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Electricity Generation Cost Simulation Model (GenSim)

Thomas E. Drennen, Arnold B. Baker and William Kamery

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ABSTRACT

The Electricity Generation Cost Simulation Model (GenSim) is a user-friendly, high-level dynamic simulation model that calculates electricity production costs for variety of electricity generation technologies, including: pulverized coal, gas combustion turbine, gas combined cycle, nuclear, solar (PV and thermal), and wind. The model allows the user to quickly conduct sensitivity analysis on key variables, including: capital, O&M, and fuel costs; interest rates; construction time; heat rates; and capacity factors. The model also includes consideration of a wide range of externality costs and pollution control options for carbon dioxide, nitrogen oxides, sulfur dioxide, and mercury. Two different data sets are included in the model; one from the U.S. Department of Energy (DOE) and the other from Platt's Research Group. Likely users of this model include executives and staff in the Congress, the Administration and private industry (power plant builders, industrial electricity users and electric utilities). The model seeks to improve understanding of the economic viability of various generating technologies and their emissions trade-offs.

The base case results, using the DOE data, indicate that in the absence of externality costs, or renewable tax credits, pulverized coal and gas combined cycle plants are the least cost alternatives at 3.7 and 3.5 cents/kwhr, respectively. A complete sensitivity analysis on fuel, capital, and construction time shows that these results coal and gas are much more sensitive to assumption about fuel prices than they are to capital costs or construction times. The results also show that making nuclear competitive with coal or gas requires significant reductions in capital costs, to the $1000/kW level, if no other changes are made. For renewables, the results indicate that wind is now competitive with the nuclear option and is only competitive with coal and gas for grid connected applications if one includes the federal production tax credit of 1.8cents/kwhr.

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Introduction

The Electricity Generation Cost Simulation Model (GenSim) is a user-friendly, high-level dynamic simulation model that calculates electricity production costs for variety of electricity generation technologies, including: pulverized coal, gas combustion turbine, gas combined cycle, nuclear, solar (PV and thermal), and wind. The model allows the user to quickly conduct sensitivity analysis on key variables, including: capital, operating and maintenance (O&M), and fuel costs; interest rates; construction time; heat rates; and capacity utilization factors. The model also includes consideration of a wide range of externality costs and pollution control options for carbon dioxide, nitrogen oxides, sulfur dioxide, and mercury. Likely users of this model include executives and staff in the Congress, the Administration and private industry (power plant builders, industrial electricity users and electric utilities). The model seeks to improve understanding of the economic viability of various generating technologies and their emissions trade-offs.

GenSim is written in Powersim Constructor[4], a dynamic simulation-modeling software package. The model's easy to use policy screens allow the user to explore "What-if?" questions, such as:

- Under what conditions can nuclear power compete economically with gas combined cycle plants--does it take $5 per MBtu gas and installed capacity costs of less than $1500 per kW?

- What capital costs (and/or capacity utilization with storage) allow solar PV to compete with pulverized coal facilities?

- What type of tax credits (cents/kwhr) makes wind clearly competitive with fossil-fuel technologies?

- How might adoption of the Bush Clear Sky's policy affect utility power plant investment decisions?

This paper provides an overview of the model structure; base case results for two different data sets; detailed sensitivity analysis on capital costs, fuel prices, and construction times; and externality analysis for the four key pollutants.

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[4] Powersim Constructor is a product of the Powersim Corporation: www.powersim.com

Model Structure and Assumptions

GenSim calculates projected levelized cost of energy (LCOE)[5] for a wide variety of electricity generation technologies: advanced coal, combined cycle natural gas, natural gas combustion, nuclear, wind, solar thermal, and solar photovoltaic (PV).[6] All values are for new plants, equipped with the best available pollution control technologies (BACT).

GenSim includes two user data sets: Department of Energy, Energy Information Administration (DOE, 2001); and 2) Platt's Research and Consulting Group (Platt's, 2002). Table 1 summarizes the key assumptions about each technology for the two data sets.[7] The Platt's data does not include nuclear cost estimates. While GenSim defaults to these assumptions, the user can easily vary the assumptions and view the implications for LCOE. For example, the user can easily explore the impacts of extended project construction time on the projected LCOE or test the economic competitiveness of combined cycle plants at higher projected natural gas costs. Table 2 summarizes the assumed fuel prices for each technology; the DOE estimates are their estimated prices in 2003.

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[5] Sometimes referred to as busbar or production costs.

[6] The costs given in this paper are for newest available technologies for each option.

[7] All dollar figures in paper are in 2002 dollars.

Table 1. Cost and Performance Characteristics for New Generating Plants (2002 $)

	Capital ($/kW)	Fixed O&M ($/kW)	Variable O&M ($/kWhr)	Fuel ($/Mbtu)	Years to Con-struct	Plant Size	Average Capacity Factor (%)	Heat Rate (MBtu/ kWh)
Nuclear								
DOE	1853	57.23	0.00044	0.42	8	600 MW	90.0	10400
Platt's[a]	-	-	-	-	-	600 MW	-	-
Coal								
DOE	1094	24.48	0.00353	1.18	3	400 MW	85.0	9386
Platt's	1202	18.00	0.00180	0.80	3	400 MW	85.0	9100
Gas CC								
DOE	571	15.12	0.00054	3.34	2	400 MW	85.0	6870
Platt's	500	15.00	0.00200	3.25	2	400 MW	85.0	7100
Gas CT								
DOE	472	9.58	0.00010	3.34	2	120 MW	30.0	9020
Platt's	375	5.00	0.04500	3.25	1	120 MW	10.0	10900
Solar PV								
DOE	3468	10.30	0.00000	0.00	2	5 MW	24.6	10280
Platt's	7842	0.00	0.07700	0.00	1	5 MW	25.4	0
Solar Thermal								
DOE	2255	50.05	0.00000	0.00	3	100 MW	24.6	10280
Platt's	2807	20.00	0.00000	0.00	2	100 MW	25.4	0
Wind								
DOE	960	26.70	0.00000	0.00	1	50 MW	28.9	0
Platt's	1000	0.00	0.01000	0.00	1	50 MW	35.0	0

[a]Nuclear cost data not provided for the Platt's data set.

Table 2. Fuel Cost Assumptions (2002 $)

	DOE ($/MBtu)	Platt's ($/MBtu)
Nuclear[b]	0.42	-
Coal	1.18	0.80
Gas	3.34	3.25

[b]Nuclear cost data not provided for the Platt's data set.

LCOE is often used as an economic measure of electricity costs as it allows for comparison of technologies with different capital and operating costs, construction times, and capacity factors. GenSim calculates the LCOE before taxes, as taxes vary across regions and tax status of the producer (public vs. private producer).[8] LCOE calculation is given by:

$$LCOE = \frac{I * CRF}{Q} + \frac{O\&M}{Q} + \frac{E}{Q} \tag{1}$$

where:

	I	= Capital investment, including financing charges (interest rate initially set at 10%)
	CRF	= Capital recovery factor
	Q	= Annual plant output (kwhr)
	O&M	= Fixed and variable O&M
	F	= Fuel costs
	E	= Externality costs.

The capital recovery factor (CRF) is calculated using:

$$CRF = r * \frac{(1+r)^n}{(1+r)^n - 1} \tag{2}$$

where:

	r	= real discount rate (initially set at 10%)
	n	= plant life (initially 30).

Financing costs assume that capital expenditures are uniformally distributed over the time of construction.

GenSim considers externality costs for emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx), carbon dioxide (CO_2), and mercury (Hg). Externality costs are initially set to zero in the model.

Figure 1 shows the GenSim summary screen. Buttons along the left allow the user to change screens. For example, clicking on assumptions allows users to see a summary of the basic model assumptions. The graph along the top illustrates the basic model results using the DOE data. This graph shows projected LCOE at all possible capacity factors (also referred to as capacity utilization). This figure allows one to compare generating technologies either at comparable capacity factors (i.e. nuclear vs. gas combined cycles at 80% capacity factors) as well as technologies operating at different capacity factors (i.e. coal at 85% with solar thermal at 25%). The

[8] Alternative methods of calculating LCOE include detailed tax and depreciation considerations. Alternative methods may be incorporated into GenSim in future versions.

same data is available in tabular form by pressing the "Table" button, Figure 2. The table includes arrows indicating historical capacity factors for each technology, as reported by the Department of Energy (DOE, 2001). The table displays LCOE in 5 percent increments up to 100 percent capacity utilization for illustrative purposes.

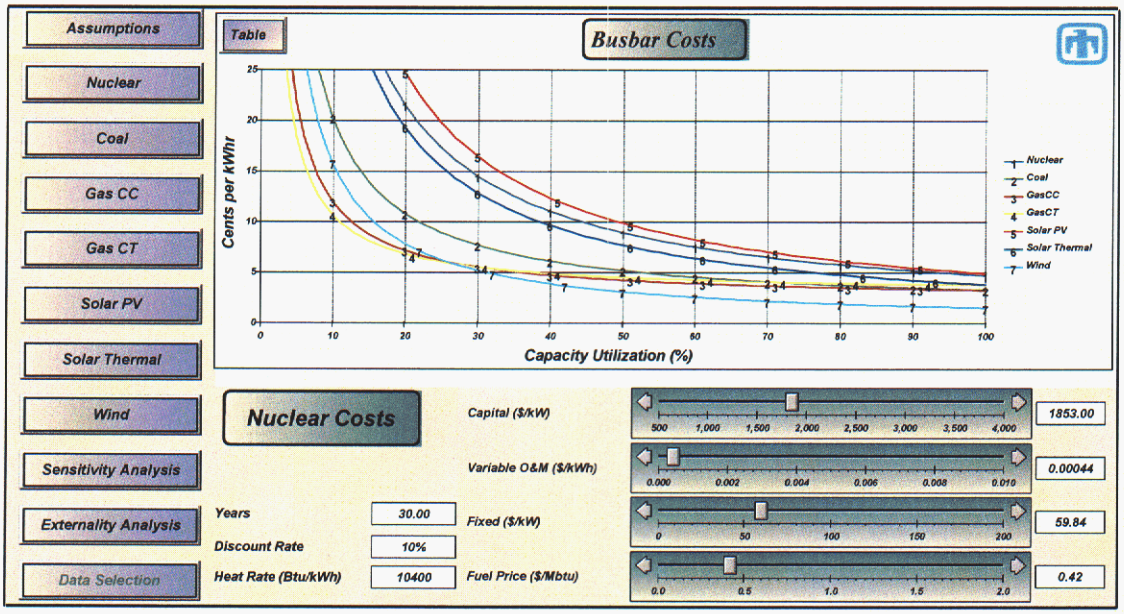

Figure 1 . GenSim's Summary Screen Showing Busbar Production Costs for all Possible Capacity Factors

