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2008

11th Annual High School Mathematical Contest in Modeling (HiMCM) Summary Sheet

(Please attach a copy of this page to each copy of your Solution Paper.)

Team Control Number: 2081
Problem Chosen: B

Please type a summary of your results on this page. Please remember not to include the name of your school, advisor, or team members on this page.

Today, with global warming quickly becoming a crisis, we should do anything we can to reduce our carbon footprint, in an attempt to save humans from an imminent destruction.

We are asked to find a method to achieve carbon neutrality, if possible, either by CO2 sequestration, emission reduction, or both. Whatever action we take must be as minimally invasive as possible and not greatly affect the U.S. economy or culture. We are asked to consider the feasibility, effectiveness, and cost of implementing our plan when determining our solution. Additionally, the problem states that the U.S. CO2 emissions cannot exceed the 2007-2008 levels.

We began by researching the three main sources of CO2 emissions: coal, natural gas, and petroleum. We then researched alternative energy solutions from renewable sources. To offset emissions from coal, which is a major source of electricity, we chose wind power. For natural gas, which is used in heating buildings, we looked at solar energy. As for petroleum, which is used in gasoline, we focused on replacing a portion of it with ethanol. After developing a specific plan revolving around these key changes, we used STELLA to model the effect of plan on the current levels of CO2 emissions.

Then, we looked at ways to consume CO2 that is already in the atmosphere, thus further lowering our net CO2 emissions. CO2 is naturally consumed by forests, urban trees, and agricultural soils every year. From our research, we concluded that reforestation would be the most effective method of sequestration. Furthermore, we chose to plant maple trees, which are especially efficient in removing CO2 from the atmosphere. After incorporating this into our Stella model, we found that, compared to reducing carbon emissions, CO2 sequestration is not very effective.

From our model, we observed that it is very difficult to achieve carbon neutrality. By continuing with our plan -- with no future changes -- neutrality might be reached in several thousand years. This is not satisfactory. Therefore, in order to achieve neutrality in a more reasonable time frame, more extreme actions must be taken. Our plan was developed with existing technology in mind, and in an effort to minimize change in American lifestyle. Therefore, we would need better technology and a willingness to initially invest in higher priced energy sources. Furthermore, our plan was focused on large scale projects, whereas carbon neutrality would require individual efforts and small scale operations as well. We did determine, however, that trying to reduce emissions is more effective than sequestering the existing carbon.

Introduction

We were asked to find a way to reduce CO_2 emissions and/or consume some atmospheric CO_2 in a minimally invasive way. Assuming that the carbon emission levels have either stayed constant or decreased from 2007-2008, we were asked to model possible solution that considered feasibility, effectiveness, and costs. We defined feasibility as being the willingness of Americans to cooperate with the plan. Cost also factors into feasibility, since most Americans will be reluctant to pay for a much more expensive plan. Additionally, a plan is deemed effective if it achieves carbon neutrality, regardless of how many years that takes. We decided that effectiveness is the most important factor; however, when choosing between different methods of emission reduction and carbon consumption, we opted for the more inexpensive options.

We researched the uses of coal, natural gas, and petroleum so that we could better understand how to replace them. When these three resources are burned, they all produce CO_2. Coal is mainly used to generate electricity, but it can be replaced by solar power and/or wind energy. Petroleum is most commonly used in gasoline; however, a small percent also contributes to electricity generation. We can replace petroleum in gasoline with ethanol, and petroleum used for electricity with wind power. Natural gas is mainly used for heating buildings and can be replaced by solar panel heating systems.

There are also ways in which we can improve carbon consumption as a whole. There are also several artificial sequestration option. It is possible to capture carbon and sink it to the bottom of the ocean with the attachment of iron atoms. Additionally, geological sequestration can be used. This approach pumps carbon dioxide into oil wells as the oil is being drilled out. Minerals can also sequester carbon when it is consumed by using solid carbonate salts. Saline aquifers are also possible options. CO_2 emissions are pumped into deep-saline aquifers and then stay there permanently due to the carbonate minerals. These additional artificial methods of sequestration might help the nation reach the goal of carbon neutrality. We did not look at all of these, because increasing sequestration is not as effective as reducing carbon emissions. Therefore, we only focused on increasing one type of sequestration: reforestation.

Initial Assumptions

- The US national carbon footprint is the net amount of CO_2 emitted into the atmosphere from human activities. Only the continental US, Alaska, and Hawaii are accounted for.
- The US carbon footprint is contributed to only by coal, natural gas, and petroleum sectors.
- The only way for the US to decrease our carbon footprint is to reduce our CO_2 emissions and/or to increase our CO_2 consumption.
- CO_2 emissions are capped at 2007 levels indefinitely. Therefore, if the CO_2 emissions by fuel type have been increasing in reality after 2007, they will still be constant in our model. However, if they have been decreasing in reality, they will continue to decrease in our model.
- Carbon neutrality is achieved when there is no net contribution of CO_2 to the atmosphere by humans.
- CO_2 emissions are measured in million metric tons.
- Feasibility is measured by the willingness of Americans to cooperate with the plan.
- Americans dislike change. A plan with little or no effect on the average Americans lifestyle is preferable to a plan with a large effect.

Reduction in CO_2 emissions from Coal

As of 2007, the CO_2 emissions from burning coal were increasing, and we capped the emissions at that level (see Appendix G). We assumed the following statistics when addressing CO_2 emissions from coal:

- the 2007 level of CO_2 emission from coal was 2154.
- 48.981% of electricity is generated with coal.
- 92% of all coal is used to generate electricity.
- in 2006, wind turbines accounted for 1% of electricity generation.
- in 2006, there were 983,040 wind turbines.
- An increase in electricity generated from wind turbines will affect all fossil fuel sources of electricity at rates proportionate to current percentages of electricity production. (See Appendix F)

Using these statistics, we calculated the amount of CO_2 from burning coal saved per one wind turbine. (See Appendix D) We decided to implement 589,824 new wind turbines (60% of the number of turbines in 2006) every year until coal dependence for electricity has been completely eliminated. Following this plan, CO_2 emissions from coal will decrease by 13.5% in 50 years, by 27.0% in 100 years. The CO_2 emissions from coal will continue to decrease linearly until they eventually reach 8% of the current CO_2 emissions from coal, at which point they will level off. (See Appendix C). With this plan, we will never be completely independent of coal.

Reduction in CO_2 emissions from Petroleum

In 2007, CO_2 emissions due to petroleum were decreasing at .1% (see Appendix G); therefore, we maintained this constant decrease in our model. We plan to reduce the CO_2 emissions from petroleum by replacing a portion of petroleum in gasoline with ethanol. Ethanol, unlike Petroleum, yields no net CO_2 when combusted (see Appendix H). Additionally, we assumed the following:

- An average of 42.86% of all petroleum is used as gasoline.
- The current percent of ethanol in gasoline is 10%.
- Current petrol-running engines cannot handle gasoline with over a 20% ethanol content.
- Ethanol-converted engines can use gasoline with up to an 85% ethanol content.
- In 2006, petroleum averaged a cost of $60.00 per barrel.
- In 2006, ethanol averaged a cost of $63.00 per barrel.

