Electricity Generation Cost Simulation Model (GenSim)

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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. 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 4.0 and 3.8 cents/kWhr, respectively. A complete sensitivity analysis on fuel, capital, and construction time shows that these results in 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, below $1320/kW for coal and $1230/kW for gas.

Model Structure and Assumptions

GenSim calculates projected levelized cost of energy (LCOE)[1] 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).[2] 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, 2002); and 2) Platt's Research and Consulting Group (Platt's, 2002). Table 1 summarizes the key economic assumptions about each technology for the two data sets.[3] 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 performance characteristics for each technology.

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). The LCOE calculation is given by:

Table 1
Cost Estimates for New Generating Plants (2003 $)

	Capital ($/kW)	Fixed O&M ($/kW)	Variable O&M ($/kWhr)	Fuel ($/MBtu)
Nuclear				
DOE	1821	60.84	0.00045	0.43
Platt's[a]	-	-	-	-
Coal				
DOE	1122	25.51	0.00319	1.27
Platt's	1028	18.32	0.00183	0.81
Gas CC				
DOE	586	10.63	0.00212	3.40
Platt's	443	15.27	0.00204	3.31
Gas CT				
DOE	457	8.50	0.00319	3.40
Platt's	347	5.09	0.00046	3.31
Solar PV				
DOE	3526	10.47	0.00000	0.00
Platt's	7185	0.00	0.07839	0.00
Solar Thermal				
DOE	2293	50.88	0.0000	0.00
Platt's	2514	20.36	0.0000	0.00
Wind				
DOE	976	27.15	0.0000	0.00
Platt's	896	0.00	0.01018	0.00

[a] no nuclear data supplied

Table 2
Performance Characteristics for New Generating Plants (2003 $)

	Years to Construct	Plant Size (MW)	Average Capacity Factor (%)	Heat Rate (MBtu/kWh)
Nuclear				
DOE	5	600	90.0	10400
Platt's[a]	-	600	-	-
Coal				
DOE	4	400	85.0	9000
Platt's	3	400	85.0	9100
Gas CC				
DOE	3	400	85.0	7000
Platt's	2	400	85.0	7100
Gas CT				
DOE	2	120	30.0	9394
Platt's	1	120	10.0	10900
Solar PV				
DOE	2	5	24.6	10280
Platt's	1	5	25.4	0
Solar Thermal				
DOE	3	100	24.6	10280
Platt's	2	100	25.4	0
Wind				
DOE	3	50	28.9	0
Platt's	1	50	35.0	0

[a] no nuclear data supplied

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[1] See footnotes at end of text.

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

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 (initially set to 0).

The capital recovery factor (CRF) is calculated using:

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

where: r = real discount rate (initially set at 10%)
n = plant life (initially 20).

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

A key feature of GenSim is its graphical user interface. For example, the main GenSim screen shows projected LCOE at all possible capacity factors (also referred to as capacity utilization). This 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 same data is available in tabular form. Unfortunately, the images are not reproducible in this space.[4]

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 4.0 and 3.8 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, 2002) 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 22 and 62 cents/kWhr, respectively. This major difference is due to the assumed capital costs: 3526$/kW for the DOE data, compared to 7185 $/kW for the Platt's data.

Table 3
Comparison of Base Case Results Using DOE and Platt's Data (2003 $)

	DOE ($/kWhr)	Platt's ($/kWhr)
Nuclear	0.050	-
Coal	0.040	0.037
Gas CC	0.038	0.038
Gas CT	0.061	0.103
Solar PV	0.223	0.618
Solar Thermal	0.173	0.205
Wind	0.066	0.059

Sensitivity Analysis

GenSim's structure makes sensitivity analysis simple and powerful. GenSim 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%). The LCOE estimates change as the user changes key assumptions in the model. For example, changing the assumed capital costs for solar PV from 3,526 $/kW to 1,500 $/kW reduces the LCOE from 22.3 cents/kWhr to 9.8 cents/kWhr.

Another key assumption driving LCOE estimates is construction time and financing rates. LCOE estimates change as the user varies construction times, capital costs, or financing rates. For example, the default setting for nuclear plant construction time is 5 years. If construction time increases to 8 years, the LCOE increases from 5.01 to 5.63 cents/kWhr. This difference is due to the effects on financing as the total financed costs increase from 2446 $/kW to 2863 $/kW. 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 6.68 cents/kWhr, assuming a linear borrowing pattern and the default capital costs.

The sensitivity analytical tools 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 (3.84 vs. 4.03 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 3.67 $/MBtu, 0.27 $/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 5.07 $/MBtu.

Tables 4 – 7 summarize the key results of sensitivity analysis for new gas combined cycle, coal, nuclear, and wind generating technologies. Each table shows breakeven fuel and capital costs for each technology. For example, Table 4 shows the results for new gas combined cycle facilities. The first numerical column indicates the breakeven natural gas prices at which other technologies can compete with gas combined cycle facilities. Specifically, using the DOE base assumptions, nuclear becomes cost competitive with a gas combined cycle facility at a delivered natural gas cost of $5.07/MBtu, 1.67 $/MBtu higher than the DOE assumption. The breakeven natural gas cost for a coal facility is $3.67 $/MBtu, or just 0.27$/MBtu higher than the assumed price.