Busbar Costs (cents/kwhr) Graph

Cap Factor (%)	Nuclear	Coal	GasCC	GasCT	Solar PV	Solar Thermal	Wind
5	84.81	39.21	21.77	18.35	99.36	77.71	31.67
10	42.70	20.33	12.06	10.69	49.68	38.85	15.84
15	28.66	14.04	8.82	8.13	33.12	25.90	10.56
20	21.64	10.90	7.20	6.85	24.84	19.43	7.92
25	17.43	9.01	6.23	6.09	⇨ 19.87	⇨ 15.54	6.33
30	14.62	7.75	5.59	⇨ 5.58	16.56	12.95	⇨ 5.28
35	12.61	6.85	5.12	5.21	14.19	11.10	4.52
40	11.11	6.18	4.78	4.94	12.42	9.71	3.96
45	9.94	5.65	4.51	4.73	11.04	8.63	3.52
50	9.00	5.24	4.29	4.56	9.94	7.77	3.17
55	8.24	4.89	4.11	4.42	9.03	7.06	2.88
60	7.60	4.61	3.97	4.30	8.28	6.48	2.64
65	7.06	4.36	3.84	4.20	7.64	5.98	2.44
70	6.60	4.16	3.74	4.12	7.10	5.55	2.26
75	6.20	3.98	3.64	4.04	6.62	5.18	2.11
80	5.85	3.82	3.56	3.98	6.21	4.86	1.98
85	5.54	⇨ 3.68	⇨ 3.49	3.92	5.84	4.57	1.86
90	⇨ 5.26	3.56	3.43	3.87	5.52	4.32	1.76
95	5.01	3.45	3.37	3.83	5.23	4.09	1.67
100	4.79	3.35	3.32	3.79	4.97	3.89	1.58

Figure 2. Tabular Results for DOE Data

(Arrows indicate historical capacity factors for each technology)

The base case results using each data set are summarized in Table 3. These results suggest that, at historical capacity factors, and in the absence of externality costs and renewable tax credits, pulverized coal and gas combined cycle plants are the least cost alternatives at 3.7 and 3.5 cents/kwhr, respectively. The results also indicate some fundamental differences in the two data sets. Platt's assumes that any new gas combustion turbine (CT) facilities will serve solely as peaking units, with capacity factors around 10%, whereas historical data (DOE, 2001) indicates an average capacity factor close to 30% for these plants.

The largest difference in the base case results is for the case of solar photovoltaic. Estimated costs using DOE and Platt's data are 20 and 60 cents/kWhr, respectively. This major difference is due to the assumed capital costs: $3468 $/kW for the DOE data, compared to 7842 $/kW for the Platt's data.

In the current version of GenSim, the variable and fixed O&M estimates are based on the default capacity factors in Table 1, as O&M data for other capacity factors were not available. These O&M estimates may not be valid at different rates of capacity utilization. The actual O&M costs for gas CT facilities might be expected to be quite different operating at 50 or 60% capacity utilization on a sustained basis, than at 30%.

For example, using the default O&M assumptions for the whole range of possible capacity factors for gas CT facilities indicate that they can still be competitive with gas CC plants at higher capacity factors. However, this conclusion is not valid as the O&M costs are based on estimated capacity factors of just 30% in the DOE data.

Table 3. Comparison of Base Case Results Using DOE and Platt's Data (2002 $)

	DOE ($/kwhr)	Platt's ($/kwhr)
Nuclear	0.053	-
Coal	0.037	0.036
Gas CC	0.035	0.037
Gas CT	0.055	0.146
Solar PV	0.199	0.607
Solar Thermal	0.155	0.201
Wind	0.055	0.058

Sensitivity Analysis

GenSim's structure makes sensitivity analysis easy. A representative screen is shown in Figure 3. This screen allows the user to compare LCOE costs at either comparable capacity factors (i.e. all at 50%), or at default or user defined capacity factors (i.e., solar PV at 20% with nuclear at 90%). LCOE estimates are displayed in the top center. These estimates change as the user changes key assumptions using either the sliders or number boxes on the bottom half of the screen. For example, changing the assumed capital costs for solar PV from 3,468 $/kW to 1,500 $/kW reduces the LCOE from 19.9 cents/kwhr to 8.9 cents/kwhr.

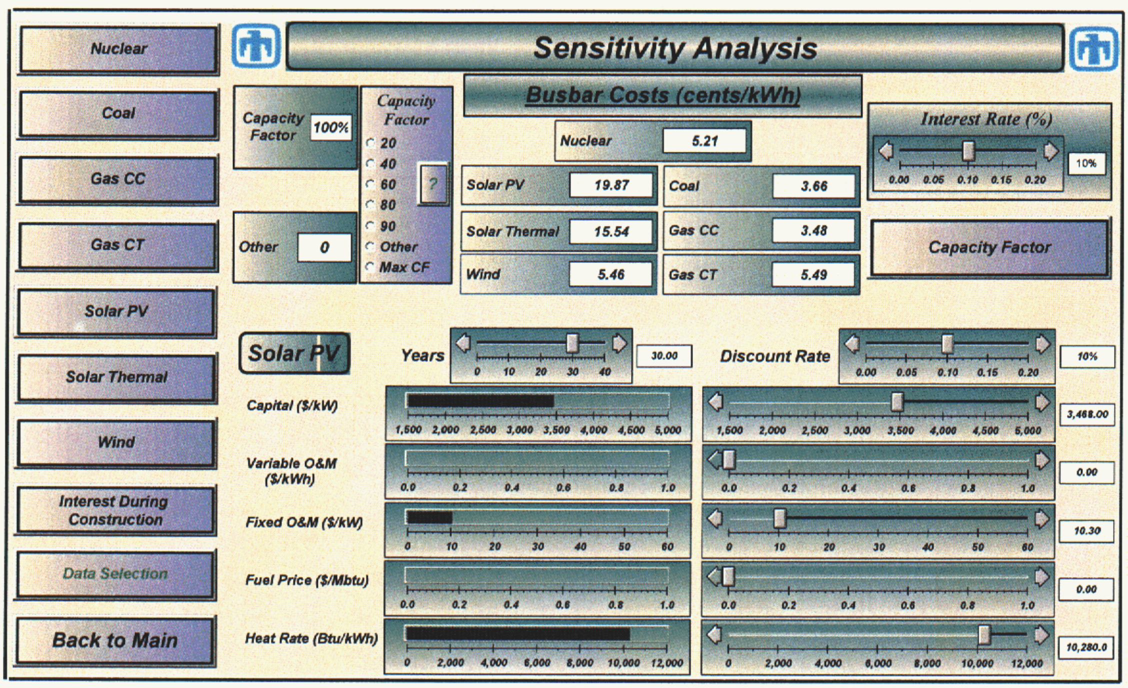

Figure 3. Main Sensitivity Analysis Screen

Another key assumption driving LCOE estimates is construction time and financing rates, Figure 4. As with the other screens, the graph on the top is dynamic and changes as the user varies construction times, capital costs, or financing rates. For example, the default setting for nuclear plant construction time is 8 years. By reducing construction time from 8 to 5 years, the LCOE falls from 5.26 to 4.69 cents/kwhr. This difference is due to the effects on financing as the total financed costs drop from 2914 $/kW to 2489 $/kW. As a further example, reducing the initial capital costs from 1853 $/kW to $1200 $/kW reduces LCOE further to 3.88 cents/kwhr. Construction time is clearly a key factor in the future financial success of nuclear power. If delays in construction lead to an extended construction period of 12 years, LCOE costs increase to 6.23 cents/kwhr, assuming a linear borrowing pattern and the default capital costs.

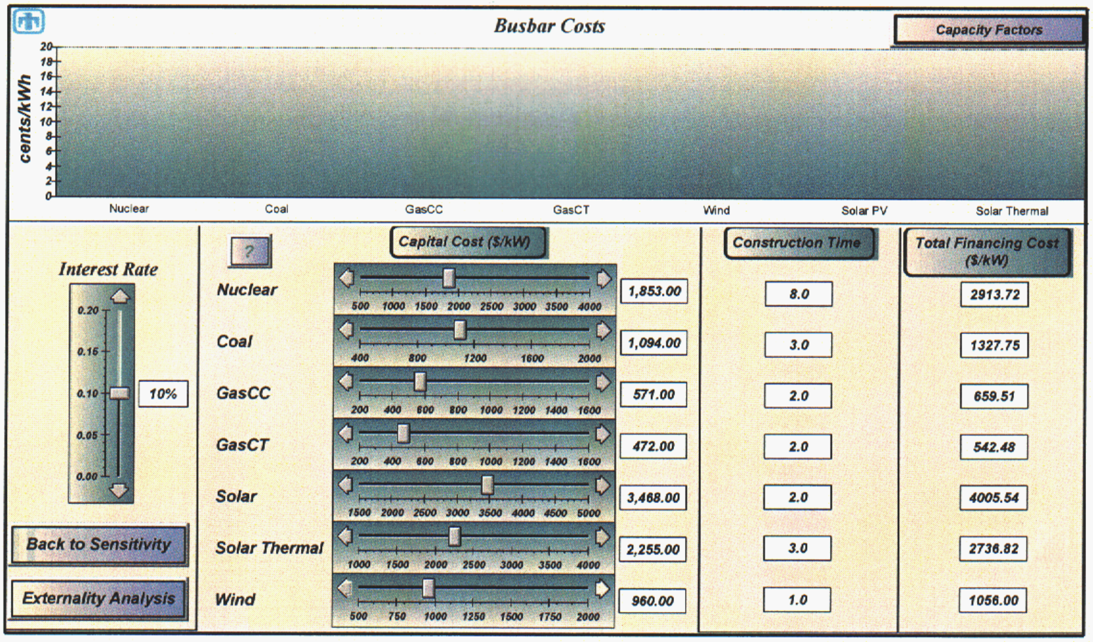

Figure 4. Sensitivity Analysis Screen for Construction Time and Financing

The sensitivity screens are also ideal for answering "what-if?" type questions. For example, using the default DOE assumptions, gas combined cycle plants have a slight economic advantage over advanced coal plants at historical capacity factors (3.48 vs. 3.66 cents/kwhr). A typical type of "what-if" type question might be: at what real natural gas price over the life of the plant does the coal option become cheaper? The answer, using the sensitivity screen, is that the breakeven natural gas price is 3.60 $/MBtu, 0.26 $/MBtu higher than the default assumption. This has important implications given the volatility in natural gas prices. Using the same process, the breakeven natural gas price at which nuclear becomes competitive with gas is 5.93 $/MBtu.

The following three sections provide a more detailed sensitivity analyses, derived from GenSim. In the first section, production costs for various technologies are plotted against specific fuel prices. This type of analysis is useful for determining fuel price breakeven costs, such as the coal price at which nuclear is cost competitive. The next section determines capital cost breakeven points, such as at what capital costs nuclear becomes competitive with coal, gas, or wind. The third section discusses the results of sensitivity analysis for nuclear plant construction time. All examples use the DOE's data set; comparable analysis using the Platt's data set is included in Appendix A.

Fuel Price Sensitivity Results

Figure 5 illustrates a real dollar, life of plant breakeven analysis for coal, nuclear, and wind technologies against natural gas prices. The breakeven natural gas fuel price with coal, nuclear, and wind are (in $/MBtu) 3.60, 5.93, and 6.25, respectively. For comparison, the assumed DOE natural gas fuel price of 3.34 $/MBtu. An approximate 0.26 $/MBtu increase in the assumed price of natural gas makes pulverized coal facilities the least cost option. Given the relative volatility of natural gas prices[9] compared to coal prices, this result suggests that while LCOE for natural gas plants are lower, the results are highly dependent on fuel prices. Compared to fuel prices,

Figure 5 shows that the results are not particularly sensitive to natural gas capital costs. A 10% change in capital cost in either direction only change these results by 0.09 $/MBtu.