Because we wanted to minimize the effect on American lives, we decided to improve the current petroleum-based gasoline instead of making new cars that would run on ethanol and forcing Americans to adopt new methods of transportation. Therefore, we propose to require by law that gas-manufacturers maximize the ethanol content in gasoline (20%). This will immediately reduce petroleum CO_2 emissions by 4.3% (over 100 mmt CO_2). CO_2 emissions from petroleum will then continue to decrease based on the 2007 rate of growth (-.1%).

Petroleum also contributes to electricity generation. Therefore, carbon emissions from petroleum would be affected by our wind energy plan. In addition to previous assumptions, we assume the following statistics:

- 1.583% of electricity is generated from petroleum
- 2% of petroleum is used for electricity

We used the same method as before to calculate the effect of our new wind turbines on current CO_2 emissions from petroleum. (See Appendix E) The effect was small, since petroleum does not play a huge role electricity production, our results make sense. Therefore, ethanol replacement has the greatest impact on carbon emissions from petroleum. We predict a decrease of 8.96% after 50 years, a decrease of 13.4% after 100 years.

Reduction in CO_2 emissions from Natural Gas

The CO_2 emissions from natural gas were increasing in 2007. Therefore, we assumed a constant level of emissions for our model. Natural gas is primarily used to heat buildings. We plan to reduce natural gas emissions by using solar power as an alternative energy source. Solar power, while very efficient, must be used in conjunction with another energy source.

We assumed the following:

- The current level of CO_2 emissions from natural gas is 1234 mmt CO_2
- 62.3% of natural gas is used for heating buildings, whether residential, commercial, or industrial.
- There are approximately 100,000,000 buildings in the US.
- A building that uses solar power cuts down on its natural gas consumption by 75%.

Using these values, we calculated how much CO_2 emissions one building equipped with solar energy would save. (See Appendix E) In order to increase this value, we propose a tax decrease incentive for any building powered by solar energy. Our target is 1 million new solar energy systems per year, which would linearly decrease the CO_2 emissions from natural gas until it natural gas dependency for heating has been minimized. Then, the emissions would level off.

Natural gas is the second greatest source of electricity. Therefore, it would also be affected by our wind power plan. In addition to previously stated assumptions, we assumed the following:

- 20.003% of electricity is generated from natural gas
- 30% of natural gas is used for electricity

We used the same method as before to model the effect of wind power on CO_2 emissions from natural gas (See Appendix D). With both solar and wind power taking the place of natural gas, the carbon emissions will decrease by 25% in 50 years, by 48.8% in 100 years.

Sequestration

We can actually remove carbon from the atmosphere by carbon sinks. This is already a natural occurrence forests, agricultural soils, and even urban trees. Forests absorb 10.6% of atmospheric carbon every year and store it in the soil as dead organic matter. Although in lesser quantities, urban trees also sequester 1.5% of the carbon. Reforestation is one way we can increase sequestration. We developed a sequestration plan to reduce our net carbon emissions, using the following assumptions:

- A tree consumes the same amount of CO_2 every year.
- One million apple trees absorb 45 pounds of CO_2 per year, which converts to 1.0205 mmt CO_2 per year.

We propose planting five million maple trees each year in order to consume 1.0205 mmt CO_2 each year. Right now, agricultural soils are only consuming .8% of the atmospheric CO_2, but this is an area where we can hope for drastic improvement. These soils, which include pasteurized land, are readily available for reforestation. 95% of the US farmland is available for sequestration since only 5% use no-till and residue mulching. We incorporated this data into our STELLA model by subtracting 12.8% (the total % of consumed carbon) of the total carbon emissions every year. (See Appendix D)

Costs and Conclusion

The cost of our plan supports its implementation (see Appendix I). The price difference between gasoline with a 10% ethanol content and a 20% ethanol content is relatively small – 3 dollars a barrel. Additionally, although wind turbines may seem expensive at first, they really are a good investment. After installation is complete, wind-generators do not demand any more money and simply produce energy free-of-charge. Solar panels also have similar attributes. Once a solar panel system is invested in, the panels will continue to heat the building for many years to come. Although wind turbines and solar panel systems have high installment costs, they will end up saving the American people money after installation. We have decided that these three alterations should be put into effect because their cost difference is either minimal or beneficial over a longer period of time.

Based on our model, in 50 years, total carbon emissions will be reduced by 23.7%. In 100 years, they will have fallen by 34.1%. Finally, by year 2222, the US carbon footprint will have been cut in half. We have found that it is impossible to achieve neutrality in a reasonable time period with such a model. However, for sake of simplification, we did not take into account all available technologies in harnessing renewable sources of energy. For example, we did not look at nuclear power or hydropower. Furthermore, we developed our model trying to minimize change in American lifestyles. However, in order to achieve neutrality, we would have to demand more change from the people. For example, we would need to expect people to switch to cars, which run on ethanol-based gasoline (containing up to 85% ethanol), which at this point are very expensive. To take it to the extreme, we might consider restructuring cities to make reduce emissions from transportation by shortening walking distances. However these would have a greater affect on American culture, which we were asked to avoid for this project. Therefore, for the guidelines we were given, we conclude that carbon neutrality is impossible

Epilogue

We began our approach with researching background information. We read many articles on carbon emissions and sequestration and learned about which sectors have the largest influence on the US carbon footprint. By educating ourselves on the CO2 problem, we were able to make knowledgeable decisions about which facts to simplify. For example, based on our research we decided that it did not matter where the CO2 emissions were coming from (industries, residential sectors, commercial activities, or transportation), but only what actual resources were emitting the CO2. This is a strength of our model because we were able to formulate a solution that was simple enough to produce in a short amount of time (36 hours), but also complex enough to give us an accurate answer. Additionally our group collaborated well; we delegated positions and had some people do research while others worked on the model. The only problem with the research part of the project was that we spent a lot of time looking up information that we didn't need in the long run. Once we got on track, however, the research was much more focused and the model fell into place.

The most difficult part of the project was finding accurate values for our models. Many of our values are averages for entire years; therefore, our model would have been more accurate if we had taken monthly values into account. Since our knowledge of the modeling program STELLA is limited, we had some trouble in the beginning configuring our charts, graphs, and even the model. However, after we improved the basic equations, our model began to run much more smoothly. Our other weakness was that as the hours passed, time took its toll on our group and we, at some moments, snapped at each other.