The second numerical column demonstrates the fuel price sensitivity for 10% changes in capital costs. Increasing the assumed capital costs for gas combined cycle facilities by 10% lowers the breakeven fuel cost for nuclear and coal to 4.91 and 3.51 $/MBtu, respectively.

The final column indicates the capital cost for the gas combined cycle facility at which the competing technologies become cost competitive. As indicated in Table 4, holding all else constant, the nuclear option would only be competitive with gas combined cycle plants if the capital costs for the gas plant increased from the assumed cost of 586 $/kW to 1205 $/kW. Capital costs for gas combined cycle facilities would have to increase to 2015 $/kW before the wind option was competitive.

Table 4
Gas Combined Cycle Sensitivity Analysis

	Gas CC Fuel Price ($/MBtu) (DOE Capital Cost)	Gas CC Fuel Price ($/MBtu) (+10% Capital Cost)	Capital Cost ($/kW)
Nuclear	5.07	4.91	1205
Coal	3.67	3.51	687
Gas CC	-	-	-
Gas CT	6.61	6.45	1775
Solar PV	29.80	29.64	10350
Solar Thermal	22.55	22.40	7670
Wind	7.27	7.11	2015

Tables 5 – 7 summarize results for nuclear, coal, and wind technologies. Interesting results include:

- Nuclear capital costs would have to fall to around 1239 $/kW (from 1821 $/kW) to be competitive with coal (Table 5).
- Decreased nuclear fuel prices alone cannot make nuclear competitive with coal or gas CC plants (Table 5).
- Small decreases in coal prices or increases in natural gas prices can make coal the cheapest option (Table 6). Coal becomes competitive with gas at 1.06 $/MBtu or if gas prices increase by about 0.27 $/MBtu. The base case assumes a delivered coal cost of 1.27 $/MBtu.
- Wind is competitive with nuclear, coal, and gas CC plants at installed costs of 703, 528, and 494 $/MBtu respectively (Table 7). Assumed capital costs for wind are currently at 976 $/MBtu.

Table 5
Nuclear Sensitivity Analysis

	Fuel Price ($/MBtu) (DOE Capital Cost)	Fuel Price ($/MBtu) (+10% Capital Cost)	Capital Cost ($/kW)
Nuclear	-	-	-
Coal	NC	NC	1335
Gas CC	NC	NC	1239
Gas CT	1.47	1.12	2362
Solar PV	17.08	16.73	10475
Solar Thermal	12.20	11.85	7940
Wind	1.91	1.56	2595

[a]NC, Not Competitive

Table 6
Pulverized Coal Sensitivity Analysis

	Fuel Price ($/MBtu) (DOE Capital Cost)	Fuel Price ($/MBtu) (+10% Capital Cost)	Capital Cost ($/kW)
Nuclear	2.35	2.11	1615
Coal	-	-	-
Gas CC	1.06	.81	1026
Gas CT	3.55	3.31	2155
Solar PV	21.59	21.34	10310
Solar Thermal	15.95	15.71	7765
Wind	4.07	3.82	2385

Table 7
Wind Sensitivity Analysis

	Capital Cost ($/kW)
Nuclear	703
Coal	528
Gas CC	494
Gas CT	895
Solar PV	3787
Solar Thermal	2883
Wind	-

Construction Time Sensitivity

Figure 1 illustrates the overall sensitivity of nuclear economics to construction time. These results assume constant capital expenditures over the life of the project. Even reduced construction time does not allow nuclear to compete with coal or gas CC facilities. If nuclear plant construction is delayed beyond 11 years, then wind technologies become cost competitive with nuclear. Varying the assumed nuclear capital costs by 10% shifts 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.