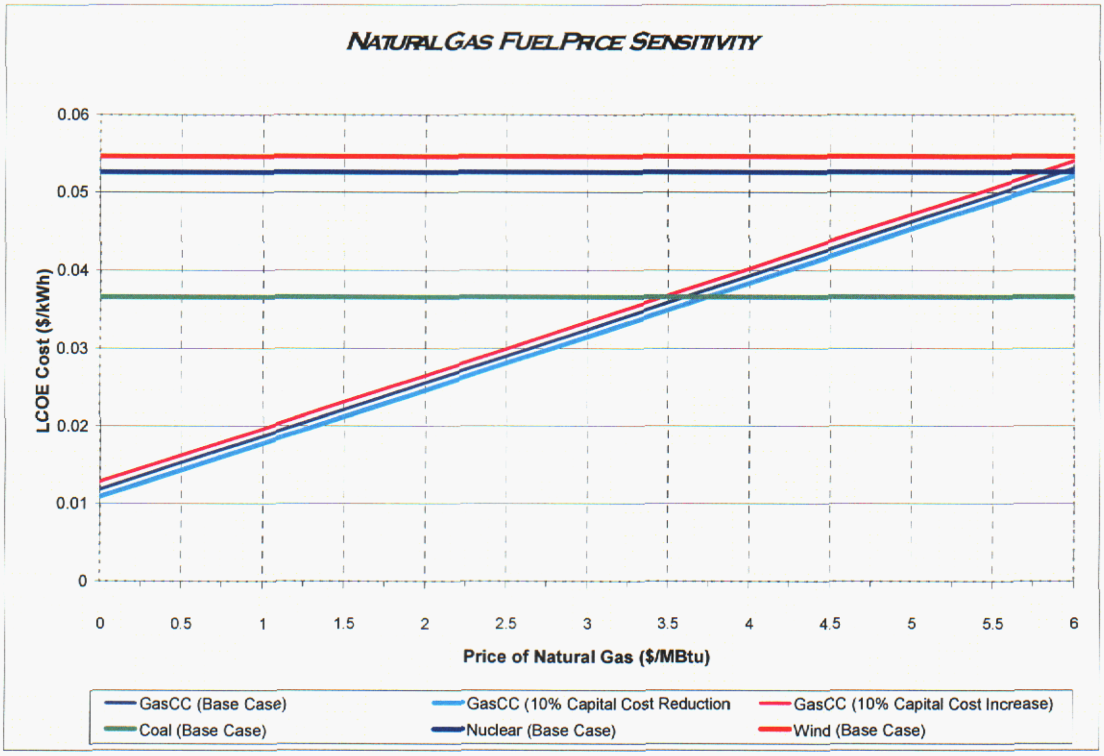

Figure 5. Natural Gas Fuel Price Sensitivity Analysis

[9] The delivered costs of natural gas to electric utility plants averaged 4.49 $/MBtu, 4.30 $/MBtu, and 2.57 $/MBtu in 2002, 2001, and 2000, respectively. Natural gas prices peaked at a high of 9.21 $/MBtu in January 2001. For the same years (2002-2000), coal prices averaged: 1.23 $/MBtu, 1.20 $/MBtu, and 121.6 $/MBtu (DOE, 2002).

Figure 6 illustrates a similar analysis for advanced coal technology. This analysis shows that breakeven fuel prices that make coal competitive with gas combined cycle, nuclear, and wind technologies are 0.99 \$/MBtu, 2.89 \$/MBtu, and 3.10 \$/MBtu, respectively. The default DOE coal price in GenSim is 1.18 \$/MBtu. As with the previous example, these results indicate that coal's competitiveness with natural gas is very dependent on assumed fuel prices. These results are not very sensitive to changes in capital costs; a 10% difference in capital costs changes these results by 0.19 \$/MBtu.

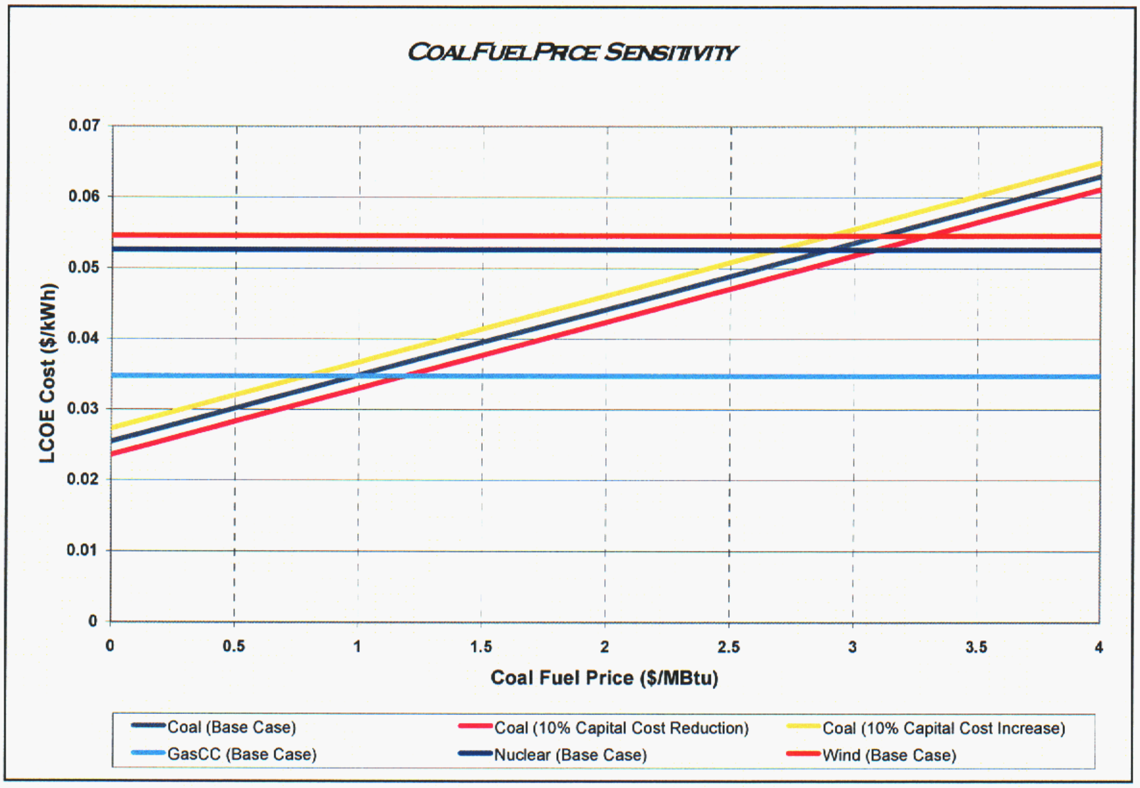

Figure 6. Coal Fuel Price Sensitivity Analysis

Figure 7 illustrates the results of the nuclear fuel price sensitivity analysis. This analysis shows that nuclear is only competitive with wind and higher priced technologies, such as solar thermal and solar PV (not shown). There is no nuclear fuel price for which nuclear becomes the low cost alternative. This result reflects the low total fuel cost for nuclear power relative to the capital and O&M costs. The breakeven nuclear fuel price with wind technologies is 0.61 $/MBtu. For comparison, the DOE default fuel price assumption is 0.42 $/MBtu. A 10% difference in nuclear capital costs changes these results by 0.38 $/MBtu.

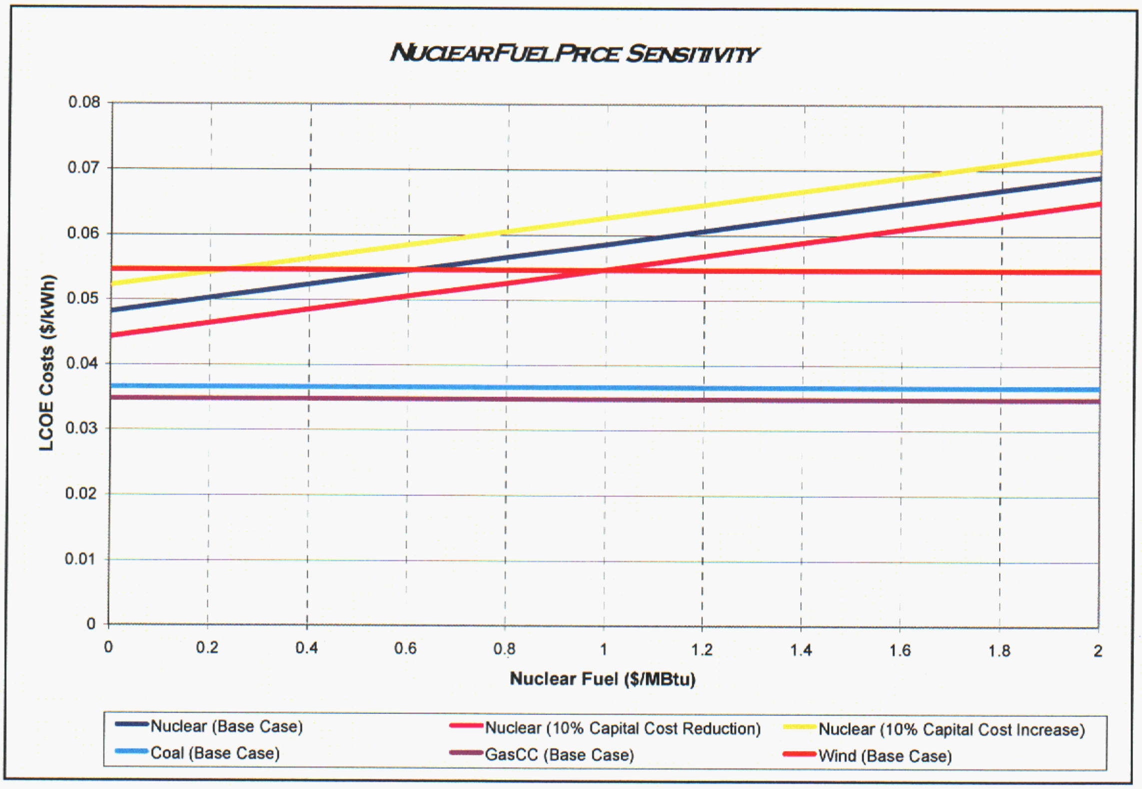

Figure 7. Nuclear Fuel Price Sensitivity Analysis

Capital Costs Sensitivity Analysis

Figures 8-12 illustrate breakeven points based on varying capital costs.

Figure 8 shows the results for gas combined cycle plants. The default DOE gas CC capital cost is 571 $/kW. The capital cost at which advanced coal technologies become the cheaper option is 689 $/kW. Gas combined cycle plants are competitive with wind, solar, and nuclear technologies for gas CC capital costs below 1654 $/kW.

