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The Electricity Portfolio Simulation Model (EPSim) Technical Description

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ABSTRACT

Stakeholders often have competing interests when selecting or planning new power plants. The purpose of developing this preliminary Electricity Portfolio Simulation Model (EPSim) is to provide a first cut, dynamic methodology and approach to this problem, that can subsequently be refined and validated, that may help energy planners, policy makers, and energy students better understand the tradeoffs associated with competing electricity portfolios. EPSim allows the user to explore competing electricity portfolios annually from 2002 to 2025 in terms of five different criteria: cost, environmental impacts, energy dependence, health and safety, and sustainability. Four additional criteria (infrastructure vulnerability, service limitations, policy needs and science and technology needs) may be added in future versions of the model. Using an analytic hierarchy process (AHP) approach, users or groups of users apply weights to each of the criteria. The default energy assumptions of the model mimic Department of Energy's (DOE) electricity portfolio to 2025 (EIA, 2005). At any time, the user can compare alternative portfolios to this reference case portfolio.

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Two alternative portfolios are compared to the reference portfolio in 2010: the zero coal portfolio and the zero energy dependence portfolio. The main effect of removing coal combustion from the portfolio in 2010 is cost-- the overall levelized cost of the portfolio increases from 2.85 cents/kWhr to 4.35 cents/kWhr ($2003), total emissions of key pollutants, including carbon, drop by 1.66 trillion tons, and dependency, measured in terms of amount of oil and natural gas in the electricity sector, increases from 4.2% to 16.3%. The portfolio also becomes slightly safer in terms of worker deaths and less sustainable in terms of the depletion rate of domestic fossil fuel reserves.

Despite the elimination of any imported oil or natural gas in the electricity sector in the second alternative portfolio discussed here (the zero energy dependence portfolio), U.S. imports of petroleum are barely affected; removing all petroleum from the electricity sector only decreases U.S. oil import rate from 57.9% to 56.9% in 2010. In terms of future work, EPSim would benefit from a number of enhancements, including adding four additional criteria, expanded definitions of currently completed criteria, and rigorous review and testing in small groups.

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Introduction

Stakeholders often have competing interests when selecting or planning new power plants. For some, the key concern is cost. Others may be more interested in the environmental impact or health and safety issues. Making tradeoffs among various generating choices is not an easy task. The purpose of developing this preliminary Electricity Portfolio Simulation Model (EPSim) is to provide a first cut, dynamic methodology and approach to this problem, that can subsequently be refined and validated, that may help energy planners, policy makers, and energy students better understand the tradeoffs associated with some of the important criteria that affect electricity power plant portfolio decisions

.

EPSim allows the user to explore competing electricity portfolios annually from 2002 to 2025 in terms of five different criteria: cost, environmental impacts, energy dependence, health and safety, and sustainability. Four other criteria (infrastructure vulnerability, service limitations, policy needs and science and technology needs) may be added in the future. Using an analytic hierarchy process (AHP) approach, users or groups of users apply weights to each of the criteria. The default energy assumptions of the model mimic Department of Energy's (DOE) electricity portfolio to 2025 (EIA, 2005). At any time, the user can compare alternative portfolios to this reference case portfolio.

Model Structure

The overall EPSim model structure is illustrated in Figure 1. The model runs annually from 2002 to 2025. Total electricity demand (in kilowatt hours—kWh) in each year is allocated by market shares to alternative electricity options, including: pulverized coal, petroleum combustion, natural gas combined cycle, nuclear, wind, solar photovoltaic (PV) and solar thermal. This allocation is determined either by using the reference assumptions of the Department of Energy's Annual Energy Outlook 2005 (AEO2005) or by user specified market shares. New generating facilities are added each year according to the previously designated shares. The number of new facilities required depends on the overall level of electricity demand, the projected efficiency of the new plants, and the retirement rate of the old plants. Each criterion is re-estimated annually for the selected portfolio.