Externality Analysis

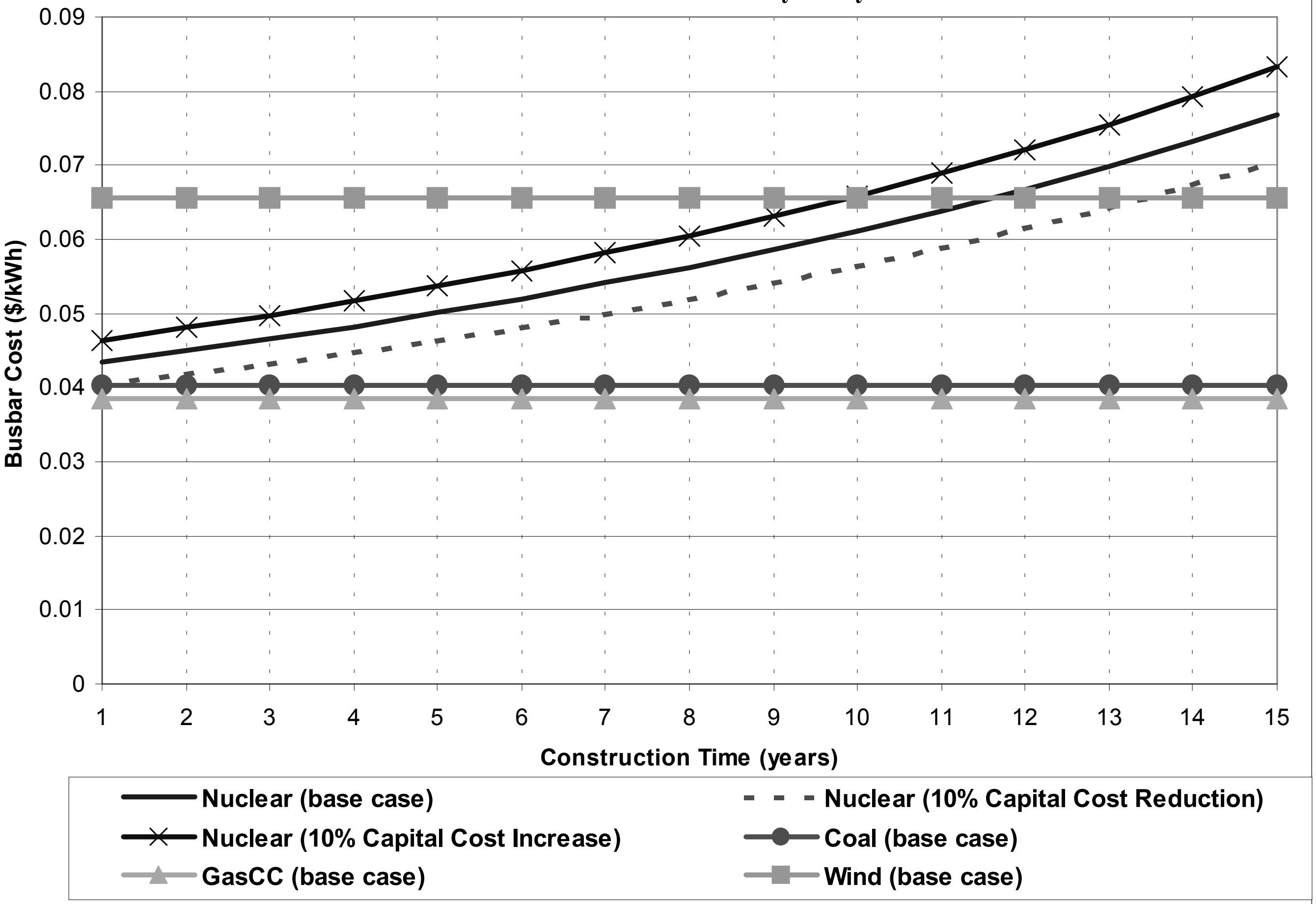
GenSim includes an extensive externality component that allows the user to consider the costs of externalities on LCOE estimates. Initially, GenSim assumes that the prices for all four externalities, CO_2, SO_2, NOx, and mercury (Hg) are set at zero. The capital costs for each generating option includes 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.

For example, assume there are externality costs imposed on CO_2, SO_2, and NOx of $100/ton, $150/ton, and $1500/ton, respectively. This increases the estimated LCOE of coal from 4.03 to 6.39 cents/kWhr. The estimates for gas CC increase from 3.84 to 4.91 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. Coal is affected more than gas as natural gas does not contain sulfur and releases less CO_2 per unit of energy consumed.

Consider the effect of just CO_2. A 100 $/ton tax on carbon emissions would increase electricity production costs from coal by 2.32 cents/kWhr, from 4.03 cents/kWhr to 6.35 cents/kWhr. For a gas CC plant, LCOE costs increase by 0.99 cents/kWhr, from 3.84 cents/kWhr to 4.83 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 eventual emplacement of this material in a central geological repository, such as at Yucca Mountain, Nevada. GenSim

Figure 1
Nuclear Construction Time Sensitivity Analysis



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 0.60 and 0.04 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.[5]

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 also permits a wide range of sensitivity and externality analysis. Its ease of use and intuitive, graphical display will help provide students of energy policy, as well as policy makers, energy executives and their staffs a better understanding of the economic viability and trade offs among power generating technologies and their emissions trade-offs.

Footnotes

[1] Sometimes referred to as busbar or production costs. Transmission and distribution costs are not included.

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

[3] All dollar figures in paper are in 2003 dollars.

[4] More detailed versions of this paper with relevant screen shots are available from the authors in the Sandia National Laboratories report SAND2002-3376, *Electricity Generation Cost Simulation Model (GenSim)*.

[5] Additional details are available upon request from the authors.

References

Platt's Research and Consulting Group. 2002.

U.S. Department of Energy (DOE). 2002. *Assumptions to the Annual Energy Outlook 2003.*

SAND2002-3376, *Electricity Generation Cost Simulation Model (GenSim)*, November 2002.