Appendices

Appendix A
General Data

CATEGORY:	AMOUNT:
% of Ethanol in Gasoline	20%
Total Wind Turbines in 2006	983,040
Wind Turbines Added Every Year	589,824
Wind Power % of Total Electricity - 2006	1%
% of CO_2 Sequestered by Forests	10.6%
% of CO_2 Sequestered by Urban Trees	1.5%
% of CO_2 Sequestered by Agricultural Soils	.8%
Initial Amount of Maple Trees	5,000,000
Maple Trees Absorption Annually	45 lbs
Average Cost of Petroleum in 2006	$60.00 per barrel
ΔPetroleum Annually	-.1
Average Cost of Ethanol in 2006	$63.00 per barrel
ΔEmission for Electric Power Sector	3.0%

Appendix B

Chart from STELLA model

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Years	Coal	Natural Gas	Petroleum	Yearly CO2
0	2,153.99	1,234.00	2,472.29	5,984.00
1	2,148.17	1,227.79	2,469.82	5,089.37
2	2,142.35	1,221.58	2,467.35	5,190.27
3	2,136.52	1,215.37	2,464.88	5,162.73
4	2,130.70	1,209.16	2,462.42	5,151.80
5	2,124.87	1,202.95	2,459.95	5,138.71
6	2,119.05	1,196.74	2,457.50	5,125.91
7	2,113.23	1,190.53	2,455.04	5,113.06
8	2,107.40	1,184.32	2,452.58	5,100.23
9	2,101.58	1,178.11	2,450.13	5,087.40
10	2,095.76	1,171.90	2,447.68	5,074.56
11	2,089.93	1,165.69	2,445.23	5,061.74
12	2,084.11	1,159.48	2,442.79	5,048.91
13	2,078.28	1,153.27	2,440.34	5,036.08
14	2,072.46	1,147.06	2,437.90	5,023.26
15	2,066.64	1,140.85	2,435.47	5,010.44
16	2,060.81	1,134.64	2,433.03	4,997.62
17	2,054.99	1,128.43	2,430.60	4,984.81
18	2,049.16	1,122.22	2,428.17	4,971.99
19	2,043.34	1,116.01	2,425.74	4,959.18
20	2,037.52	1,109.80	2,423.31	4,946.37
21	2,031.69	1,103.59	2,420.89	4,933.56
22	2,025.87	1,097.38	2,418.47	4,920.76
23	2,020.04	1,091.17	2,416.05	4,907.96
24	2,014.22	1,084.96	2,413.63	4,895.16
25	2,008.40	1,078.75	2,411.22	4,882.36
26	2,002.57	1,072.54	2,408.81	4,869.56
27	1,996.75	1,066.33	2,406.40	4,856.77
28	1,990.93	1,060.12	2,403.99	4,843.97
29	1,985.10	1,053.91	2,401.59	4,831.18
30	1,979.28	1,047.69	2,399.19	4,818.39
31	1,973.45	1,041.48	2,396.79	4,805.61
32	1,967.63	1,035.27	2,394.39	4,792.82
33	1,961.81	1,029.06	2,392.00	4,780.04
34	1,955.98	1,022.85	2,389.61	4,767.26
35	1,950.16	1,016.64	2,387.22	4,754.49
36	1,944.33	1,010.43	2,384.83	4,741.71
37	1,938.51	1,004.22	2,382.44	4,728.94
38	1,932.69	998.01	2,380.06	4,716.17
39	1,926.86	991.80	2,377.68	4,703.40
40	1,921.04	985.59	2,375.30	4,690.63
41	1,915.21	979.38	2,372.93	4,677.87

CO2 Emissions (Million Metric Tons): (1)

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Years	Coal	Natural Gas	Petroleum	Yearly CO2
42	1,909.39	973.17	2,370.56	4,665.10
43	1,903.57	966.96	2,368.19	4,652.34
44	1,897.74	960.75	2,365.82	4,639.58
45	1,891.92	954.54	2,363.45	4,626.83
46	1,886.10	948.33	2,361.09	4,614.07
47	1,880.27	942.12	2,358.73	4,601.32
48	1,874.45	935.91	2,356.37	4,588.57
49	1,868.62	929.70	2,354.01	4,575.82
50	1,862.80	923.49	2,351.66	4,563.08
51	1,856.98	917.28	2,349.31	4,550.33
52	1,851.15	911.07	2,346.96	4,537.59
53	1,845.33	904.86	2,344.61	4,524.85
54	1,839.50	898.65	2,342.27	4,512.11
55	1,833.68	892.44	2,339.92	4,499.38
56	1,827.86	886.23	2,337.58	4,486.64
57	1,822.03	880.02	2,335.25	4,473.91
58	1,816.21	873.81	2,332.91	4,461.18
59	1,810.39	867.60	2,330.58	4,448.46
60	1,804.56	861.39	2,328.25	4,435.73
61	1,798.74	855.62	2,325.92	4,423.01
62	1,792.91	849.86	2,323.59	4,410.73
63	1,787.09	844.09	2,321.27	4,398.40
64	1,781.27	838.33	2,318.95	4,386.08
65	1,775.44	832.56	2,316.63	4,373.76
66	1,769.62	826.79	2,314.31	4,361.44
67	1,763.79	821.03	2,312.00	4,349.12
68	1,757.97	815.26	2,309.69	4,336.80
69	1,752.15	809.50	2,307.38	4,324.49
70	1,746.32	803.73	2,305.07	4,312.18
71	1,740.50	797.97	2,302.76	4,299.87
72	1,734.67	792.20	2,300.46	4,287.56
73	1,728.85	786.43	2,298.16	4,275.26
74	1,723.03	780.67	2,295.86	4,262.96
75	1,717.20	774.90	2,293.57	4,250.66
76	1,711.38	769.14	2,291.27	4,238.36
77	1,705.56	763.37	2,288.98	4,226.06
78	1,699.73	757.60	2,286.69	4,213.77
79	1,693.91	751.84	2,284.41	4,201.47
80	1,688.08	746.07	2,282.12	4,189.18
81	1,682.26	740.31	2,279.84	4,176.89
82	1,676.44	734.54	2,277.56	4,164.61
83	1,670.61	728.77	2,275.28	4,152.32

CO2 Emissions (Million Metric Tons): (2)

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Years	Coal	Natural Gas	Petroleum	Yearly CO2
84	1,664.79	723.01	2,273.01	4,140.04
85	1,658.96	717.24	2,270.73	4,127.76
86	1,653.14	711.48	2,268.46	4,115.48
87	1,647.32	705.71	2,266.19	4,103.20
88	1,641.49	699.95	2,263.93	4,090.93
89	1,635.67	694.18	2,261.66	4,078.66
90	1,629.84	688.41	2,259.40	4,066.39
91	1,624.02	682.65	2,257.14	4,054.12
92	1,618.20	676.88	2,254.89	4,041.85
93	1,612.37	671.12	2,252.63	4,029.59
94	1,606.55	665.35	2,250.38	4,017.32
95	1,600.73	659.58	2,248.13	4,005.06
96	1,594.90	653.82	2,245.88	3,992.81
97	1,589.08	648.05	2,243.63	3,980.55
98	1,583.25	642.29	2,241.39	3,968.29
99	1,577.43	636.52	2,239.15	3,956.04
100	1,571.61	630.76	2,236.91	3,943.79
101	1,565.78	624.99	2,234.67	3,931.54
102	1,559.96	619.22	2,232.44	3,919.30
103	1,554.13	613.46	2,230.21	3,907.05
104	1,548.31	607.69	2,227.98	3,894.81
105	1,542.49	601.93	2,225.75	3,882.57
106	1,536.66	596.16	2,223.52	3,870.33
107	1,530.84	590.39	2,221.30	3,858.09
108	1,525.01	584.63	2,219.08	3,845.86
109	1,519.19	578.86	2,216.86	3,833.63
110	1,513.37	573.10	2,214.64	3,821.39
111	1,507.54	567.33	2,212.43	3,809.17
112	1,501.72	561.56	2,210.21	3,796.94
113	1,495.90	555.80	2,208.00	3,784.71
114	1,490.07	550.03	2,205.80	3,772.49
115	1,484.25	544.27	2,203.59	3,760.27
116	1,478.42	538.50	2,201.39	3,748.05
117	1,472.60	532.74	2,199.19	3,735.83
118	1,466.78	526.97	2,196.99	3,723.62
119	1,460.95	521.20	2,194.79	3,711.41
120	1,455.13	515.44	2,192.59	3,699.19
121	1,449.30	509.67	2,190.40	3,686.99
122	1,443.48	503.91	2,188.21	3,674.78
123	1,437.66	498.14	2,186.02	3,662.57
124	1,431.83	492.37	2,183.84	3,650.37
125	1,426.01	486.61	2,181.65	3,638.17