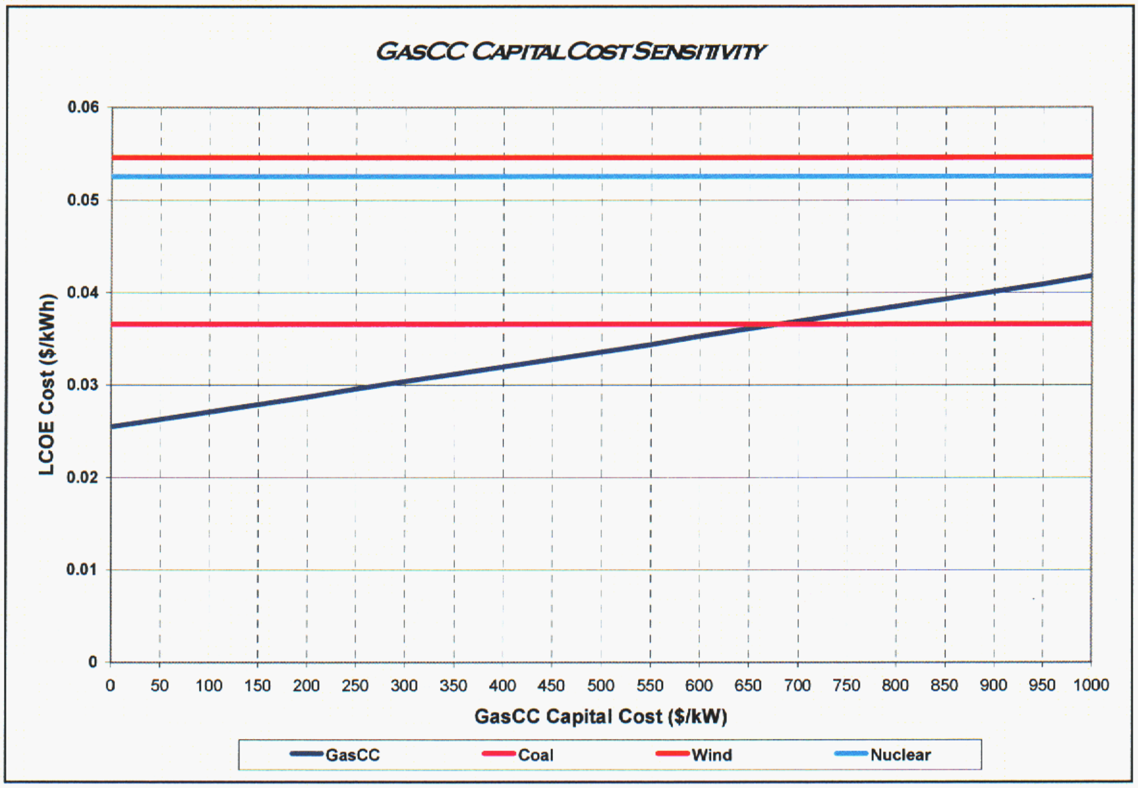

Figure 8. Gas Combined Cycle Capital Cost Sensitivity

Advanced coal generating facilities are cost competitive with wind, solar, and nuclear at any nuclear capital cost below 2038 $/kW, Figure 9. The point at which gas CC facilities become cost competitive is at 983 $/kW. The default DOE capital cost assumption for advanced coal facilities is 1094 $/kW.

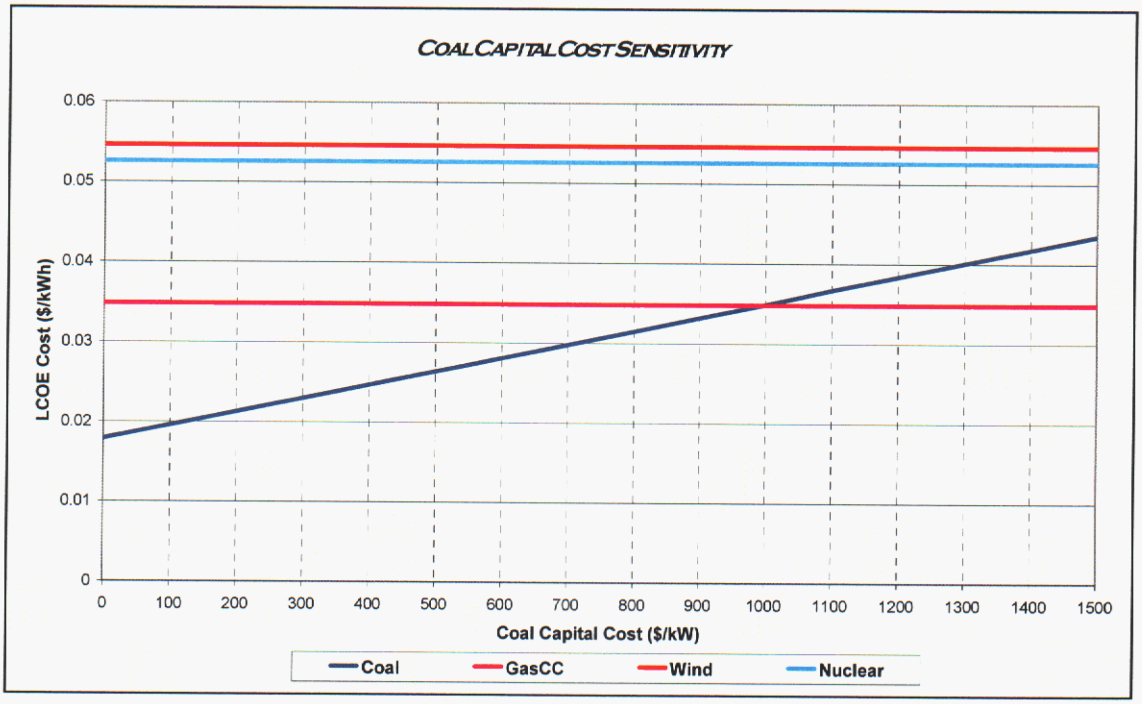

Figure 9. Advanced Coal Capital Costs Sensitivity

The nuclear option becomes cost competitive with wind, coal, and gas CC technologies at 1947 $/kW, 1093 $/kW, and 1007 $/kW, Figure 10. The default DOE capital cost assumption for nuclear is 1853 $/kW. This means that nuclear capital costs would have to fall below $1100/kW before it could compete with either coal or gas combined cycle plants, holding all else constant.

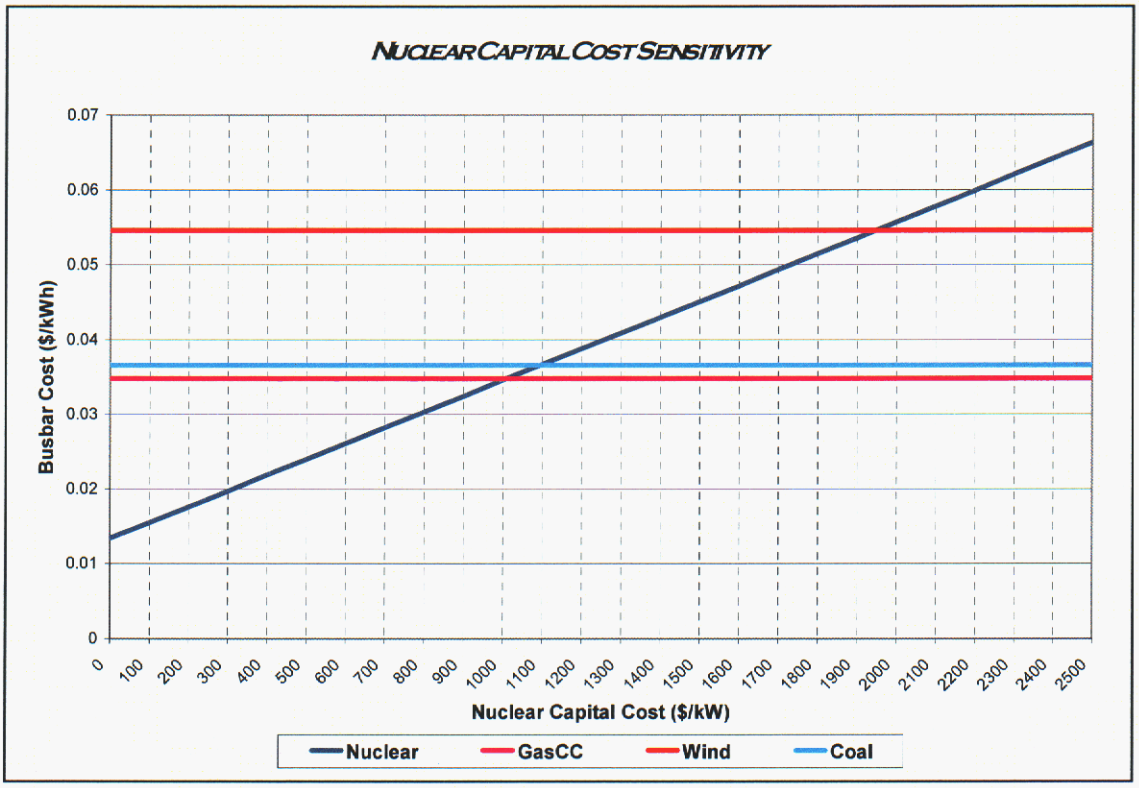

Figure 10. Nuclear Capital Cost Sensitivity Analysis

Grid connected wind generated electricity becomes cost competitive with nuclear, coal, and gas CC at wind capital costs of 918 $/kW, 587 $/KW, 526 $/kW, respectively, Figure 11. For comparison, the default DOE wind capital cost assumption is 960 $/kWhr. Figure 11 also illustrates the impact on wind economics of a 1.8 cent per kWhr production tax credit (PTC).[10] This PTC greatly improves the economic feasibility of wind systems. The gas combined cycle capital cost at which nuclear, coal, and gas CC technologies are competitive increase to 1312, 968, and 920 $/kW, respectively. This is comparable to reducing wind's capital costs by over 400 $/kW. This result also implies that wind technologies on the grid are currently competitive with gas CC and coal plants, even with its low average capacity factor. Evidence of this cost competitiveness is apparent from the number of recently constructed or proposed wind projects in the U.S.[11]

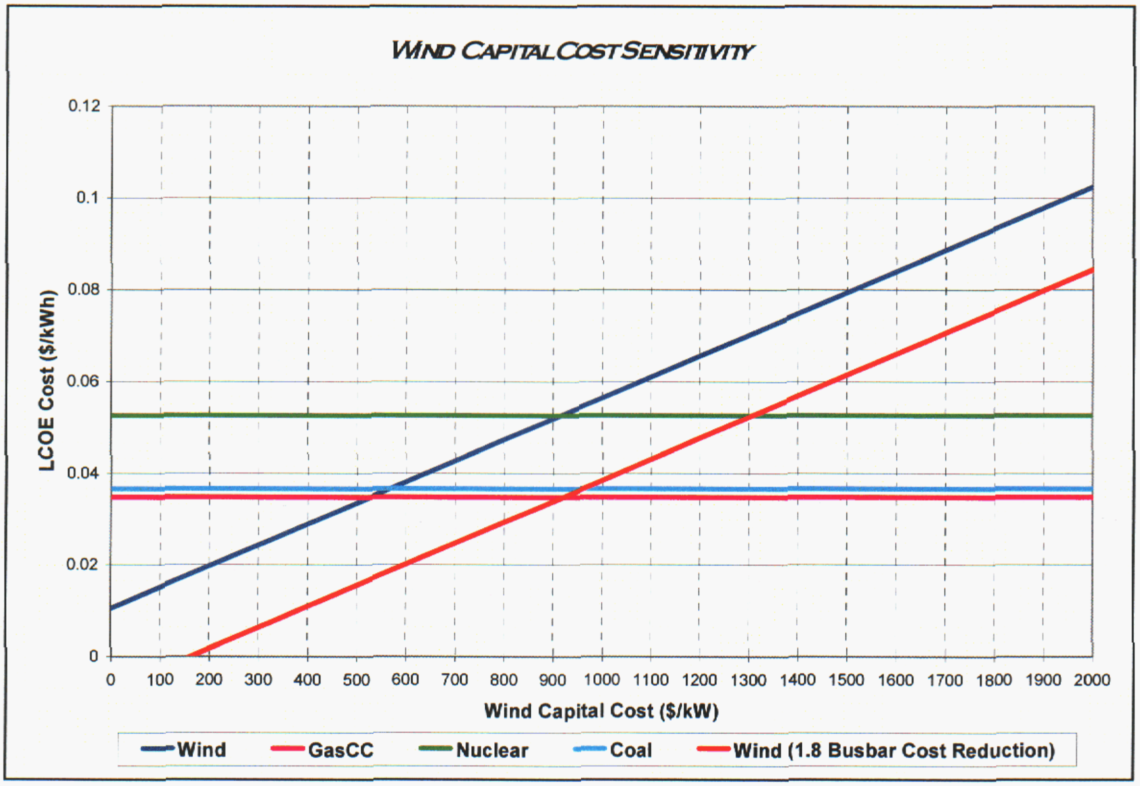

Figure 11. Wind Capital Cost Sensitivity Analysis

[10] The Energy Policy Act of 1992 established a 1.5 cent per kWhr production tax credit for wind-powered electricity, adjusted annually for inflation. This amounts to 1.8 cents per kWhr in 2002.
[11] The American Wind Energy Association reports that 1,696 MW of new wind capacity was added in 2001. This number dropped off considerably in 2002 due to uncertainty in extension of the PTC, but is expected to top 2,000 MW in 2003 (AWEA, 2002).

