	183	478	0.9	1.8	3.0	7.1
Total	345	506	672	1283	6.0	8.6	11.1	19.8

** Represents countries within former Soviet Union.
** Includes other centrally planned Asian economies.

Global secondary energy use by energy type changes significantly by 2100 even through the sector shares of global secondary energy use remain relatively constant. A seven- to eight-fold increase in secondary energy use in China, with a large share of that energy use provided by coal, results in tripling of global secondary uses of coal. Secondary uses of liquid and gases fuels double in the same time period. Electricity use increases by a factor of five due to increased income and lower growth in prices relative to fossil fuels.

DEVELOPMENT OF REGIONAL COST CURVES

Estimates of the costs of reducing secondary energy use were based on available data from different country studies. Primary sources for these cost estimates were the country studies prepared for and used by the EIS (IPCC, 1991). These were supplemented by country studies developed for the U.S. EPA (Chandler, 1990).

The data provided in the different country studies varied considerably. Many of the studies provided estimates of energy use reductions that could be achieved at no net cost to the economy, i.e., those reductions where the cost of reducing energy use is less than the cost of the energy that would be saved. For the USSR and Eastern Europe, the reference scenario assumed very little progress is made toward restructuring the economies. As a result, the country studies first provided an estimate of the reductions that could be achieved by restructuring the economy (e.g., market based pricing and reduced importance of energy intensive industries) and then estimates of further reductions that could be achieved through energy conservation and efficiency improvements, all of which could be achieved while reducing total national costs. For developing countries, the country studies provided a reference scenario and a low emissions scenario that could be achieved with no reduction in GDP, which we have interpreted as at no net cost to the economy. Table 2 summarizes the reductions in secondary energy use that the different country studies assumed could be achieved at no net cost to the economy.

For purposes of the EMF 12 study, we assumed that the regional/sector specific reductions in secondary energy use, shown in Table 2, would incur some implementation costs: $.50/gigajoule of secondary energy use, reduced or around $25/metric ton carbon if energy use is oil. Further reductions could be achieved using a price elasticity of -0.8 (e.g., a doubling of oil prices results in a 43% reduction in energy use).

UTILIZATION OF REGIONAL COST CURVES

The regional cost curves describe above are combined with the energy supply structure of the ASF energy module in order to estimate the marginal and average costs of achieving

Table 2. Country Study Estimates of Energy Efficiency Improvements Over the Reference Scenario at No Net Cost

	Reference Scenario Secondary Energy Use(EJ)				Percent Reduction at No Net Cost			
Region	Trans	R/C	Ind	Tot	Trans	R/C	Ind	Tot
United States	28.1	23.9	30.4	82.4	13%	24%	15%	14%
Western Europe and Canada								
Netherlands				2.8				29%
U.K.	2.7	2.7	1.9	7.3	15%	44%	23%	28%
Canada				10.9				29%
Regional Average			21.0	15%	44%	23%	29%	
Eastern OECD								
Japan	3.7	2.9	10.6	17.2	16%	16%	19%	18%
USSR & Eastern Europe								
USSR				123.0				30%
Poland				13.2				60%
Hungary				1.8				38%
Regional Average			138.0	27%	56%	34%	33%	
China	8.4	14.4	37.5	60.3	23%	8%	13%	13%
Latin America								
Brazil	4.6	1.3	5.0	10.9	37%	36%	42%	39%
Mexico	2.4	1.6	5.5	9.5	42%	47%	10%	24%
Venezuela	0.6	0.3	3.7	4.6	17%	11%	10%	11%
Regional Aver.	7.6	3.2	14.3	25.0	37%	39%	21%	28%
South and East Asia								
India	7.2	4.7	15.6	27.5	25%	22%	13%	18%
Indonesia	4.0	1.5	3.0	8.5	17%	17%	17%	17%
Korea	2.1	1.0	4.9	8.0	36%	17%	22%	25%

specified regional or global emission targets.[1] Emission targets are first specified for each region. The model selects for each year and region a marginal emission reduction cost, determines the changes in energy use and emissions that can achieved at this cost, and identifies whether the emission reductions meet or exceed the specified targets. If the reductions do not meet or exceed the emission reduction target, then the selected regional marginal emission reduction cost is adjusted.