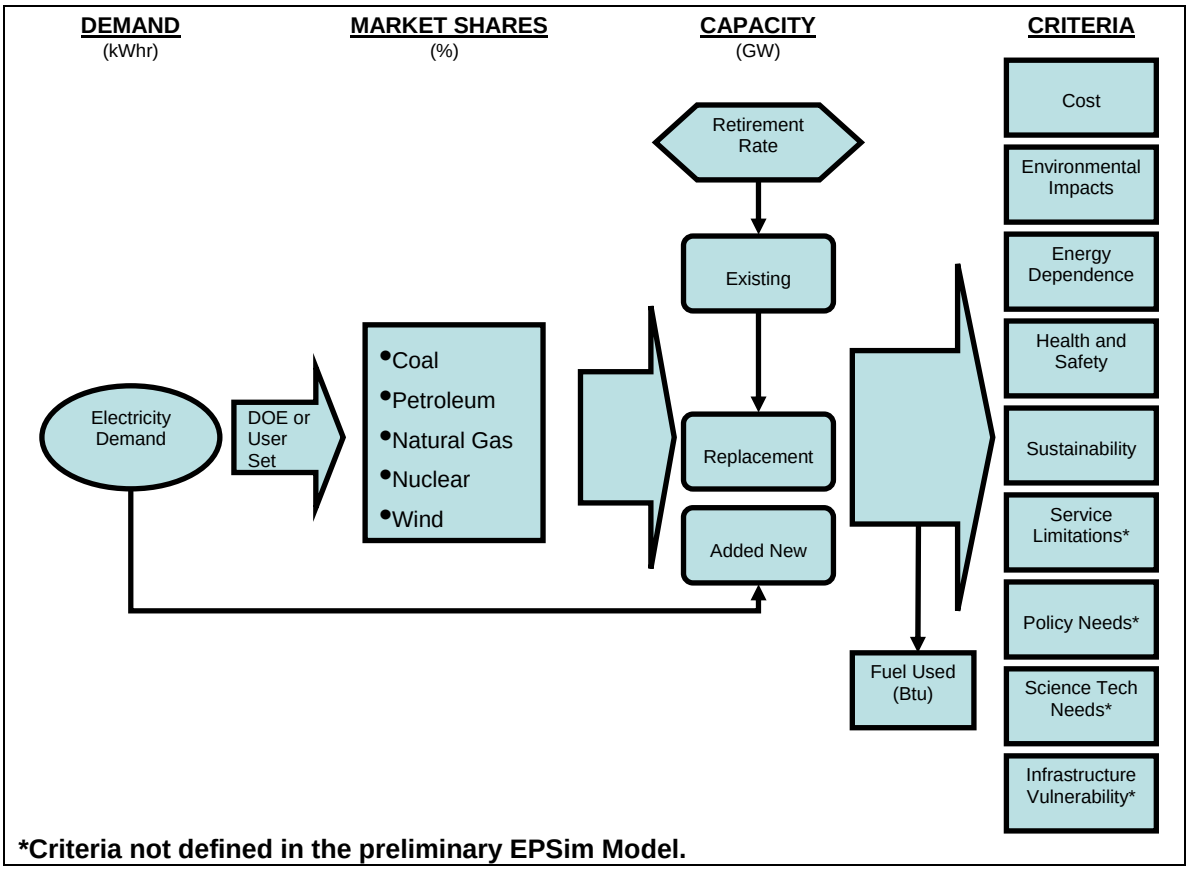

Figure 1. Electricity Portfolio Simulation Model Structure

The five criteria are:

- **Cost**. The levelized per kWhr electricity production cost in real $2003..
- **Environmental Impacts**. Emissions of various pollutants (carbon dioxide, volatile organic compounds, nitrogen oxides, carbon monoxide, sulfur oxides, coarse particulate matter, fine particulate matter ($PM_{2.5}$) and other greenhouse gases).
- **Energy Dependence**. Percentage of total petroleum and natural gas imported per year.
- **Health and Safety**. Worker deaths directly attributable to extraction, production and transmission, control and distribution.
- **Sustainability**. Percentage of domestic reserves consumed per year.

In the future, four additional criteria may be added.

- **Infrastructure Vulnerability**
- **Service Limitations**
- **Policy Needs**
- **Science and Technology Needs**

Illustrative Output

Figure 2 shows a representative screen from EPSim for 2010. Each pair of bars represents a different criterion. The green bars represent values for natural gas electricity generation, while the blue bars represent electricity portfolio totals. The financial assumptions used to calculate the 2010 cost of electricity from natural gas are visible on the bottom half of the screen. Above each set of bars is the user derived weights, which sum to one, for these four criteria.

The weighted average cost of electricity production from all natural gas facilities (19.96 % of total portfolio) is 4.57 cents/kWhr; the production cost from new natural gas facilities added in 2010 is 5.17 cents/kWhr (4.36% of installed natural gas share). While the cost for the natural gas facilities is higher than the portfolio average (2.85 cents/kWhr), the emissions from the natural gas facilities accounts for 14.2% of the emissions from all electricity sources (0.36 of 2.53 trillion tons). The screen also illustrates that in 2010, the U.S. imports 11.98% of its natural gas, whereas only 4.2% of the fuel used for the entire portfolio is imported (does not include nuclear imports). Finally, the fourth set of bars illustrates that out of the 47 deaths in 2010 directly attributable to the electricity sector, 11 of those deaths are associated with electricity production from natural gas.