Construction Time Sensitivity

Figure 12 illustrates the overall sensitivity of nuclear economics to construction time. These results assume constant capital expenditures over the life of the project. Even considering construction time, nuclear cannot compete with coal or gas CC facilities. If nuclear plant construction is delayed beyond the estimated 8 years, then wind technologies become cost competitive with nuclear. Varying the assumed nuclear capital costs by 10% moves the breakeven point for nuclear by 2 years compared to wind technologies, but does not make nuclear competitive with gas or coal technologies. According to these results, the only way to make nuclear competitive, even with a reduced construction cycle, is by drastically reducing capital costs, or if non-nuclear fuel or externality costs increased significantly.

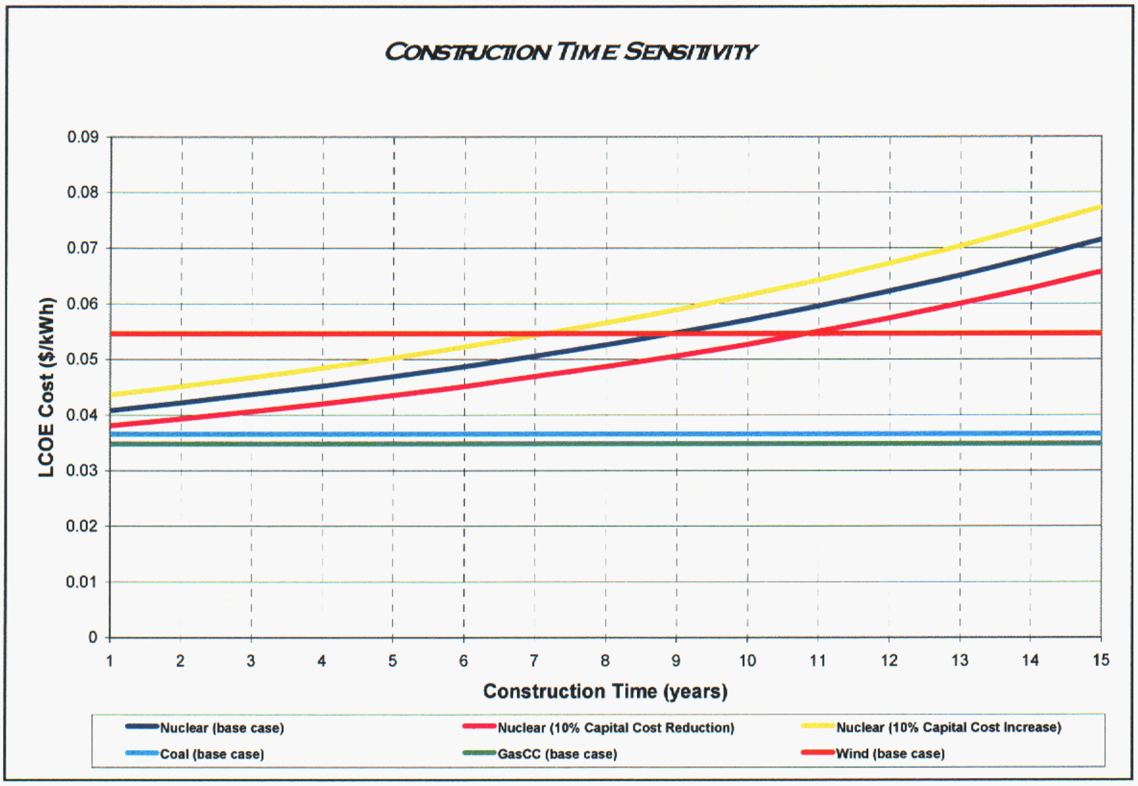

Figure 12. Nuclear Construction Time Sensitivity Analysis

Externality Analysis

GenSim includes an extensive externality component that allows the user to consider the costs of externalities on LCOE estimates. Initially, GenSim assumes that the prices for all four externalities, CO_2, NOx, SO_2, and mercury (Hg) are set at zero. The capital costs for each generating option includes capital costs associated with the best available control technologies for both SO_2 and NOx. CO_2 and mercury emission technology costs are not included in the default capital costs. Using this externality component, the user can explore the effect of externality costs and/or different pollution control technologies on the estimates of LCOE.

Figure 13 shows the externality summary screen. From this screen, the user can explore the effects of pollution taxes for the default pollution control technologies, Table 4. Additional options, including technology choices for pollution reduction, are accessed by clicking one of the choices on the left of the screen. These options are summarized in Appendix B.

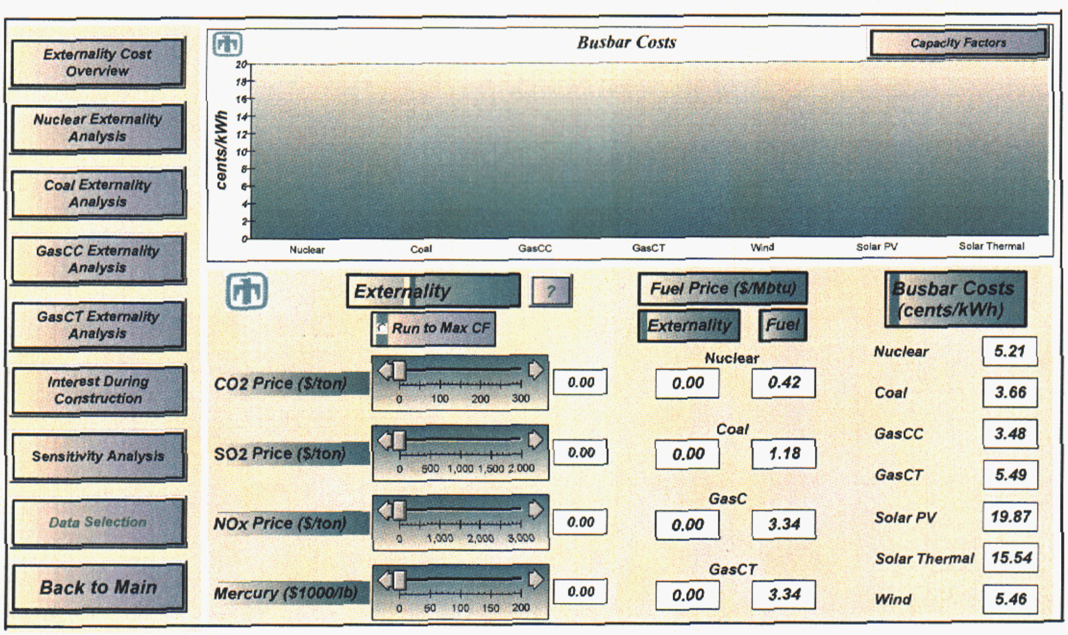

Figure 13. Main Externality Analysis Screen

Table 4. Default Pollution Control Technology Assumptions

Plant Type	Pollutant	Default Technology	% of Pollutant Removed
Coal	SO_2	Limestone Forced Oxidation (LSFO)	95
	NOx	Low NOx Burner with Overfire Air (LNB with OFA) and Selective Catalytic Reduction (SCR)	95
Gas CC	NOx	Selective Catalytic Reduction (SCR)	80
Gas CT	NOx	Selective Catalytic Reduction (SCR)	80

As an example, Figure 14 illustrates the potential impact of including externality costs for CO_2, SO_2, and NOx. Both SO_2 and NOx are currently regulated under the Clean Air Act, which requires emission allowances for these pollutants. CO_2 and mercury emissions are not currently regulated, although there are proposals to regulate them.

This example assumes CO_2 prices of $100/ton, SO_2 prices of $150/ton, and NOx prices of $1500/ton. This increases the estimated LCOE of coal from 3.50 to 5.96 cents/kwhr. The estimates for gas CC increase from 3.5 to 4.5 cents/kwhr. This increased cost for coal and gas CC is equivalent to increased fuel costs of 2.62 $/MBtu and 1.53 $/MBtu, respectively, also shown in Figure 14. Coal is affected more than gas as natural gas does not contain sulfur and releases less CO_2 per unit of energy consumed.

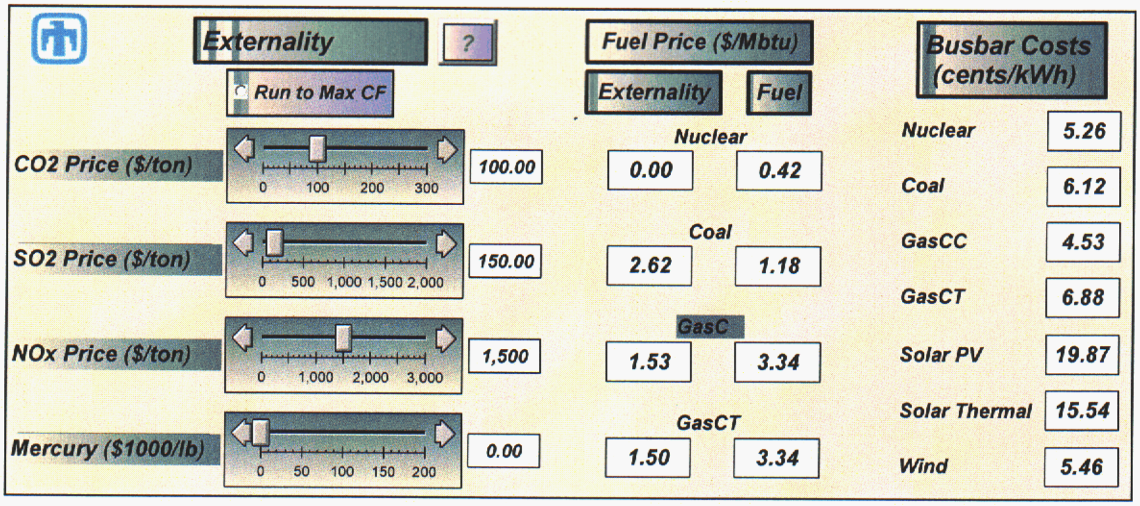

Figure 14. Three Pollutant Externality Example

Consider the effect of just CO_2. A 100 $/ton tax on carbon emissions would increase electricity production costs from coal by 2.41cents/kwhr, from 3.66 cents/kwhr to 6.07 cents/kwhr. For a gas CC plant, LCOE costs increase by 0.97cents/kwhr, from 3.48 cents/kwhr to 4.45 cents/kwhr. The relative small change over the three pollutant example reflects the assumption that each new plant already includes SO_2 and NOx pollution control technologies.