CO2 Emissions (Million Metric Tons): (3)

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Years	Coal	Natural Gas	Petroleum	Yearly CO2
126	1,420.19	480.84	2,179.47	3,625.97
127	1,414.36	475.08	2,177.29	3,613.77
128	1,408.54	469.31	2,175.11	3,601.57
129	1,402.71	463.55	2,172.94	3,589.38
130	1,396.89	463.55	2,170.77	3,577.19
131	1,391.07	463.55	2,168.60	3,570.76
132	1,385.24	463.55	2,166.43	3,563.60
133	1,379.42	463.55	2,164.26	3,556.53
134	1,373.59	463.55	2,162.10	3,549.45
135	1,367.77	463.55	2,159.93	3,542.38
136	1,361.95	463.55	2,157.77	3,535.30
137	1,356.12	463.55	2,155.62	3,528.23
138	1,350.30	463.55	2,153.46	3,521.16
139	1,344.47	463.55	2,151.31	3,514.10
140	1,338.65	463.55	2,149.16	3,507.03
141	1,332.83	463.55	2,147.01	3,499.97
142	1,327.00	463.55	2,144.86	3,492.90
143	1,321.18	463.55	2,142.72	3,485.84
144	1,315.36	463.55	2,140.57	3,478.79
145	1,309.53	463.55	2,138.43	3,471.73
146	1,303.71	463.55	2,136.29	3,464.68
147	1,297.88	463.55	2,134.16	3,457.62
148	1,292.06	463.55	2,132.02	3,450.57
149	1,286.24	463.55	2,129.89	3,443.52
150	1,280.41	463.55	2,127.76	3,436.48
151	1,274.59	463.55	2,125.63	3,429.43
152	1,268.76	463.55	2,123.51	3,422.39
153	1,262.94	463.55	2,121.38	3,415.35
154	1,257.12	463.55	2,119.26	3,408.31
155	1,251.29	463.55	2,117.14	3,401.27
156	1,245.47	463.55	2,115.03	3,394.24
157	1,239.64	463.55	2,112.91	3,387.20
158	1,233.82	463.55	2,110.80	3,380.17
159	1,228.00	463.55	2,108.69	3,373.14
160	1,222.17	463.55	2,106.58	3,366.12
161	1,216.35	463.55	2,104.47	3,359.09
162	1,210.53	463.55	2,102.37	3,352.07
163	1,204.70	463.55	2,100.27	3,345.04
164	1,198.88	463.55	2,098.17	3,338.02
165	1,193.05	463.55	2,096.07	3,331.00
166	1,187.23	463.55	2,093.97	3,323.99
167	1,181.41	463.55	2,091.88	3,316.97

CO2 Emissions (Million Metric Tons): (4)

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Years	Coal	Natural Gas	Petroleum	Yearly CO2
168	1,175.58	463.55	2,089.79	3,309.96
169	1,169.76	463.55	2,087.70	3,302.93
170	1,163.93	463.55	2,085.61	3,295.94
171	1,158.11	463.55	2,083.52	3,288.93
172	1,152.29	463.55	2,081.44	3,281.93
173	1,146.46	463.55	2,079.36	3,274.92
174	1,140.64	463.55	2,077.28	3,267.92
175	1,134.81	463.55	2,075.20	3,260.92
176	1,128.99	463.55	2,073.13	3,253.92
177	1,123.17	463.55	2,071.05	3,246.93
178	1,117.34	463.55	2,068.98	3,239.93
179	1,111.52	463.55	2,066.91	3,232.94
180	1,105.70	463.55	2,064.85	3,225.93
181	1,099.87	463.55	2,062.78	3,218.96
182	1,094.05	463.55	2,060.72	3,211.97
183	1,088.22	463.55	2,058.66	3,204.99
184	1,082.40	463.55	2,056.60	3,198.00
185	1,076.58	463.55	2,054.54	3,191.02
186	1,070.75	463.55	2,052.49	3,184.04
187	1,064.93	463.55	2,050.44	3,177.06
188	1,059.10	463.55	2,048.38	3,170.09
189	1,053.28	463.55	2,046.34	3,163.11
190	1,047.46	463.55	2,044.29	3,156.14
191	1,041.63	463.55	2,042.25	3,149.17
192	1,035.81	463.55	2,040.20	3,142.20
193	1,029.99	463.55	2,038.16	3,135.23
194	1,024.16	463.55	2,036.12	3,128.27
195	1,018.34	463.55	2,034.09	3,121.31
196	1,012.51	463.55	2,032.05	3,114.34
197	1,006.69	463.55	2,030.02	3,107.38
198	1,000.87	463.55	2,027.99	3,100.43
199	995.04	463.55	2,025.96	3,093.47
200	989.22	463.55	2,023.94	3,086.51
201	983.39	463.55	2,021.91	3,079.56
202	977.57	463.55	2,019.89	3,072.61
203	971.75	463.55	2,017.87	3,065.66
204	965.92	463.55	2,015.86	3,058.71
205	960.10	463.55	2,013.84	3,051.77
206	954.27	463.55	2,011.83	3,044.83
207	948.45	463.55	2,009.81	3,037.88
208	942.63	463.55	2,007.80	3,030.94
209	936.80	463.55	2,005.80	3,024.00

CO2 Emissions (Million Metric Tons): (5)