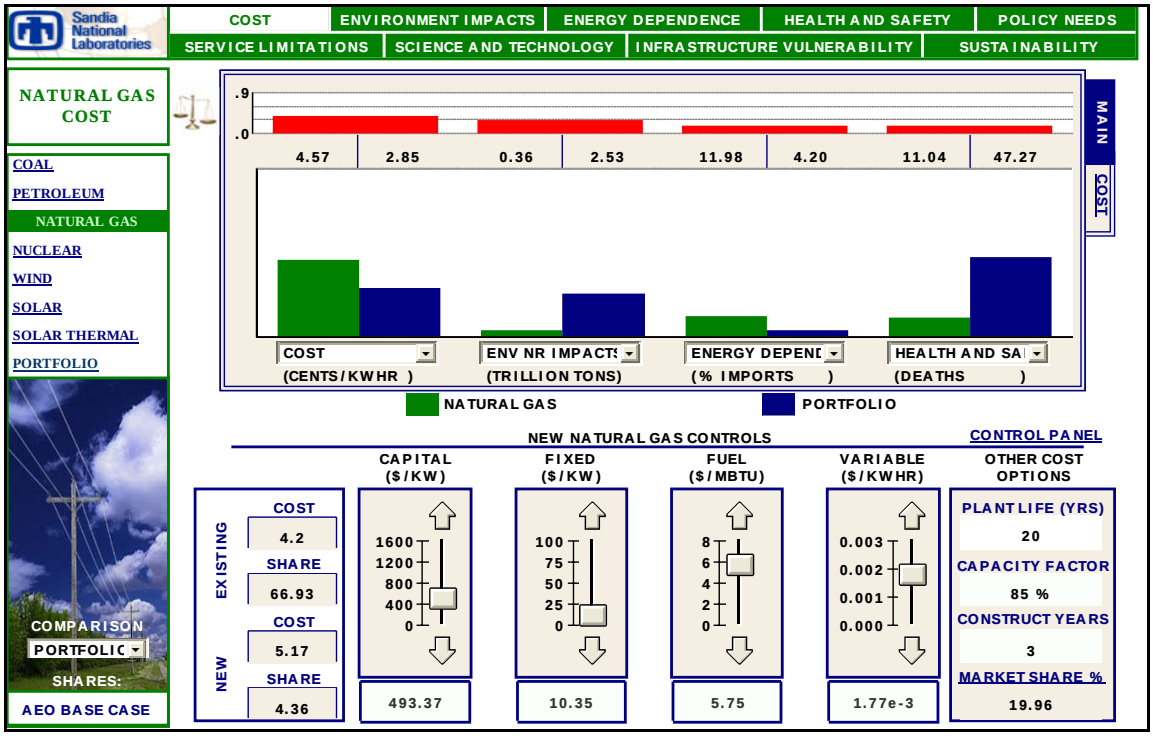

Figure 2. Natural Gas Cost Screen Displaying Main Graph and New Plant Cost Assumptions

Additional detail about the assumptions and operation of EPSim are discussed in the following sections.

Market Shares

Total electricity demand and the reference case market shares in EPSim are derived from the Department of Energy's Annual Energy Outlook 2005 (EIA, 2005). Two methods are used to determine market shares. Base case market shares are calculated using the AEO 2005 data for total kilowatt hours for each technology. In addition, the user can specify fuel shares for electricity generation. When a share slider is adjusted in the model, the change in market share is automatically distributed among the other technologies in proportion to existing market shares. For example, if nuclear's share is increased by the user, coal's share decreases more than other shares because it initially accounts for over 50 percent of electricity generation, more than any other electricity source.

Throughout the model runs, total electricity demand (in kWhrs) is kept consistent with the AEO2005 reference case. The model differentiates between existing (pre-2002) and new power generation facilities. Technical and financial assumptions from new facilities change over time to reflect the assumptions of the AEO2005. In the base case, existing facilities (pre-2002) have an assumed 2% annual retirement rate[3]; as with all other base case assumptions, the user can explore how changes in retirement rate affect the overall model results. Added generating capacity is a function of the assumed retirement rates and overall demand growth.

When the user changes a market share, the difference is added or subtracted from the other fuel shares according to the other technologies' fuel share. When one generation type gains market share, the added capacity is assumed to have the same characteristics as the capacity built in that year. When the market share of a fuel is reduced, generating capacity is withdrawn from pre 2002 capacity first, until that capacity fuel type is exhausted, and then from the newest capacity built after 2002.

EPSim is currently limited to seven electricity generating technologies: pulverized coal, petroleum combustion, natural gas combined cycle, nuclear, wind, solar photovoltaic (PV) and solar thermal. Hydro[4] and other technologies are not included in the available portfolio options.

Figure 3 illustrates the reference case results for coal generation (kWhrs) through 2025. Total electricity provided by coal totaled 1933 billion kilowatt hours in 2002 (first green bar). For any year, such as 2025, the red and blue portions of the bar represent generation from added pulverized cost capacity due to retirement (718 billion kWhrs) or due to increased demand (957 billion kWhrs), respectively. The green portion of the bar comes from the remaining capacity (1215 billion kWhrs) that was operating in 2002.

[3] EPSIM assumes a zero percent retirement rate for nuclear facilities.
[4] Limited opportunities for additional hydro capacity exist.