For the nuclear option, the externality analysis is limited to consideration of dealing with the spent fuel. Currently, U.S. reactors are charged a flat fee of 1 mill/kwhr produced electricity. This charge is expected to cover the cost of the enventual entombment of this material in a central location, such as at Yucca Mountain, Nevada. GenSim allows the user to explore the impact of changing this assumption about spent fuel storage costs, or could add other externalities as well through increased storage costs. The base case assumes a 1 mill/kwhr charge.
GenSim also allows the user to consider the overall costs of pollution control. Without pollution control technologies included in the analysis, LCOE estimates for coal and natural gas decrease 0.48 and 0.03 cents/kwhr for coal and gas CC plants, respectively. These are the implied costs of the required pollution control devices.

In addition to the type of externality analysis illustrated here, GenSim allows users to conduct a wide range of more detailed externality analyses. The various options by technology and pollutant are summarized in Appendix B.

Conclusions

The Electricity Generation Cost Simulation Model (GenSim) is a user-friendly, high-level dynamic simulation model that calculates electricity production costs over a wide range of plant and economic assumptions including capital, O&M, and fuel costs, construction times, and interest and discount rates. These electrical production costs are calculated for a variety of electricity generation technologies, including: pulverized coal, gas combustion turbine, gas combined cycle, nuclear, solar (PV and thermal), and wind.

The model permits a wide range of sensitivity and externality analysis. Its ease of use and intuitive, graphical display will give policy makers, energy executives, and their staffs a better understanding of the economic viability and trade offs among generating technologies and their emissions trade-offs.

References

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Appendix A. Sensitivity Analysis Using Platt's Data

This appendix replicates the sensitivity analysis contained in the main section of this report using the Platt's data. Nuclear related analysis is not possible as the Platt's data does not include nuclear data.