The first step in identifying the emission reductions that can be achieved at a specified marginal reduction cost ($/ton[2] C) is to place the marginal emission reduction cost on a fuel price basis. For example, a reduction of 1000 GJ of oil use at a cost of $1.00/GJ yields a decrease in carbon emissions of 20 metric tons of carbon at $50/ton C ($1.00/Gj = $50/ton C * .020 tons C/GJ). Replacing 1000 GJ of a liquid fuel derived from coal by a non-carbon liquid fuel at an additional cost (i.e., cost over and above the cost of the coal synfuel) of $2.00/GJ reduces carbon emissions by 40 tons at a cost of $50/ton C ($2.00/GJ = $50/ton C * 0.040 tons C/GJ). The marginal cost of emission reductions from reducing electricity use depends on the cost of reducing the electricity demand along with the mix of fuels used to generate the electricity and the conversion efficiency of the generation.

Next, the model identifies the reductions in energy use and change in energy supply that would occur at these marginal costs. The model maps marginal reduction costs for energy by energy type against the regional cost curves to estimate the reduction in secondary energy use that can be achieved at these costs. It then estimates the revised electricity demand and energy mix used to generate the electricity. The model calculates total primary energy use and carbon emissions and the reduction in carbon emissions from the reference scenario. Finally, the average costs per ton C are estimated for the reductions.

Changes in regional electricity generation mix are estimated by converting the marginal cost of carbon reductions to marginal energy reduction cost (as described above) and applying this marginal energy reduction cost to the fuel mix equations of the ASF energy module. Note that in the ASF, hydro electricity is fixed and, subsequently, the cost model does not allow hydro electricity to vary. The costs of changing the energy supply mix is estimated using the following equation:

$$\text{Cost} = \text{sum}_i \{(S^n_i - S^o_i) * \text{cost}_i\} * G$$

where i is the index of the energy type including hydro, S^n_i and S^o_i are the new and old shares of electricity produced by the energy type, cost_i is the cost of producing electricity by energy type, and G is the regional electricity demand.

The biomass supply curves from the ASF are used to estimate the increase in regional biomass supply available at the selected marginal reduction costs. For this calculation, it is assumed, that on the margin, biofuels replace the backstop fuel which is oil and gas from synfuels. Therefore, the marginal increase in biofuel costs is set equal to the marginal increase in coal costs adjusted for differences in synfuel conversion efficiency. Increased biofuel production is first used to offset coal used for synfuel production. Then, if needed, biofuel production offsets coal use for electricity generation and for secondary uses. The average cost of the increased biofuel production is estimated by integrating under the biofuel supply curve.

RESULTS FROM THE ANALYSIS

We developed eight emission reduction scenarios for EMF 12 along with two alternative reference scenarios. All scenarios provided global estimates of emission reduction costs. Two of the scenarios represented futures where the underlying energy supply assumptions varied. For

Table 3. EMF 12 Scenarios

Scenario	Emission Constraints* Developed Economies	Developing Economies
Reference	None	None
1	20% reduction by 2010	Capped at 50% growth
2	20% by 2010, 50% by 2050	Capped at 50% growth
3	Stabilize at 1990 levels by 2010	Capped at 50% growth
4	Like scenario 1 but with advanced non-carbon energy technologies	
5	Like scenario 1 but allowing international emissions trading	
6	Use a $15/ton C tax in 1990 which increases 5% annually until it reaches $1000/ton C	
7	(not implemented)	
8	(not implemented)	
9	Reduce emissions from reference scenario levels by 2% annually	
10	Like scenario 1 but assuming that four times the undiscovered natural gas resources exist	

* All emission reductions or targets based on 1990 regional emission levels.

these two cases, we developed alternative reference scenarios which reflected these energy supply assumptions and estimated the costs of meeting emission targets against these scenarios. Table 3 summarizes the assumptions used in these scenarios.

Scenario 1

This scenario includes emission targets for the developed economies that equal 80% of 1990 emissions by the year 2010. Emissions in developing countries are constrained to 150% of 1990 levels.

Primary energy use in the developed economies continues to grow through 2100 even with a fixed emission constraint. This is due primarily to the increased penetration of non-carbon energy sources. In fact, the reduction in primary energy use required to meet the emission targets stays relatively constant from 2010 to 2100 at 33%.

Both the marginal and average costs of meeting these targets vary considerably. Both marginal and average costs of meeting the emission targets are almost uniformly lowest for the USSR and Eastern Europe where structural change in the economy results in huge improvements in energy efficiency at very little costs. Conversely, the costs were highest in China which experience very rapid economic growth combined with strong rapid improvements in energy efficiency in the reference scenario.

Changes in energy prices and energy supply mean that the net costs of meeting the emission targets decline over time. The energy supply mix in the reference scenario changes uniformly over time, emphasizing greater reliance on non-carbon energy sources and coal synfuels which have over twice the carbon per unit of delivered energy than conventional oil and gas. Subsequently, in scenario 1, similar improvements in energy efficiency in the later years yield much greater reductions in emissions than in 2010 since most of the reductions come from reductions in coal synfuels. Also, over time the differential between the non-carbon backstop fuels and fossil fuels declines due to increases in fossil fuel prices.