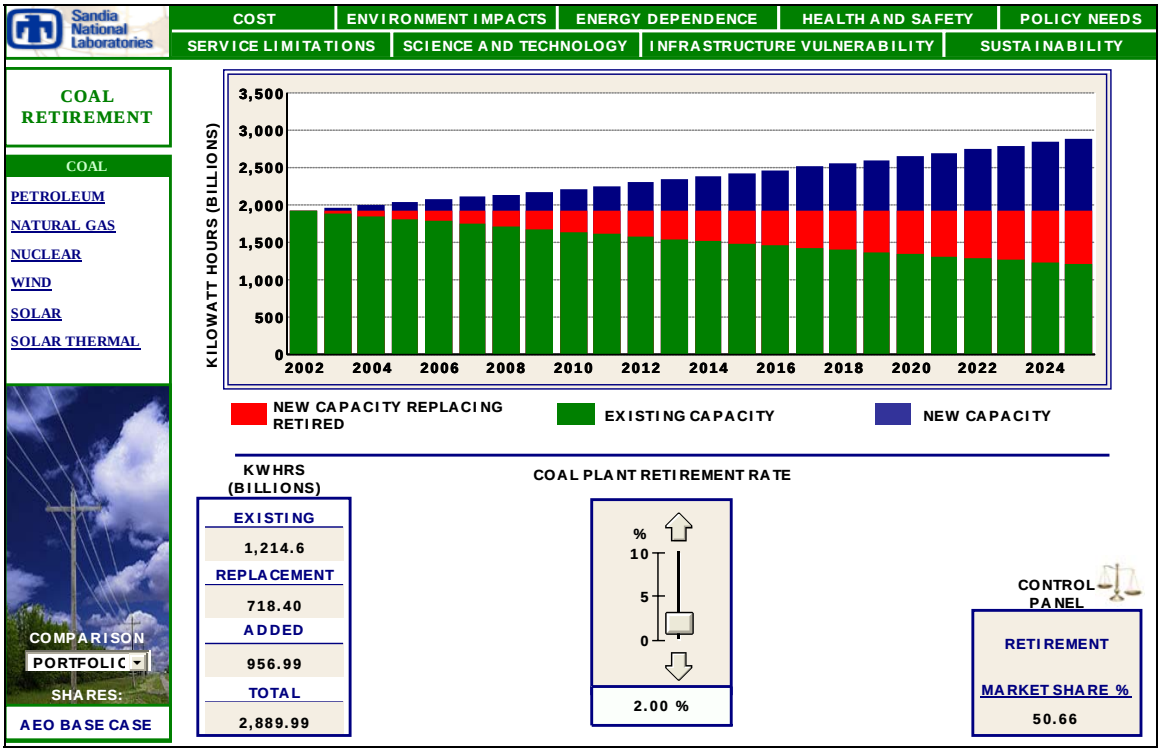

Figure 3. Coal Generation (kWhrs) through 2025, including Retirement and Additional Demand

Criteria Weighting

Several methodologies exist for ranking and/or comparing criteria (Hobbs and Meier, 2000). An extensive discussion of these methodologies was completed for a companion document, *Multi-attribute Criteria Applied to Electric Generation: Energy Systems Analysis LDRD* (Kuswa et al., 2005).

EPSim uses a pairwise comparison methodology for ranking of the criteria. The methodology used is based on earlier work at Sandia for the Vital Issues Process.[5] Pairwise comparison allows the user to compare each criterion directly with each other criteria, to obtain specific weights. The weighting matrix allows the user to make pair wise comparisons using relative descriptions (e.g., "greater than," "lower than", etc.) to specify and rank the criteria relationships (Figure 4).

Sandia National Laboratories	COST greater than ENV IMPACTS	COST much greater DEPENDENCE	COST much greater HEALTH SAFETY
ENV IMPACTS lower than COST		ENV IMPACTS greater than DEPENDENCE	ENV IMPACTS greater than HEALTH SAFETY
DEPENDENCE much lower th COST	DEPENDENCE lower than ENV IMPACTS		DEPENDENCE the same as HEALTH SAFETY
HEALTH SAFETY much lower th COST	HEALTH SAFETY lower than ENV IMPACTS	HEALTH SAFETY the same as DEPENDENCE	

Figure 4. Pairwise Comparison Matrix
(4 criteria shown)

Figure 4 also illustrates a possible user input ranking scheme. If and when the additional four criteria are added to the model, the weighting matrix would be expanded as well. If EPSim is used in a group setting, individuals would each fill out a paper version of this matrix and the average group response would then be input into EPSim's weighting matrix.

[5]The pairwise comparison methodology used in the Vital Issues Process is described in Engi and Glicken, 1995. .

For purposes of calculations, numerical values are assigned to the pairwise comparison terms, with “1” corresponding to “much lower than” and “5” corresponding to “much greater than.” Based on these numerical scores, EPSim calculates the normalized relative values of the specific criteria used in the matrix (Table 1). Each pair of criteria is compared twice (ex. criteria 1 vs. criteria 2 and criteria 2 vs. criteria 1) as a method to assure overall consistency. A series of red bars, located at the bottom of the weighting matrix, visually assure consistency. The sum of the results of two comparisons involving the same criteria must equal 6 to be consistent. The red bars at the bottom of the weighting matrix will completely disappear when all the comparisons are consistent. The weights should not be analyzed until any problems of inconsistency are resolved.

Table 1. Numerical Values of Example Weighting Matrix (Figure 4)

	COST	ENV IMPACTS	DEPENDENCE	HEALTH SAFETY
COST		4	5	5
ENV IMPACTS	2		4	4
DEPENDENCE	1	2		3
HEALTH SAFETY	1	1	3	

The matrix can operate either as a quick method of weighting the criteria, or as an interface to calculate the relative weights after a formal Point-Counterpoint-Score Pairwise Comparison process has taken place.[6] The normalized relative values are shown in the red bars above the main graph. EPSim currently allows the user to display four criteria on the main screen. Displayed criteria are compared using the pull down menus in the weighting matrix.