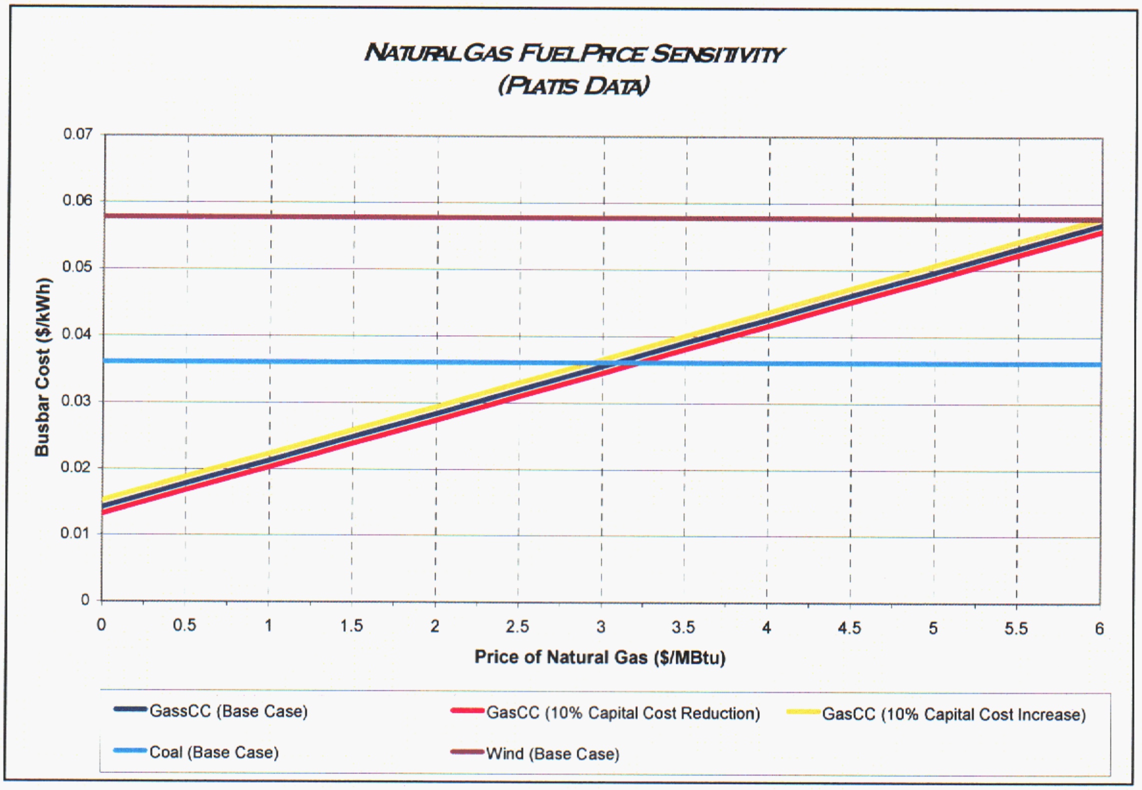

Figure A1. Sensitivity Analysis for Natural Gas Fuel Prices Using Platt's Data

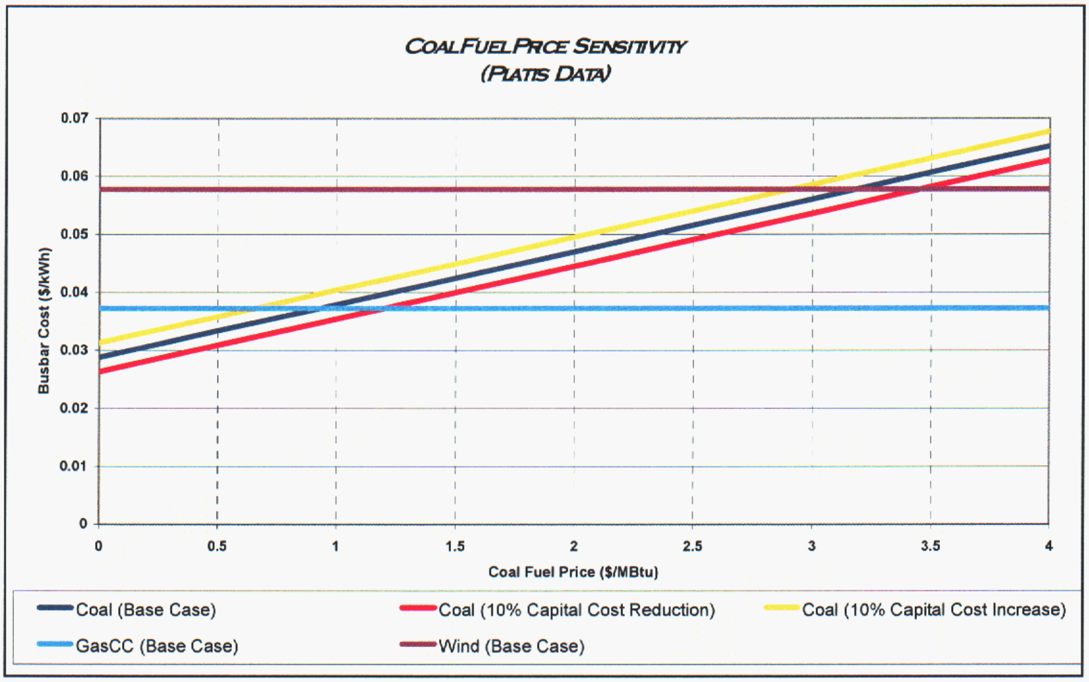

Figure A2. Sensitivity Analysis for Coal Fuel Prices Using Platt's Data

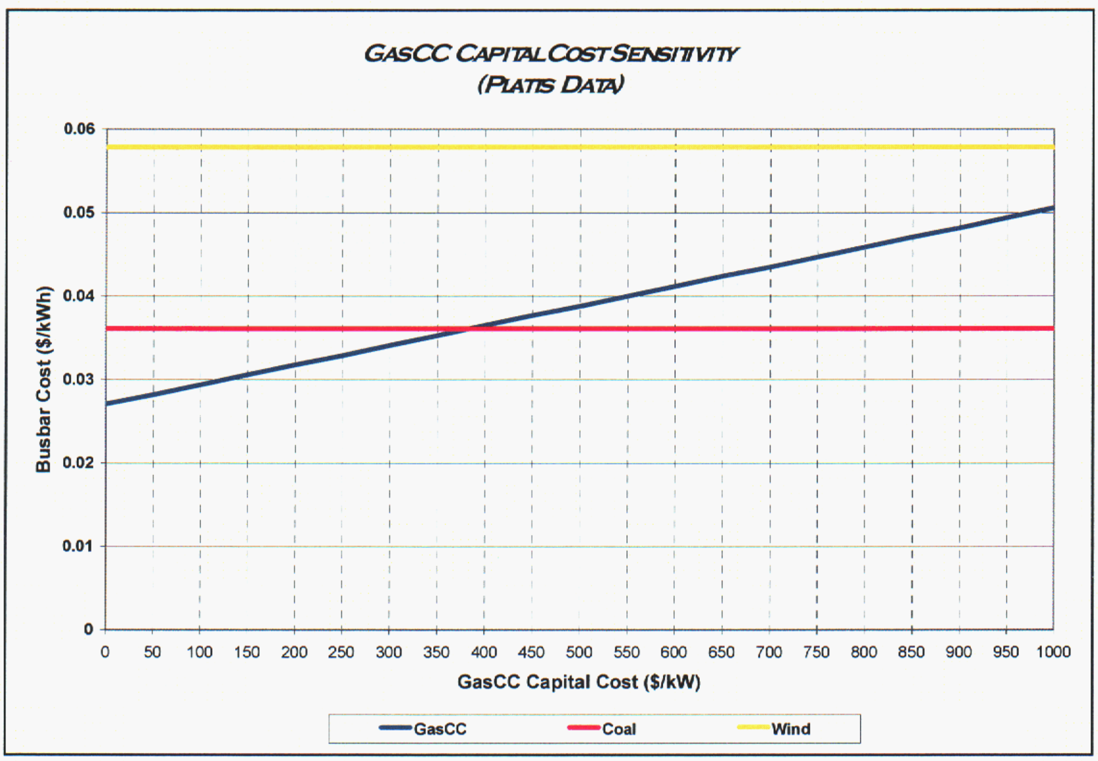

Figure A3. Sensitivity Analysis of Gas CC Capital Costs Using Platt's Data

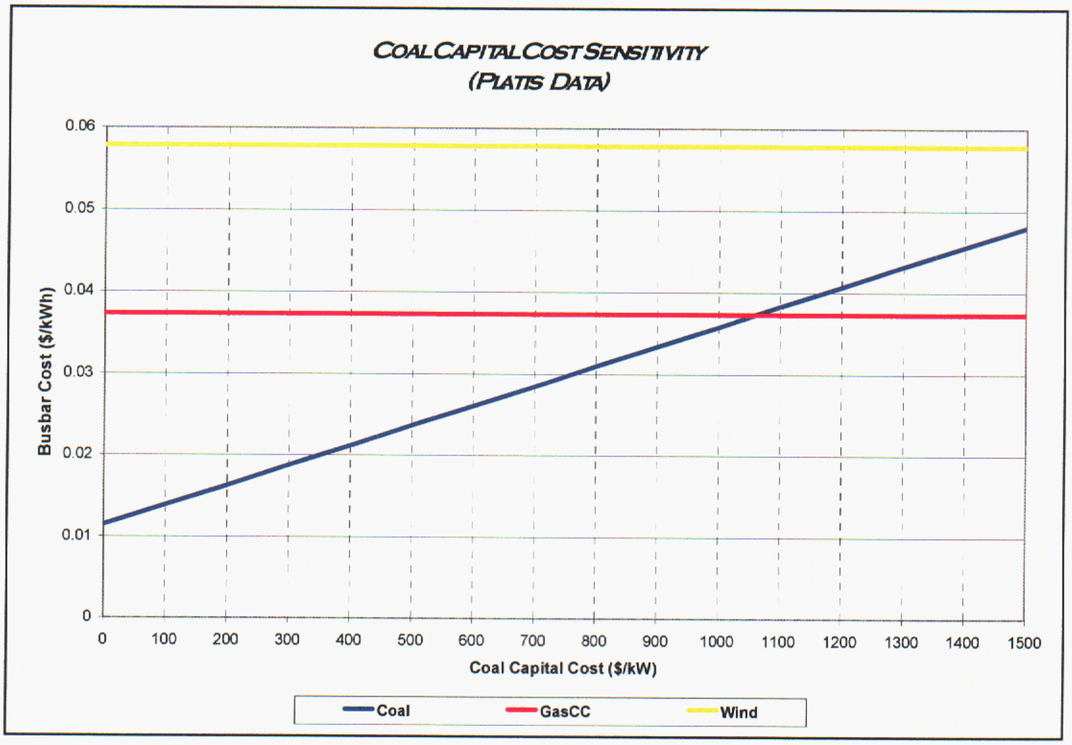

Figure A4. Sensitivity Analysis on Coal Capital Costs Using Platt's Data

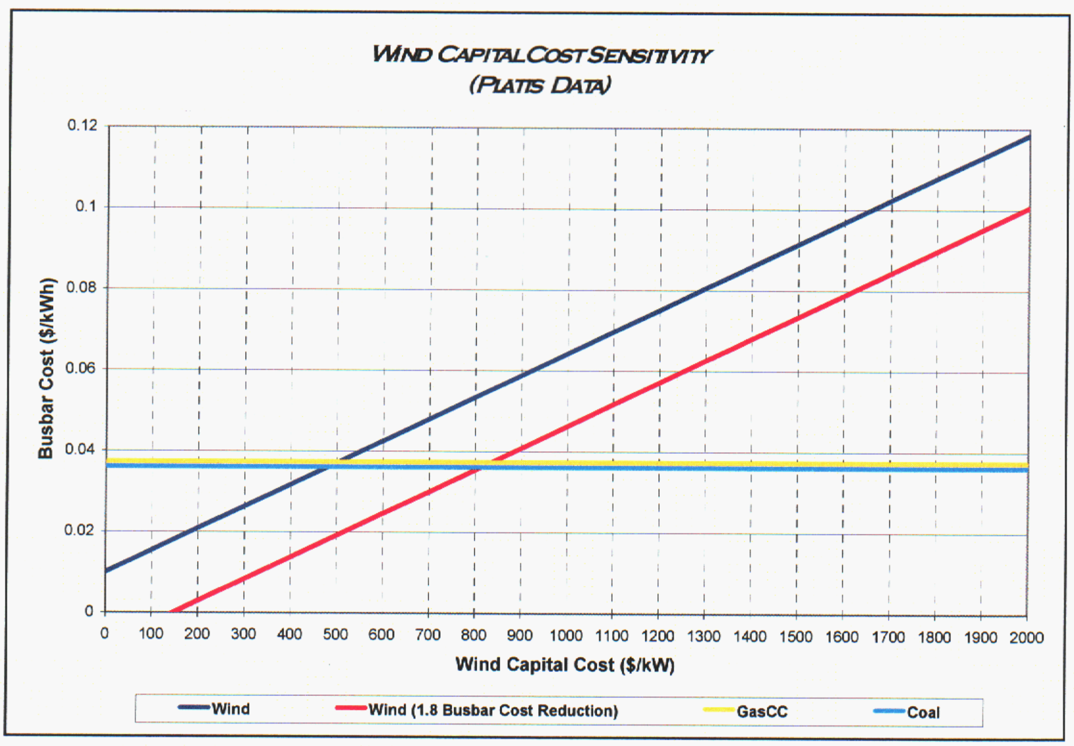

Figure A5. Sensitivity Analysis on Wind Capital Costs Using Platt's Data

Appendix B. Detailed Externality Assumptions Available in GenSim

Table B1. SO_2 Removal Options from Coal-fired Plants and Resulting Emissions[1]

Technology	Pollutant Removed (%)	Pollutant remaining (lbs/MBtu)
Limestone Forced Oxidation	95	0.18
Magnesium Enhanced Lime Slurry	96	0.15
Lime Spray Drying	90	0.36
No Controls	0	3.60

[1]Assumes 2% sulfur content and coal heat content of 11,000 Btu/lb. User may change these assumptions.

Table B2. NOx Removal Technology Options for Coal-fired Plants and Resultant Pollution Reduction and Remaining Emissions

Boiler	Technology	Pollutant Removed (%)	Pollutant Remaining (lbs/MBtu)
Dry Bottom Wall Fired	*Low NOx burner, w/o overfired air and:*		
	Selective catalytic reduction	96	.05
	Non-selected catalytic reduction	76	.19
	Natural Gas Reburn	81	.15
	No post combustion control	63	.30
	Low NOx burner, with overfired air and:		
	Selective catalytic reduction	95	.05
	Non-selected catalytic reduction	67	.26
	Natural Gas Reburn	75	.20
	No post combustion control	50	.40
Tangentially Fired	*LNC1*		
	Selective catalytic reduction	95	.05
	Non-selected catalytic reduction	66	.27
	Natural Gas Reburn	74	.21
	No post combustion control	47	.42
	LNC2		
	Selective catalytic reduction	95	.05
	Non-selected catalytic reduction	69	.25
	Natural Gas Reburn	76	.19
	No post combustion control	52	.38
	LNC3		
	Selective catalytic reduction	96	.05
	Non-selected catalytic reduction	72	.22
	Natural Gas Reburn	79	.17
	No post combustion control	57	.34

Boiler	Technology	Pollutant Removed (%)	Pollutant Remaining (lbs/MBtu)
Cell Burner	Selective catalytic reduction	96	.05
	Non-selected catalytic reduction	74	.21
	Natural Gas Reburn	80	.16
	No post combustion control	60	.32
Cyclone	Selective catalytic reduction	95	.05
	Non-selected catalytic reduction	68	.26
	Natural Gas Reburn	75	.20
	No post combustion control	50	.40
Wet Bottom	Selective catalytic reduction	95	.05
	Non-selected catalytic reduction	68	.26
	Natural Gas Reburn	75	.20
	No post combustion control	50	.40
Vertically Fired	Selective catalytic reduction	94	.05
	Non-selected catalytic reduction	61	.31
	Natural Gas Reburn	70	.24
	No post combustion control	40	.48

Table B3. NOx Removal Technologies for Gas Combined Cycle and Gas Combustion Turbine Facilities

Technology	Pollutant Removed (%)	Pollutant Remaining (lbs/MBtu)
Selective Catalytic Reduction	80	.16
Non-Selected Catalytic Reduction	50	.40
No Controls	0	.80

Appendix C. Multiple Data Switch

William Kamery of Hobart and William Smith Colleges developed the Multiple Data Switch (MDS). This data switch, developed in Powersim Constructor, allows a dynamic model to contain multiple and editable data sets. Currently, the common way to have multiple values assigned to variables is done by using a Powersim Constructor notation known as a switch. A reoccurring problem with this methodology is that a variable affecting output cannot have external input (i.e.-edited via a slider or number box). This has been solved by the MDS. GenSim will be used as an example to explain the construction of an MDS. The finished design of an MDS will look like Figure C1, where each button represents two separate sets of data, Department of Energy data and Platt's data. Figure C1 is comprised of these two buttons oriented on top of one another for display purpose.

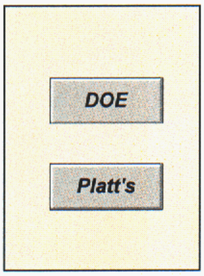

Figure C1. MDS Buttons in Display Mode

Figure C2 and Figure C3 are the data set definition windows for the Department of Energy and Platt's data buttons seen in Figure C1. In one button, all of the variables for the Department of Energy data are listed (Figure C2), while the Platt's data set is defined with the same variables in Figure C3. While highlighting a specific variable, enter the corresponding data set value under 'values' in the 'clear field.' In this example you can see that the value for Coal_Capital in Figure C2 is 1046.00, while the same model variable in Figure C3 is given the value of 1010.00. In order for the MDS to operate properly, the exclusive box must be checked as well as having the command sequence configured to set, set, clear, and displaying the button as 1-state.