The results for the developing economies is dramatically different. While unconstrained CO_2 emissions in the reference scenario from developed economies grow 30% by 2010 and another 40% by 2100, unconstrained emissions from developing economies grow 80% by 2010 and another 600% by 2100 (e.g., emissions in 2100 are 680% greater than 1990 emissions). Subsequently, the emission constraint for the developing economies which allows 50% growth is less costly to achieve in the early years than the cost of meeting the constraint in the developed economies but much more costly in the later years. Average costs of meeting the constraints increase from \$22/ton C in 2010 to \$130/ton C in 2100. Table 4 summarizes the marginal and average costs of meeting the emission targets.

Scenario 2

This scenario is like scenario 1 until 2025, where the emission constraint in the developed economies is changed so that by 2050 it is at a level equal to 50% of 1990 emissions. As expected the costs of meeting the emission targets up to 2025 for all regions are the same as in scenario 1 and is the same through 2100 for the developing economies.

After 2025, the costs of meeting the more stringent emission targets for the developed economies grow significantly. In developed economies in 2050, the marginal emission reduction costs range from \$200 to \$220/ton C, compared to marginal costs ranging from \$65 to \$105/ton C needed to meet the less stringent emission targets in scenario 1. Average costs of the emission reductions are \$79/ton C compared to \$19/ton C in scenario 1. Table 5 compares these costs to the emission reduction costs in scenario 1.

Scenario 3

This scenario contains the same emission constraints for the developing economies as scenario 1 but less stringent emission targets for the developed economies, requiring reductions only to 1990 emission levels by 2010. The result is that both the marginal and average costs of meeting these emission targets are much less for the developed economies while staying the same for the developing economies. Another interesting result of this scenario is that in the later years, the reductions in energy use in the developing countries cause a redistribution of primary oil and gas supply to the developed economies, effectively reducing their use of coal synfuels and CO_2 emissions at no cost. As an illustration, in the U.S. in 2100, a 14% or 9 EJ reduction in

Table 4. Emission Reduction Costs for Scenario 1
($/ton C)

Region	Marginal Costs 2010	2025	2050	2100	Average Costs 2010	2025	2050	2100
United States	160	150	65	83	57	50	15	20
Other OECD	127	142	101	121	51	51	34	56
USSR/E Europe	115	120	75	55	23	36	22	13
China/CP Asia	20	140	219	198	16	63	143	166
Rest of World	42	157	163	129	24	94	104	98

secondary energy use from the reference scenario is sufficient to reduce primary energy use by 21.1 EJ and reduce CO_2 emissions by 581 million tons of carbon (Mt C) while primary uses of oil and gas increase by 9 exajoules. Table 6 summarizes these results.

Scenario 4

Scenario 4 is like scenario 1 but assumes that the costs of non-carbon energy sources are much less than in the reference scenario and their availability has been accelerated. In order to estimate the costs of meeting the specified emission targets, we first had to estimate the impact of the revised energy costs on energy use and emissions by creating the Advanced Technology Alternative Reference Scenario (see below) and then estimating the costs of reducing emissions from that scenario.

Alternative Reference Scenario - Advanced Technology: The purpose of this scenario is to provide a basis for the costs of meeting the same emission targets as in scenario 1 but assuming that the costs of non-carbon energy sources are much lower and the availability of these energy sources has been accelerated.

Table 5. Emission Reduction Costs for Scenario 2 vs Scenario 1
($/ton C)

Region	Marginal Costs 2010	2025	2050	2100	Average Costs 2010	2025	2050	2100
Scenario 1								
United States	160	150	65	83	57	50	15	20
Other OECD	127	142	101	121	51	51	34	56
USSR/E Europe	115	120	75	55	23	36	22	13
China/CP Asia	20	140	219	198	16	63	143	166
Rest of World	42	157	163	129	24	94	104	98
Scenario 2								
United States			213	163			76	70
Other OECD			217	168			91	86
USSR/E Europe			200	156			70	49

Figure 7. Comparison of Energy Use and Carbon Emissions Technology Reference Scenario vs Reference Scenario

	2010	2025	2050	2100
Alternative Reference Scenario				
Primary Energy Use (EJ)	508	711	959	1415
Carbon Emissions (Bt C)	8.4	10.2	10.7	16.0
Reference Scenario	506	672	845	1283
Primary Energy Use (EJ)	8.6	11.1	13.4	19.8