Table 2 illustrates the relative weights for four selected criteria based on the user supplied responses from Table 1. Theoretically, these user defined weights should then be used within EPSim in making future capacity additions. For example, for a user with similar weights to those summarized in Table 2, future portfolios would first minimize cost, but would also consider environmental impacts in the decision.

Table 2. Normalized Relative Weights for Example Weighting Matrix

	COST	ENV IMPACTS	DEPENDENCE	HEALTH SAFETY
Normalized Relative Value	**0.39**	**0.28**	**0.17**	**0.17**

[6] The Point – Counterpoint – Score method is a three step process in which each criterion is addressed individually. One group member champions the importance of that criterion; another member rebuts the points made by the champion. After discussion of each criterion in this method, the group members commence with the pairwise voting process.

The Criteria

In this section, each of the five criteria currently modeled in EPSim are discussed in further detail.

Cost

Cost is defined as the per kWhr electricity production cost, often referred to the levelized cost of electricity (LCOE). LCOE for existing facilities is not generally available; EPSim uses estimated production costs that exclude capital costs. This is common practice.[7] The calculation of LCOE for new facilities follows the methodology used for Sandia's Electricity Generation Simulation Model (GenSim) (Drennen et al., 2005).

New capacity additions include capital costs, which, along with fuel costs and heat rates, change yearly (Cost and performance characteristics for these new plants are summarized in Table A-2.) Growth rates for these variables are derived from AEO 2005. The user can set capital, fuel, fixed and variable costs for both 2002 capacity and capacity added after 2002. It is also possible to change assumptions about plant life, capacity factors (capacity utilization), construction times, financial assumptions (interest and discount rates), and income tax and depreciation considerations. The estimated cost for the whole portfolio is the weighted average of each year's LCOE. For example, the displayed cost for electricity derived from coal in 2010 is the weighted average of the production costs for pre-2002 capacity (for which capital cost is zero), and capacity added in each year through 2010. The LCOE of pre-2002 capacity and capacity added in later years is summarized in Table 3. The assumption that the capital cost of pre-2002 capacity is zero makes the cost of generation for each fuel increase over time. The exception is solar PV generation because there is very little pre-2002 solar PV capacity.

[7] For example, when the Nuclear Energy Institute announces that electricity generated by existing nuclear facilities is economically competitive with coal fired facilities, they consider just fuel and operating and maintenance costs.

Table 3. LCOE for Pre-2002 and Added Capacity

Coal	Pre-2002 (cents/kWhr)	Added (cents/kWhr)
2002	1.87	4.51
2010	1.88	4.44
2025	1.89	4.34
Petroleum		
2002	4.63	6.86
2010	4.94	6.87
2025	5.59	7.48
Gas		
2002	4.31	5.49
2010	4.20	5.17
2025	3.99	4.78
Nuclear		
2002	1.35	5.26
2010	1.35	5.13
2025	1.35	4.87
Wind		
2002	0.81	5.52
2010	0.81	5.50
2025	0.81	5.47
Solar PV		
2002	0.48	26.40
2010	0.48	23.47
2025	0.48	17.99
Solar Thermal		
2002	1.74	14.62
2010	1.74	13.67
2025	1.74	11.89

Environmental Impacts

The environmental impacts of electricity generation are calculated in the model by estimating the tons of emissions produced during the production of electricity.[8] Nuclear, wind, solar PV and solar thermal technologies are assumed to have zero emissions. The model breaks down the emissions from pulverized coal, combined cycle natural gas, and petroleum combustion into carbon dioxide ($C0_2$), volatile organic compounds (VOC), nitrogen oxides (NO_x), carbon monoxide (C0), sulfur oxides ($S0_2$), coarse particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$) and other greenhouse gases (other). Pre-2002 emissions are determined using emissions per Btu coefficient for 2002 (Table 4). This coefficient was estimated using total tons of emissions from electric generation per fuel in 2002 and dividing by the 2002 fuel content (in Btu's) used in electricity generation. The heat rates used to calculate total Btus used in electricity generation are in Appendix A, Table A-1, and are consistent with DOE predictions. Carbon emissions from 2002 are from Table A18 of the Annual Energy Outlook for 2005. All other emissions data comes from the U.S. EPA National Emissions Inventory Air Pollutant Emission Trends Data and Estimation Procedure 1993-2002 (EPA, 2005). Capacity added after 2002 is multiplied by a Government Performance and Results Act (GPRA) 2000 annual performance measure (DOE, 2000). Total emissions for a fuel are the sum of emissions from pre 2002 capacity and emissions produced by capacity added in all subsequent years. The portfolio emissions statistic is the total amount of emissions produced by electricity generation technologies. In many ways, adding the various pollutants together is not satisfactory, as they have different levels of toxicity. This also illustrates the potential for misuse of this type of tool: the user who is seeking to minimize emissions needs to pay close attention to which pollutants are actually being reduced. Future versions of this model should consider means for more clearly dealing with this question.