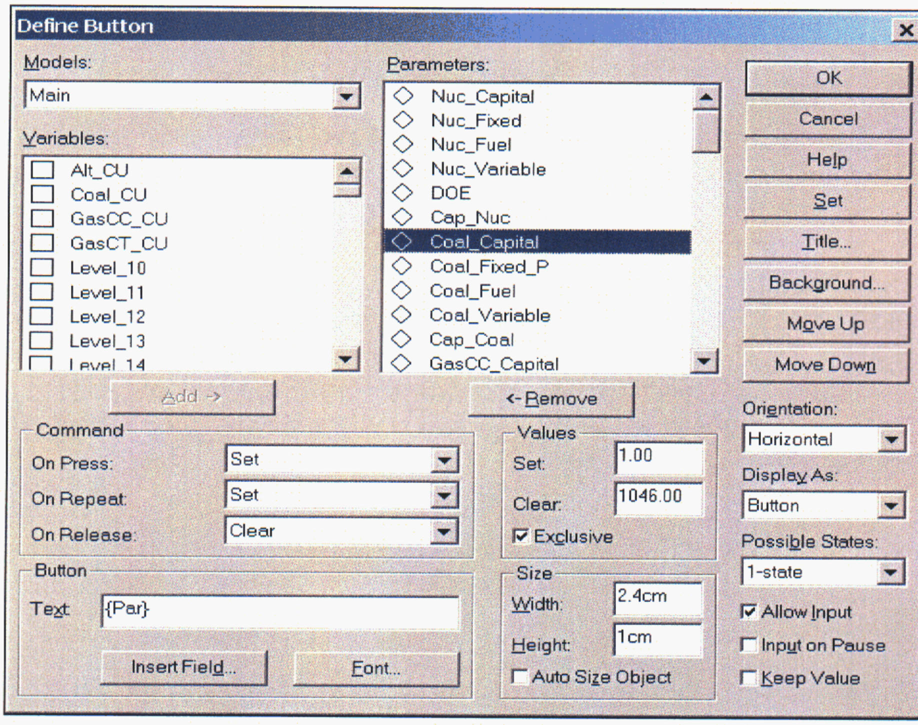

Figure C2. Department of Energy MDS Definition Window

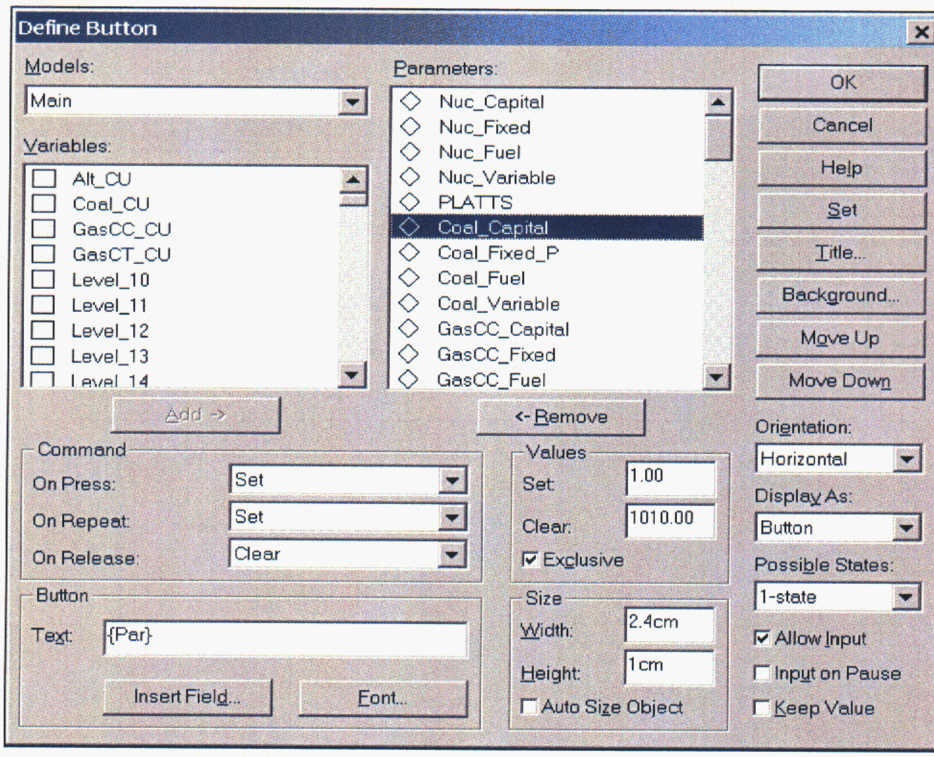

Figure C3. Platt's MDS Definition Window

Display methods of a MDS are optional. In GenSim the user is informed of which data set is chosen via a multimedia message box using dummy variables for the different data sets (shown as "DOE" and "PLATTS" in figures C2 and C3). If this is the desired method for display, then construct one dummy variable for each data set, setting the default data set dummy variable to 1 and accompanying data set dummy variables to 0, as seen in Figure C4.

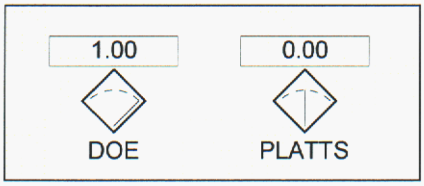

Figure C4. MDS Multimedia Dummy Variables

Next, include these dummy variables in their respective data set buttons (Figures C2 and C3). For the default data set, set the button 'clear' value at 1 and accompanying data set at 2, as seen in Figure C5.

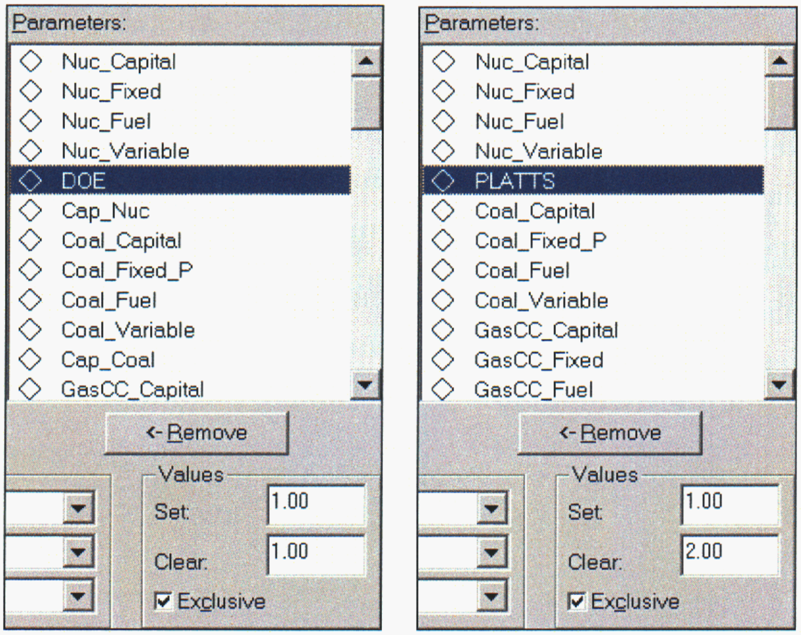

Figure C5. MDS Definition Window for Dummy Variables

Informing the user of the switch in data sets is done by using a multimedia command. Inside the multimedia window (Figure C6) set the parameter to the default data set dummy variable having a condition equal to one. For the secondary data set, set the parameter to the corresponding dummy variable with a condition equal to two.

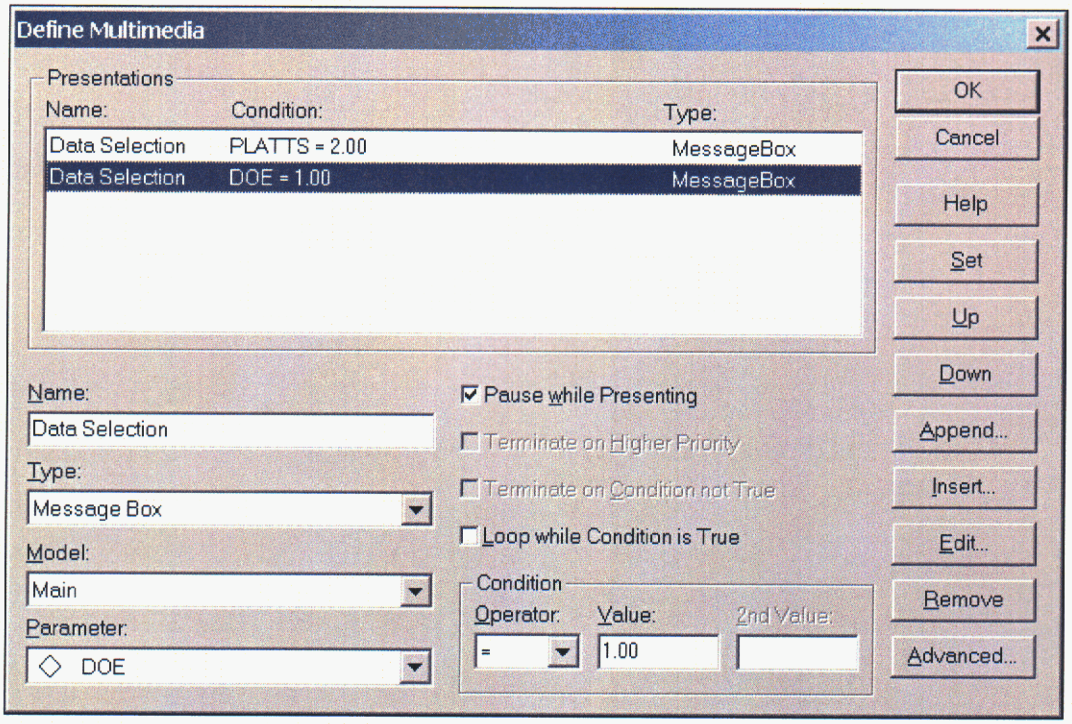

Figure C6. MDS Multimedia Definition Window

Finally, after these message boxes are inserted, you must set the return value for all dummy variables to zero, as seen in Figure C7.

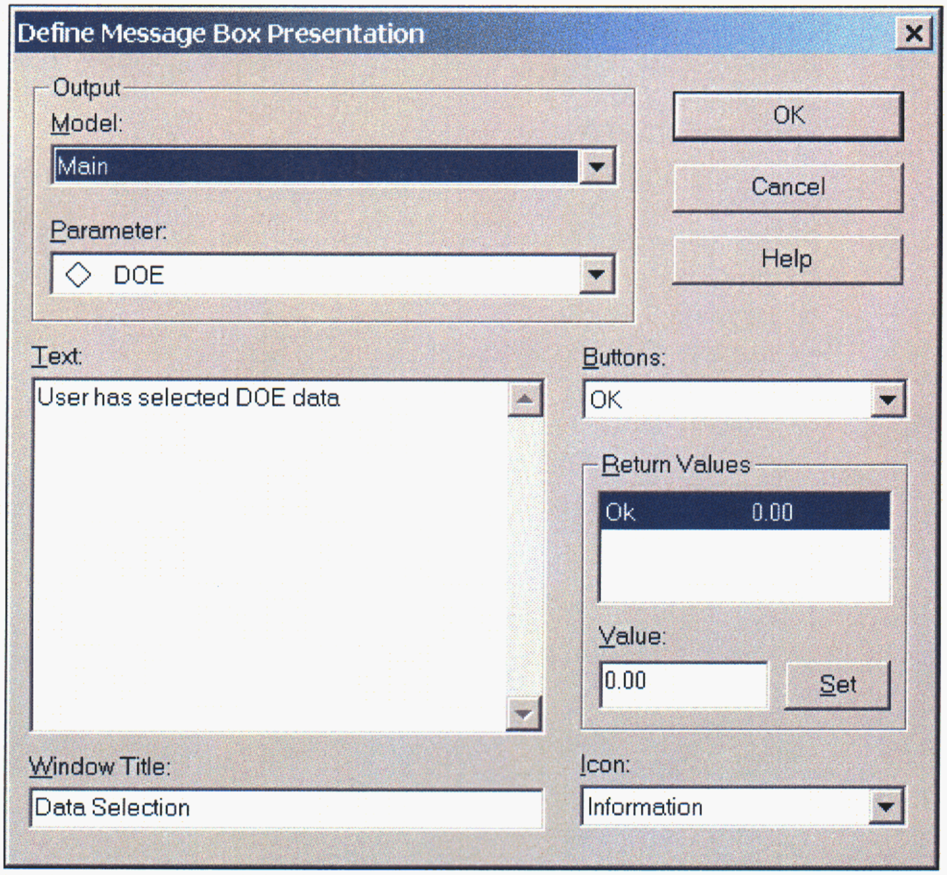

Figure C7. MDS Message Definition Window

Distribution

1	MS-0724	Eagan, Bob, 6000
1	MS-0771	Berry, Dennis, 6800
1	MS-0736	Blejwas, Tom, 6400
1	MS-0701	Davies, Peter, 6100
1	MS-9054	McLean, Bill, 8300
1	MS-0741	Tatro, Margie, 6200
1	MS-0451	Varnado, Sam, 6500
2	MS-0749	Baker, Arnie, 6010
2	MS-0749	Drennen, Thomas, 6010
1	MS-0749	Malczynski, Len, 6010
1	MS-0749	Paananen, Orman, 6010
1	MS-9018	Central Technical File, 8945-1
2	MS-0899	Technical Library, 9616
1	MS-0612	Review & Approval Desk, 9612 for DOE/OSTI