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Years	Coal	Natural Gas	Petroleum	Yearly CO2
210	930.98	463.55	2,003.79	3,017.07
211	925.16	463.55	2,001.79	3,010.13
212	919.33	463.55	1,999.78	3,003.20
213	913.51	463.55	1,997.78	2,996.27
214	907.68	463.55	1,995.79	2,989.34
215	901.86	463.55	1,993.79	2,982.41
216	896.04	463.55	1,991.80	2,975.49
217	890.21	463.55	1,989.81	2,968.56
218	884.39	463.55	1,987.82	2,961.64
219	878.56	463.55	1,985.83	2,954.72
220	872.74	463.55	1,983.84	2,947.80
221	866.92	463.55	1,981.86	2,940.88
222	861.09	463.55	1,979.88	2,933.97
223	855.27	463.55	1,977.90	2,927.05
224	849.44	463.55	1,975.92	2,920.14
225	843.62	463.55	1,973.94	2,913.23
226	837.80	463.55	1,971.97	2,906.32
227	831.97	463.55	1,970.00	2,899.42
228	826.15	463.55	1,968.03	2,892.51
229	820.33	463.55	1,966.06	2,885.61
230	814.50	463.55	1,964.09	2,878.71
231	808.68	463.55	1,962.13	2,871.81
232	802.85	463.55	1,960.17	2,864.91
233	797.03	463.55	1,958.21	2,858.01
234	791.21	463.55	1,956.25	2,851.12
235	785.38	463.55	1,954.29	2,844.23
236	779.56	463.55	1,952.34	2,837.33
237	773.73	463.55	1,950.39	2,830.45
238	767.91	463.55	1,948.43	2,823.56
239	762.09	463.55	1,946.49	2,816.67
240	756.26	463.55	1,944.54	2,809.79
241	750.44	463.55	1,942.60	2,802.91
242	744.62	463.55	1,940.65	2,796.03
243	738.79	463.55	1,938.71	2,789.15
244	732.97	463.55	1,936.77	2,782.27
245	727.14	463.55	1,934.84	2,775.39
246	721.32	463.55	1,932.90	2,768.52
247	715.50	463.55	1,930.97	2,761.65
248	709.67	463.55	1,929.04	2,754.78
249	703.85	463.55	1,927.11	2,747.91
250	698.02	463.55	1,925.18	2,741.04
251	692.20	463.55	1,923.26	2,734.18

CO2 Emissions (Million Metric Tons): (6)

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Years	Coal	Natural Gas	Petroleum	Yearly CO2
252	686.38	463.55	1,921.33	2,727.31
253	680.55	463.55	1,919.41	2,720.45
254	674.73	463.55	1,917.49	2,713.59
255	668.90	463.55	1,915.58	2,706.73
256	663.08	463.55	1,913.66	2,699.88
257	657.26	463.55	1,911.75	2,693.02
258	651.43	463.55	1,909.83	2,686.17
259	645.61	463.55	1,907.92	2,679.32
260	639.79	463.55	1,906.02	2,672.47
261	633.96	463.55	1,904.11	2,665.62
262	628.14	463.55	1,902.21	2,658.77
263	622.31	463.55	1,900.30	2,651.93
264	616.49	463.55	1,898.40	2,645.08
265	610.67	463.55	1,896.51	2,638.24
266	604.84	463.55	1,894.61	2,631.40
267	599.02	463.55	1,892.71	2,624.57
268	593.19	463.55	1,890.82	2,617.73
269	587.37	463.55	1,888.93	2,610.89
270	581.55	463.55	1,887.04	2,604.06
271	575.72	463.55	1,885.15	2,597.23
272	569.90	463.55	1,883.27	2,590.40
273	564.07	463.55	1,881.39	2,583.57
274	558.25	463.55	1,879.51	2,576.75
275	552.43	463.55	1,877.63	2,569.92
276	546.60	463.55	1,875.75	2,563.10
277	540.78	463.55	1,873.87	2,556.28
278	534.96	463.55	1,872.00	2,549.46
279	529.13	463.55	1,870.13	2,542.64
280	523.31	463.55	1,868.26	2,535.82
281	517.48	463.55	1,866.39	2,529.01
282	511.66	463.55	1,864.52	2,522.20
283	505.84	463.55	1,862.66	2,515.38
284	500.01	463.55	1,860.79	2,508.57
285	494.19	463.55	1,858.93	2,501.77
286	488.36	463.55	1,857.07	2,494.96
287	482.54	463.55	1,855.22	2,488.15
288	476.72	463.55	1,853.36	2,481.33
289	470.89	463.55	1,851.51	2,474.55
290	465.07	463.55	1,849.66	2,467.75
291	459.24	463.55	1,847.81	2,460.95
292	453.42	463.55	1,845.96	2,454.16
293	447.60	463.55	1,844.11	2,447.36

CO2 Emissions (Million Metric Tons): (7)

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Years	Coal	Natural Gas	Petroleum	Yearly CO2
294	441.77	463.55	1,842.27	2,440.57
295	435.95	463.55	1,840.43	2,433.78
296	430.13	463.55	1,838.59	2,426.99
297	424.30	463.55	1,836.75	2,420.20
298	418.48	463.55	1,834.91	2,413.41
299	412.65	463.55	1,833.08	2,406.63
300	406.83	463.55	1,831.24	2,399.84
301	401.01	463.55	1,829.41	2,393.06
302	395.18	463.55	1,827.58	2,386.28
303	389.36	463.55	1,825.76	2,379.50
304	383.53	463.55	1,823.93	2,372.72
305	377.71	463.55	1,822.11	2,365.95
306	371.89	463.55	1,820.28	2,359.17
307	366.06	463.55	1,818.46	2,352.40
308	360.24	463.55	1,816.65	2,345.63
309	354.42	463.55	1,814.83	2,338.86
310	348.59	463.55	1,813.01	2,332.10
311	342.77	463.55	1,811.20	2,325.33
312	336.94	463.55	1,809.39	2,318.57
313	331.12	463.55	1,807.58	2,311.80
314	325.30	463.55	1,805.77	2,305.04
315	319.47	463.55	1,803.97	2,298.28
316	313.65	463.55	1,802.16	2,291.53
317	307.82	463.55	1,800.36	2,284.77
318	302.00	463.55	1,798.56	2,278.01
319	296.18	463.55	1,796.76	2,271.26
320	290.35	463.55	1,794.96	2,264.51
321	284.53	463.55	1,793.17	2,257.76
322	278.70	463.55	1,791.38	2,251.01
323	272.88	463.55	1,789.59	2,244.27
324	267.06	463.55	1,787.80	2,237.52
325	261.23	463.55	1,786.01	2,230.78
326	255.41	463.55	1,784.22	2,224.04
327	249.59	463.55	1,782.44	2,217.30
328	243.76	463.55	1,780.66	2,210.56
329	237.94	463.55	1,778.87	2,203.82
330	232.11	463.55	1,777.10	2,197.08
331	226.29	463.55	1,775.32	2,190.35
332	220.47	463.55	1,773.54	2,183.62
333	214.64	463.55	1,771.77	2,176.89
334	208.82	463.55	1,770.00	2,170.16
335	202.99	463.55	1,768.23	2,163.43

CO2 Emissions (Million Metric Tons): (8)