Table 4. Emission Coefficients for Existing and New Capacity

	C02	VOC	N0x	C0	S02	PM_{10}	$PM_{2.5}$	other
Coal								
Existing	0.030	0.0036	0.48	0.030	1.14	0.075	0.063	0.00
New	0.025	0.0022	0.57	0.026	1.23	0.026	0.0092	0.007
Petroleum								
Existing	0.024	0.0092	0.30	0.032	0.79	0.040	0.030	0.00
New	0.021	0.0088	0.26	0.028	1.15	0.015	0.0083	0.003
Gas								
Existing	0.019	0.0030	0.12	0.038	0.0035	0.0051	0.0047	0.00
New	0.014	0.0022	0.23	0.039	0.09	0.00	0.00	0.004

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[8] The model does not include life cycle emissions.

Health and Safety

The health and safety criterion focuses solely on total deaths associated with the generation of electricity. Future versions of the model may include other factors, such as lost work days, hospital emissions, lost productivity, etc. Workers deaths are broken down into three categories: extraction, generation, and transmission, control, and distribution (TCD). Extraction deaths are the total fatalities from the extraction of natural resources attributable to electricity generation. Total deaths from extraction change yearly according growth rates derived from the 1992 - 2002 Census of Fatal Occupational Injuries produced by the US Department of Labor (BLS 2003). Table 5 summarizes total deaths per quad[9] by electricity type. These factors are used to define total worker deaths through 2025. The deaths per quad of petroleum and natural gas are assumed equal. EPSim does not include any deaths during the extraction of uranium for nuclear produced electricity. Likewise, wind, solar PV and solar thermal technologies are assumed to have no deaths from extraction.

Deaths due to generation are grouped into two categories (fossil fuel generation and other generation), and these deaths are distributed according to market share. Deaths associated with the transmission, control and distribution are combined for all fuel types and thus allocated by fuel share. The model assumes that all fuels used in electricity generation are extracted in the United States and with United States safety standards. Portfolio health and safety is the total amount of deaths attributed to electricity generation in the United States.

[9] One Quad = 10^{15} Btus

Table 5. Death per Quadrillion BTUs Coefficients

	Extraction	Generation	TCD
Coal			
2002	1.3	0.22	0.45
2010	0.84	0.19	0.40
2025	0.37	0.14	0.31
Petroleum			
2002	1.67	0.22	0.45
2010	1.29	0.19	0.40
2025	0.84	0.14	0.31
Gas			
2002	1.67	0.22	0.45
2010	1.29	0.19	0.40
2025	0.84	0.14	0.31
Nuclear			
2002	0	0.36	0.45
2010	0	0.35	0.40
2025	0	0.33	0.31
Wind			
2002	0	0.36	0.45
2010	0	0.35	0.40
2025	0	0.33	0.31
Solar PV			
2002	0	0.36	0.45
2010	0	0.35	0.40
2025	0	0.33	0.31
Solar Thermal			
2002	0	0.36	0.45
2010	0	0.35	0.40
2025	0	0.33	0.31

Energy Dependence

Energy dependence is defined as the percent of a fuel imported per year. This criterion differs from other criteria used in the model in that it requires consideration of energy use in other sectors as well. For this reason, forecasted petroleum and natural gas use in the electricity sector from EPSim is added to the forecasted amount of oil and natural gas used in other sectors (commercial, industrial, residential and transportation) in the Annual Energy Outlook 2005 (EIA, 2005). Subtracting total fuel use from AEO 2005 projections of domestic supply results in import projections. Petroleum imports are adjusted for other petroleum imports and petroleum exports. Dependence is displayed as imports of a fuel as a percentage of U.S. total use of a fuel. In this preliminary version of EPSim, imports of coal and nuclear fuel are assumed to be zero. (In reality, most of our nuclear fuel is also imported.) The levels of imports can be set to any level by the user. Portfolio dependence is the weighted average of each fuel's percentage imported.

Sustainability

The sustainability criterion is defined as the percentage of U.S. reserves used to meet total U.S. consumption. While this definition is slightly misleading in that not all U.S. consumption is derived from U.S. sources, it provides a useful metric for gauging remaining domestic supplies. Starting reserves (2002 demonstrated reserve base) of coal, petroleum and natural gas are from the U.S. Department of Energy (EIA, 2003). Yearly U.S. consumption (Table 6) is calculated as the sum of yearly energy use from the electricity sector, as calculated by the model, and energy use from all other sectors. Starting reserves are depleted yearly by U.S. energy consumption. The model also displays remaining years of reserves based on current consumption. The user can set U.S. reserves to any level only before the simulation has been started. This version of EPSim does not include U.S. uranium reserves. Portfolio sustainability is the weighted average of each fuel's yearly percent of U.S. reserves used.