The main impact of the scenario is to increase primary energy use but to decrease CO_2 emissions. Table 7 compares the results of this scenario to the reference scenario. Global primary energy use is higher in the alternative scenario by 10% in 2100, while CO_2 emissions are

Table 6. Emission Reduction Costs for Scenario 3 vs Scenario 1
($/ton C)

Region	Marginal Costs 2010	2025	2050	2100	Average Costs 2010	2025	2050	2100
Scenario 1								
United States	160	150	65	83	57	50	15	20
Other OECD	127	142	101	121	51	51	34	56
USSR/E Europe	115	120	75	55	23	36	22	13
China/CP Asia	20	140	219	198	16	63	143	166
Rest of World	42	157	163	129	24	94	104	98
Scenario 3								
United States	25	25	10	30	15	8	2	8
Other OECD	48	59	42	78	24	23	16	42
USSR/E Europe	20	45	30	28	12	14	12	8

lower by 20%. In the same year, non-carbon energy sources represent over 45% of primary energy supply compared to 34% in the reference scenario.

Costs of Meeting Emission Targets: Table 8 summarizes the costs of meeting the emission targets in scenario 4. As expected, both the marginal and average costs of meeting the specified emission targets are lower than in scenario 1 with the differences increasing over time. In scenario 4, the costs of non-carbon energy sources are much closer to fossil energy prices and are nearly equal by 2050. As a result, the net costs of using these energy sources to replace fossil energy sources decline to close to zero in this time frame. In 2010, the global average cost of meeting the emission targets is only 10% less than in scenario 1. By 2100, these costs are close to one-quarter the costs in scenario 1 and are equivalent to a rise in oil prices of less than $3.50/bbl.

Scenario 5

Scenario 5 is like scenario 1 but allows trading of emission rights among regions in order to minimize total costs of meeting the regional targets. We implemented this scenario by calculating the global emission target, estimating a global marginal emission reduction cost needed to meet this target, and then estimating the regional average reduction costs (regional marginal costs will equal the global marginal costs).

As expected, the global costs of meeting the emission targets are slightly less than in scenario 1. The regional costs of emissions reductions can vary since in the scenario some regions have higher emission reductions than in scenario 1 and effectively sell the surplus emission rights to other regions. Table 9 summarizes the regional results from 2010. It shows the costs of the emission reductions and the net average costs after emission trading of meeting the regional emission targets.

Table 8. Emission Reduction Costs Scenario 4 vs Scenario 1
($/ton C)

	Marginal Costs				Average Costs			
Region	2010	2025	2050	2100	2010	2025	2050	2100
Scenario 1								
United States	160	150	65	83	57	50	15	20
Other OECD	127	142	101	121	51	51	34	56
USSR/E Europe	115	120	75	55	23	36	22	13
China/CP Asia	20	140	219	198	16	63	143	166
Rest of World	42	157	163	129	24	94	104	98
Scenario 4								
United States	80	40	15	10	46	16	4	3
Other OECD	71	58	31	23	45	29	18	12
USSR/E Europe	60	38	25	16	26	19	13	6
China/CP Asia	15	45	42	62	13	24	35	37
Rest of World	26	42	38	56	24	39	38	31

Scenario 6

Scenario 6 is designed to use a global $15/ton carbon tax in 1990 which increases by 5% annually until 2075. We have interpreted this scenario as estimating the emission reductions that can be achieved at a marginal cost of $15/ton C in 1990, which increases as described above. Due to computational problems at the high tax levels, we have capped the tax before 2050. These taxes effectively eliminate carbon emissions by 2075.

The impact of these carbon taxes on energy use is mostly in the energy supply mix. By 2025, primary energy use is about 25% less than in the reference scenario and stays at the same relative level. The high carbon tax essentially eliminates fossil fuel use. Non-carbon energy sources represent close to 100% of primary energy use by 2100.

Table 9. Regional Emission Reductions and Costs Scenario 5 vs Scenario 1
($/ton C)

Year: 2010 Marginal Costs of Emission Reduction: $100/ton C

Region	-Emissions(Mt C)- Ref.	Sc 5	Sc 1	Average Cost of Reducing Emissions*	Average Cost of Meeting Target Sc 5**	Sc 1
United States	1636	1240	1128	27	43	57
Other OECD	1772	1181	1116	34	41	51
USSR/E Europe	2315	1397	1371	21	23	23
China/CP Asia	1047	829	939	35	11	16
Rest of World	1787	1184	1428	36	16	24
Global	8557	5833	5981	29	29	37

* Average cost of reducing emissions in that region to level of actual reduction in the scenario (e.g., reduce emissions to 1240 Mt C in the U.S.).