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Years	Coal	Natural Gas	Petroleum	Yearly CO2
336	197.17	463.55	1,766.46	2,156.71
337	191.35	463.55	1,764.69	2,149.98
338	185.52	463.55	1,762.93	2,143.26
339	179.70	463.55	1,761.17	2,136.54
340	173.87	463.55	1,759.40	2,129.82
341	168.05	463.55	1,757.65	2,123.10
342	168.05	463.55	1,755.89	2,116.38
343	168.05	463.55	1,754.13	2,115.49
344	168.05	463.55	1,752.38	2,113.85
345	168.05	463.55	1,750.63	2,112.31
346	168.05	463.55	1,748.87	2,110.75
347	168.05	463.55	1,747.13	2,109.20
348	168.05	463.55	1,745.38	2,107.65
349	168.05	463.55	1,743.63	2,106.11
350	168.05	463.55	1,741.89	2,104.56
351	168.05	463.55	1,740.15	2,103.02
352	168.05	463.55	1,738.41	2,101.47
353	168.05	463.55	1,736.67	2,099.93
354	168.05	463.55	1,734.93	2,098.39
355	168.05	463.55	1,733.20	2,096.86
356	168.05	463.55	1,731.46	2,095.32
357	168.05	463.55	1,729.73	2,093.78
358	168.05	463.55	1,728.00	2,092.25
359	168.05	463.55	1,726.28	2,090.72
360	168.05	463.55	1,724.55	2,089.19
361	168.05	463.55	1,722.82	2,087.66
362	168.05	463.55	1,721.10	2,086.13
363	168.05	463.55	1,719.38	2,084.61
364	168.05	463.55	1,717.66	2,083.08
365	168.05	463.55	1,715.94	2,081.56
366	168.05	463.55	1,714.23	2,080.04
367	168.05	463.55	1,712.51	2,078.52
368	168.05	463.55	1,710.80	2,077.00
369	168.05	463.55	1,709.09	2,075.48
370	168.05	463.55	1,707.38	2,073.97
371	168.05	463.55	1,705.67	2,072.46
372	168.05	463.55	1,703.97	2,070.94
373	168.05	463.55	1,702.26	2,069.43
374	168.05	463.55	1,700.56	2,067.92
375	168.05	463.55	1,698.86	2,066.42
376	168.05	463.55	1,697.16	2,064.91
377	168.05	463.55	1,695.46	2,063.41

CO2 Emissions (Million Metric Tons): (9)

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Years	Coal	Natural Gas	Petroleum	Yearly CO2
378	168.05	463.55	1,693.77	2,061.90
379	168.05	463.55	1,692.08	2,060.40
380	168.05	463.55	1,690.38	2,058.90
381	168.05	463.55	1,688.69	2,057.40
382	168.05	463.55	1,687.00	2,055.90
383	168.05	463.55	1,685.32	2,054.41
384	168.05	463.55	1,683.63	2,052.92
385	168.05	463.55	1,681.95	2,051.42
386	168.05	463.55	1,680.27	2,049.93
387	168.05	463.55	1,678.59	2,048.44
388	168.05	463.55	1,676.91	2,046.95
389	168.05	463.55	1,675.23	2,045.47
390	168.05	463.55	1,673.56	2,043.98
391	168.05	463.55	1,671.88	2,042.50
392	168.05	463.55	1,670.21	2,041.02
393	168.05	463.55	1,668.54	2,039.54
394	168.05	463.55	1,666.87	2,038.06
395	168.05	463.55	1,665.20	2,036.58
396	168.05	463.55	1,663.54	2,035.10
397	168.05	463.55	1,661.88	2,033.63
398	168.05	463.55	1,660.21	2,032.15
399	168.05	463.55	1,658.55	2,030.68
400	168.05	463.55	1,656.90	2,029.21
401	168.05	463.55	1,655.24	2,027.74
402	168.05	463.55	1,653.58	2,026.28
403	168.05	463.55	1,651.93	2,024.81
404	168.05	463.55	1,650.28	2,023.35
405	168.05	463.55	1,648.63	2,021.88
406	168.05	463.55	1,646.98	2,020.42
407	168.05	463.55	1,645.33	2,018.96
408	168.05	463.55	1,643.69	2,017.50
409	168.05	463.55	1,642.04	2,016.04
410	168.05	463.55	1,640.40	2,014.59
411	168.05	463.55	1,638.76	2,013.13
412	168.05	463.55	1,637.12	2,011.68
413	168.05	463.55	1,635.48	2,010.23
414	168.05	463.55	1,633.85	2,008.78
415	168.05	463.55	1,632.21	2,007.33
416	168.05	463.55	1,630.58	2,005.89
417	168.05	463.55	1,628.95	2,004.44
418	168.05	463.55	1,627.32	2,003.00
419	168.05	463.55	1,625.70	2,001.55

CO2 Emissions (Million Metric Tons): (10)

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Years	Coal	Natural Gas	Petroleum	Yearly CO2
420	168.05	463.55	1,624.07	2,000.11
421	168.05	463.55	1,622.45	1,998.67
422	168.05	463.55	1,620.82	1,997.23
423	168.05	463.55	1,619.20	1,995.80
424	168.05	463.55	1,617.58	1,994.36
425	168.05	463.55	1,615.97	1,992.93
426	168.05	463.55	1,614.35	1,991.49
427	168.05	463.55	1,612.74	1,990.06
428	168.05	463.55	1,611.12	1,988.63
429	168.05	463.55	1,609.51	1,987.21
430	168.05	463.55	1,607.90	1,985.78
431	168.05	463.55	1,606.29	1,984.35
432	168.05	463.55	1,604.69	1,982.93
433	168.05	463.55	1,603.08	1,981.51
434	168.05	463.55	1,601.48	1,980.09
435	168.05	463.55	1,599.88	1,978.67
436	168.05	463.55	1,598.28	1,977.25
437	168.05	463.55	1,596.68	1,975.83
438	168.05	463.55	1,595.08	1,974.41
439	168.05	463.55	1,593.49	1,973.00
440	168.05	463.55	1,591.90	1,971.59
441	168.05	463.55	1,590.30	1,970.18
442	168.05	463.55	1,588.71	1,968.77
443	168.05	463.55	1,587.12	1,967.36
444	168.05	463.55	1,585.54	1,965.95
445	168.05	463.55	1,583.95	1,964.55
446	168.05	463.55	1,582.37	1,963.14
447	168.05	463.55	1,580.79	1,961.74
448	168.05	463.55	1,579.20	1,960.34
449	168.05	463.55	1,577.63	1,958.94
450	168.05	463.55	1,576.05	1,957.54
451	168.05	463.55	1,574.47	1,956.14
452	168.05	463.55	1,572.90	1,954.75
453	168.05	463.55	1,571.32	1,953.35
454	168.05	463.55	1,569.75	1,951.96
455	168.05	463.55	1,568.18	1,950.57
456	168.05	463.55	1,566.62	1,949.18
457	168.05	463.55	1,565.05	1,947.79
458	168.05	463.55	1,563.48	1,946.40
459	168.05	463.55	1,561.92	1,945.01
460	168.05	463.55	1,560.36	1,943.63
461	168.05	463.55	1,558.80	1,942.25

CO2 Emissions (Million Metric Tons): (11)