Table 6. U.S. Reserves, Consumption and Production of Fossil Fuels

	Demonstrated Reserves	Yearly U.S. Consumption	Yearly U.S. Production
Coal (billion short tons)			
2002	499.40	1.07	1.09
2010	491.62	1.04	-
2025	474.33	1.30	-
Petroleum (billion barrels)			
2002	174.82	6.62	2.10
2010	118.28	7.64	2.20
2025	0	9.36	1.73
Natural Gas (trillion cubic feet)			
2002	1430.63	20.79	19.03
2010	1259.19	23.29	20.50
2025	871.10	28.92	21.91

Using EPSim

Figure 5 shows the main screen for the coal section of the model. The red bars in the top graph represent the normalized relative values calculated by the pairwise comparison matrix. The lower graph compares characteristics of coal generation to the total characteristics of the portfolio. By using the hyperlinks on the left side of the page, the user can change sections. The green bar in the main graph will always represent the characteristics of the generation technology (or total portfolio) selected. The comparison bar can be changed to represent all other fuels, the section's reference data, or the portfolio's reference data. Reference data holds market shares consistent with AEO 2005 projections, but changes in other assumptions are taken into account. The comparison bar is changed using the pull down menu in the lower left corner. The color of the comparison bar will change accordingly when the bar is changed. The criteria viewed in the main graph can be changed by using the pull down switch below the bars. The four bars can be changed to view any of the criteria in any order. The criteria have different units, so it is important to note that the value axis of the main graph has no unit or scale, instead, the units are shown below the pull down switches. The actual values of the bars are located between above the main graph and below the weight bars.

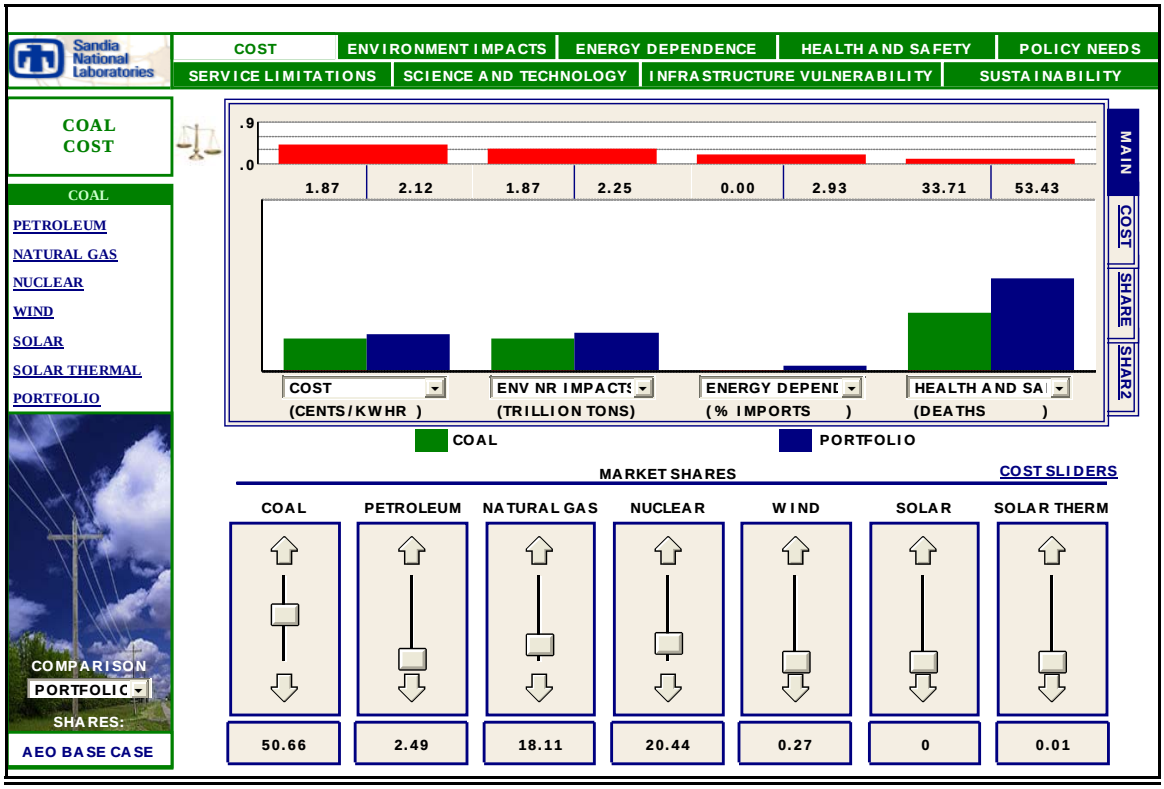


Figure 5. Coal Cost Screen Displaying Main Graph and Share Sliders

The hyperlinks at the top of the page navigate between the various criteria within each fuel section. On each criteria page, assumptions can be changed for the specific fuel, and a summary graphic of any selected changes is illustrated. The links on the left side of the graph show the graphs that can be viewed. The main graph is the dual bar comparison and weights graph, the second tab will always be a summary graph for all fuels of the criteria section being viewed (cost, environmental, energy dependence, etc). The share graph shows the total kilowatt hours of electricity produced by each fuel over time, and the second share graph (shar2) shows the current year market shares for all fuels with a comparison to the base case market shares. The bottom half of the page is where assumptions and market shares can be changed. Figure 5 shows the share sliders which can be adjusted.