** Average cost of meeting emission target which includes costs of regions own reductions plus (or minus if region exports emission rights) the difference needed to meet the emission target times the marginal emission reduction costs. In this way, all emission rights traded between countries are traded at the marginal emission reduction cost.

Scenario 9

Scenario 9 is like scenario 5 but includes a global emission target that is equal to a 2% annual reduction of emissions from the reference scenario emission levels. We have interpreted this to mean that the global emission target is given by the following equation:

$$T_t = R_t * (0.98^{(t-1990)})$$

where t is the index of the year, T_t is the global emission target for the year t, and R_t represents global CO_2 emissions in the year t.

Table 10 summarizes the global emissions and average emission reduction costs from this scenario and compares these costs to those from scenarios 1 and 5. The table shows that the emission constraint in this scenario is more stringent than the emission constraint in scenarios 1 and 5, but the emission constraint, at least in the earlier years, can be more expensive to achieve in scenario 1 since the constraints are regional specific in scenario 1. Scenario 5 allows emission trading, which from a global perspective is similar to using a global emission target.

Scenario 10

Scenario 10 is like scenario 1, except that the energy supply assumptions are revised to include four times the natural gas resources. Like scenario 4, we created an alternative reference scenario to then compare against and estimate the cost of emission reductions.

Alternative Reference Scenario: 4xNatural Gas Resources: Table 11 compares this alternative natural gas scenario to the reference scenario. As the table indicates, natural gas use increases dramatically, reaching 356 Ej annually by 2100. This increase is matched partially by decreases in coal use and in non-fossil electricity sources. Total primary energy use increases due primarily to reductions in energy prices since more natural gas is available at the same price.

Table 10. Global Emissions and Emission Reduction Costs
Scenario 9 vs Scenarios 1 and 5

Year	Emissions (Mt C) Sc 9	Sc 1	Sc 5	Average Cost of Reduction ($/ton C) Sc 9	Sc 1	Sc 5
2010	5833	5981	5832	29	37	29
2025	5482	5916	5971	67	61	53
2050	3960	5829	6022	106	77	50
2100	2151	5940	5956	123	100	90

Table 11. Global Primary Energy Use and CO_2 Emissions
4xNatural Gas Scenario vs Reference Scenario

	4xNatural Gas Scenario 2010	2025	2050	2100	Reference Scenario 2010	2025	2050	2100
Primary Energy Use (EJ)								
Oil	144	134	94	37	144	135	96	38
Gas	127	170	234	356	114	125	115	52
Coal	168	259	379	618	170	275	412	761
Biomass	0	6	12	41	0	8	35	103
Hydro	37	49	63	73	37	49	63	73
Other	39	76	105	187	40	80	125	256
Total	515	694	889	1311	506	672	845	1283
CO_2 Emission (Bt C)	8.7	11.3	14.2	20.5	8.6	11.1	13.4	19.8

Emission Reduction Costs: As described above, scenario 10 is designed to look at the cost of meeting the scenario 1 emission targets, but assumes that natural gas resources are much more abundant than assumed in the reference scenario and in scenario 1. The results of this scenario are somewhat surprising but reasonable. Because of the more abundant gas use, energy use and emissions are greater without controls. Also, the marginal emission reduction options required greater reductions in energy use to achieve the same reductions in emissions. Subsequently, the costs of meeting the emission targets are greater than if the abundant resources did not exist. Alternatively, total energy costs under the constraint are less with the abundant natural gas than if the gas did not exist. Table 12 compares primary energy use and global emission reduction costs between the two scenarios.

Table 12. Global Primary Energy Use and Emission Reduction Costs Scenario 10 vs Scenario 1

	Scenario 10 4xNatural Gas Scenario				Scenario 1 Reference Gas Scenario			
	2010	2025	2050	2100	2010	2025	2050	2100
Primary Energy Use (EJ)								
Oil	102	97	87	37	104	101	94	38
Gas	85	98	119	131	78	76	68	46
Coal	114	112	106	142	118	118	125	188
Biomass	13	77	184	438	11	74	168	419
Hydro	37	49	63	73	37	49	63	73
Other	25	50	71	128	25	53	87	188
Total	376	481	629	949	372	471	605	953
CO_2 Emission (Bt C)	6.0	6.0	5.9	6.0	6.0	5.9	5.8	5.9
Average Emission Reduction Cost ($/ton C)	41	72	95	153	37	61	77	100

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ENDNOTES

1. Fossil fuel price responses to reduced consumption are not currently implemented in the cost model.

2. Tons refers to metric tons throughout this paper.