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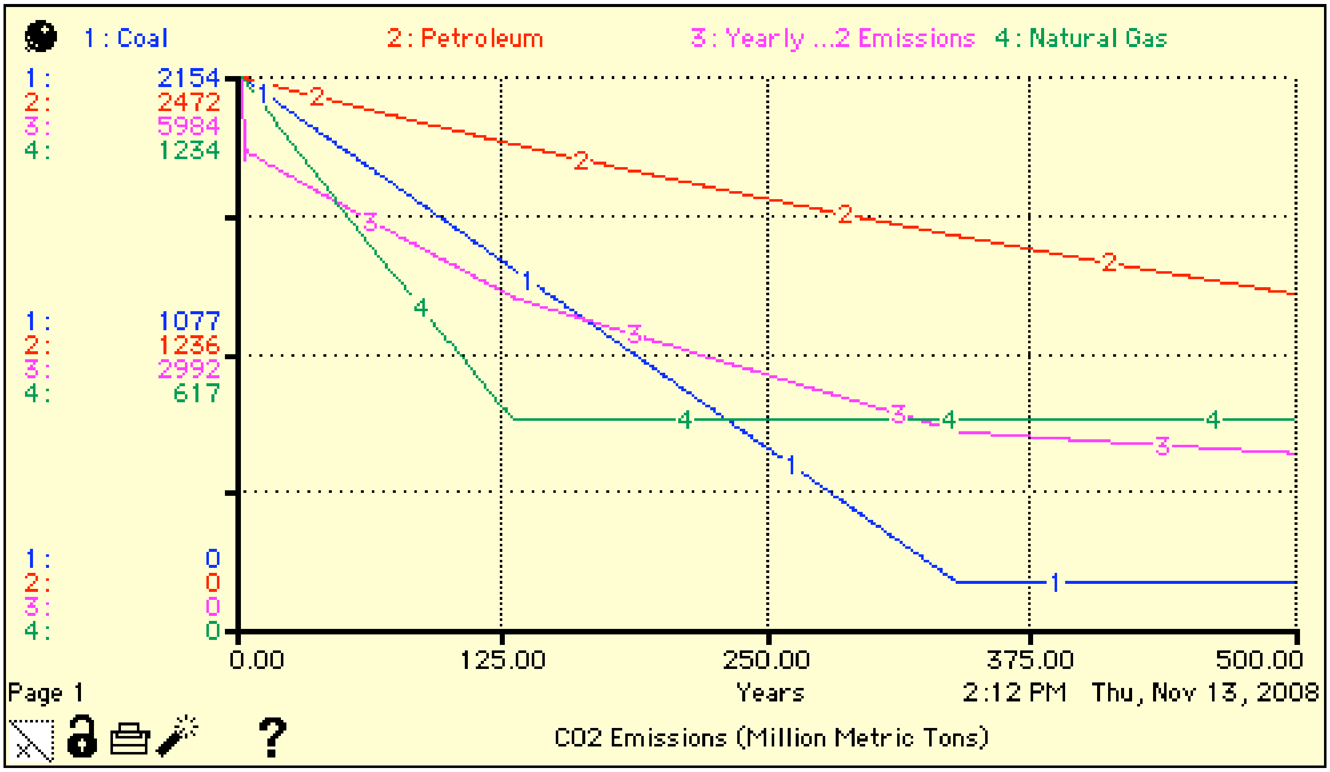
Years	Coal	Natural Gas	Petroleum	Yearly CO2
462	168.05	463.55	1,557.24	1,940.86
463	168.05	463.55	1,555.68	1,939.48
464	168.05	463.55	1,554.13	1,938.10
465	168.05	463.55	1,552.57	1,936.73
466	168.05	463.55	1,551.02	1,935.35
467	168.05	463.55	1,549.47	1,933.98
468	168.05	463.55	1,547.92	1,932.60
469	168.05	463.55	1,546.37	1,931.23
470	168.05	463.55	1,544.82	1,929.86
471	168.05	463.55	1,543.28	1,928.49
472	168.05	463.55	1,541.74	1,927.12
473	168.05	463.55	1,540.19	1,925.75
474	168.05	463.55	1,538.65	1,924.39
475	168.05	463.55	1,537.12	1,923.02
476	168.05	463.55	1,535.58	1,921.66
477	168.05	463.55	1,534.04	1,920.30
478	168.05	463.55	1,532.51	1,918.94
479	168.05	463.55	1,530.98	1,917.58
480	168.05	463.55	1,529.45	1,916.22
481	168.05	463.55	1,527.92	1,914.87
482	168.05	463.55	1,526.39	1,913.51
483	168.05	463.55	1,524.86	1,912.16
484	168.05	463.55	1,523.34	1,910.81
485	168.05	463.55	1,521.81	1,909.46
486	168.05	463.55	1,520.29	1,908.11
487	168.05	463.55	1,518.77	1,906.76
488	168.05	463.55	1,517.25	1,905.42
489	168.05	463.55	1,515.74	1,904.07
490	168.05	463.55	1,514.22	1,902.73
491	168.05	463.55	1,512.71	1,901.38
492	168.05	463.55	1,511.19	1,900.04
493	168.05	463.55	1,509.68	1,898.70
494	168.05	463.55	1,508.17	1,897.37
495	168.05	463.55	1,506.66	1,896.03
496	168.05	463.55	1,505.16	1,894.69
497	168.05	463.55	1,503.65	1,893.36
498	168.05	463.55	1,502.15	1,892.03
499	168.05	463.55	1,500.65	1,890.69
Final	168.05	463.55	1,499.15	1,889.36

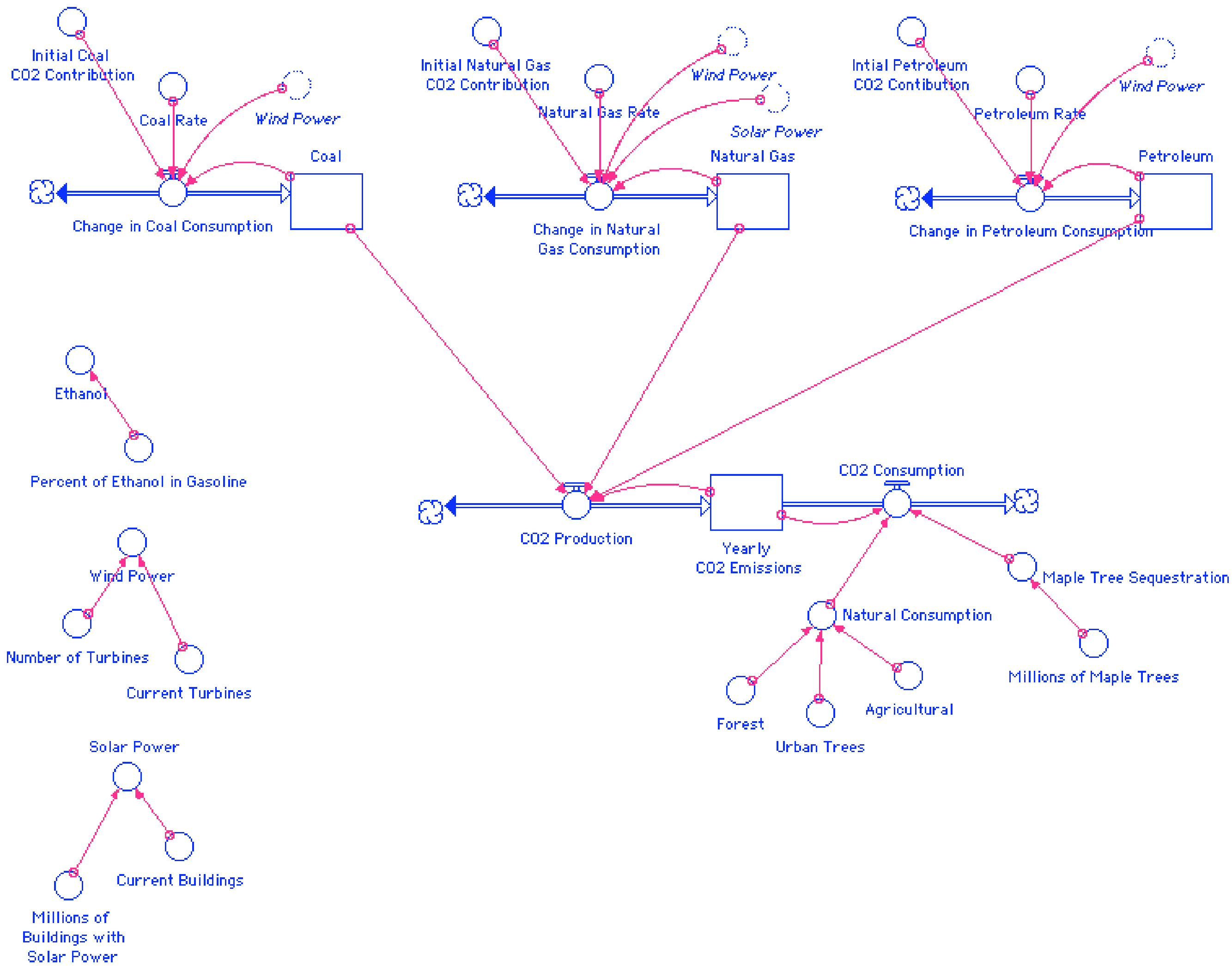
CO2 Emissions (Million Metric Tons): (12)

Appendix C

Graph from our STELLA model



Appendix D
STELLA Model



Appendix E
STELLA Model Equations

```
Coal(t) = Coal(t - dt) + (Change_in_Coal_Consumption) * dt
INIT Coal = Initial_Coal__C02_Contribution-Wind_Power
INFLOWS:
    Change_in_Coal_Consumption = If Coal<.08*Initial_Coal__C02_Contribution Then 0 Else Coal*Coal_Rate-
    (.48981*.92*Wind_Power)*Initial_Coal__C02_Contribution
Natural_Gas(t) = Natural_Gas(t - dt) + (Change_in_Natural_Gas_Consumption) * dt
INIT Natural_Gas = Initial_Natural_Gas_C02_Contribution
INFLOWS:
    Change_in_Natural_Gas_Consumption = If Natural_Gas> .7*Initial_Natural_Gas_C02_Contribution Then
    Natural_Gas*Natural_Gas_Rate - (.20003*.3*Initial_Natural_Gas_C02_Contribution*Wind_Power)-
    (Solar_Power*.623*.75*Initial_Natural_Gas_C02_Contribution) Else If Natural_Gas > .377*
    Initial_Natural_Gas_C02_Contribution Then (Solar_Power*.623*-.75*Initial_Natural_Gas_C02_Contribution)
    Else 0
Petroleum(t) = Petroleum(t - dt) + (Change_in_Petroleum_Consumption) * dt
INIT Petroleum = Intial_Petroleum__C02_Contibution-Ethanol
INFLOWS:
    Change_in_Petroleum_Consumption = If Petroleum < .98*Intial_Petroleum__C02_Contibution Then
    Petroleum_Rate*Petroleum Else Petroleum_Rate*Petroleum-(.01583*.02*Petroleum*Wind_Power)
Yearly__C02_Emissions(t) = Yearly__C02_Emissions(t - dt) + (C02_Production - C02_Consumption) * dt
INIT Yearly__C02_Emissions = 5984
INFLOWS:
    C02_Production = Coal+Natural_Gas+Petroleum-Yearly__C02_Emissions
OUTFLOWS:
    C02_Consumption = Natural_Consumption*Yearly__C02_Emissions-Maple_Tree_Sequestration
Agricultural = 0.008
Coal_Rate = 0
Current_Buildings = 100
Current_Turbines = 983040
Ethanol = (Percent_of_Ethanol_in_Gasoline-.1)*(19.15/44.68)*2583
Forest = .106
Initial_Coal__C02_Contribution = 2154
Initial_Natural_Gas_C02_Contribution = 1234
Intial_Petroleum__C02_Contibution = 2583
Maple_Tree_Sequestration = Millions_of_Maple_Trees*.2041
Millions_of_Maple_Trees = 5
Millions_of__Buildings_with_Solar_Power = 1
Natural_Consumption = Urban_Trees+Forest+Agricultural
Natural_Gas_Rate = 0
Number_of_Turbines = 589824
Percent_of_Ethanol_in_Gasoline = .2
Petroleum_Rate = -.001
Solar_Power = Millions_of__Buildings_with_Solar_Power/Current_Buildings
Urban_Trees = .015
Wind_Power = .01*(Number_of_Turbines/Current_Turbines)
```

Appendix F

Electricity Data

	Coal	Petroleum	Natural Gas	Total % from Fossil Fuels
2006 (thousand megawatt hours)	1,990,926	64,364	813,044	--
% of 2006 Resources	48.9808601%	1.583486317%	20.00254877%	70.9620041%

Appendix G

CO2 Emissions Data

Initial Contributions->	Coal	Petroleum	Natural Gas	Total Fossil Fuels
2007 (mmt of CO2)	2154	2583	1234	5984
Annual Average % Growth	1.1%	-.1%	6.6%	1.6%

Appendix H

Chemistry proves that Ethanol does not emit any CO2.

$$6CO_2 + 6H_2O + light \rightarrow C_6H_{12}O_6 + 6O_2$$
$$C_6H_{12}O_6 \rightarrow 2C_2H_6O + 2CO_2 + heat$$
$$C_2H_6O + 3O_2 \rightarrow 2CO_2 + 3H_2O + heat$$

Therefore, the net CO2 emission is zero.

Appendix I

	Equation	Calculation	Final Price in US Dollars
Total Cost for 589,824 Wind Turbines	Number_of_Turbines_in_US * Cost_Per_Turbine	589,824*1,500,000=	$8.84736 x 10^11
Total Cost for Solar Panels on all Buildings	Number_of_Buildings_in_US * Cost_Per_Solar_System	1,000,000*29,750=	$2.975 x 10^12

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