Results and Discussion

The reference case results for 2002, 2010, and 2025 are summarized in Table 7. In 2010, the generation technologies included in the model and in the portfolio calculations will account for 91.5% (5,306.4 billion kWhrs) of the total kilowatt hours generated. Other renewable generation technologies, not included in the model, account for 9.4% of the total or 392.9 billion kilowatt hours. The base case results show that in 2010, coal combustion remains the main generating source (50.5%), followed by natural gas (19.96%) and nuclear (18.11%). Petroleum combustion, wind, solar PV, and solar thermal technologies account for rest of the generation.

In 2010, the average cost of generation is 2.85 cents/kWhr ($2003) and the generation of this electricity results in 2.53 trillion tons of emissions and 47.3 worker deaths. In terms of the sustainability criterion, generating this electricity requires the U.S. to use 0.7% of its demonstrated reserves; and 4.2% of the fuel consumed for electricity production will need to be imported.

In 2010, nuclear generation is the least cost alternative with an average production cost of 1.43 cents/kWhr for all plants. Solar PV is the most expensive generation technology, with an average cost of 24.74 cents/kWhr. Nuclear generation's low average cost is due to the assumption of a zero percent retirement rate and the AEO's assumption of very little increase in nuclear generation.[10] In contrast, solar PV has a very high average cost because little solar PV capacity existed prior to 2002.

Based on the definition of the environmental criterion, coal combustion is the most unsafe and environmentally damaging method of generation with combined deaths from extraction, generation, and transmission, control, and distribution at 27.97, and total emissions at 2.07 trillion tons, partly due to its large market share. Despite petroleum combustion's small share in the electricity generation sector, it still has the highest statistics for dependency and sustainability at 57.88% imported and 6.50% of reserves used in 2010. Dependency and sustainability are both figures that are calculated using other sector's consumption of fossil fuels. As is discussed later in this paper, the petroleum consumed to produce electricity has very little effect on the dependency and sustainability figures.

[10] AEO projections do not foresee any increase in nuclear capacity; the overall increase in nuclear generation is due solely to increased performance of existing facilities.

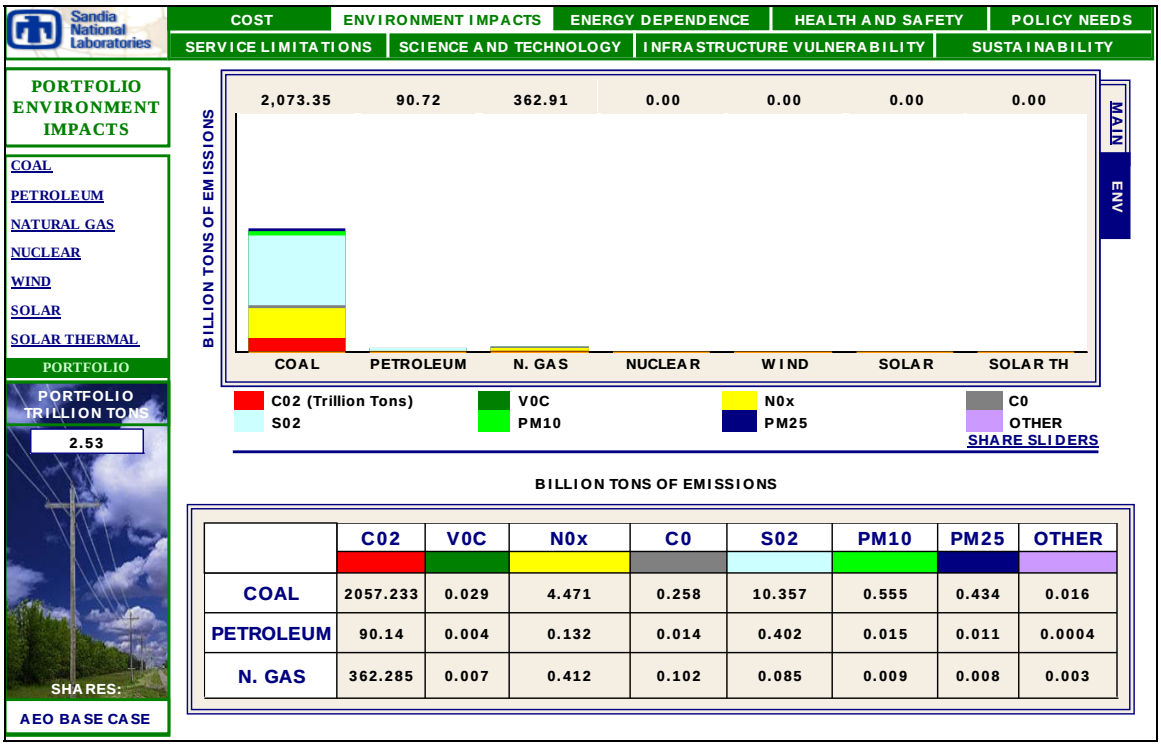
Table 7. Summary of Base Case Results

	Generation		Cost (Cents/ kWhr)	Environment Impacts (Trillion Tons)	Depend-ency (% Imported)	Health & Safety (Worker Deaths)	Sustainability (% of U.S. Reserves Used)
	(Billion kWhrs)	(%)					
Coal							
2002	1933.00	50.66	1.87	1.87	0.00	33.71	0.18
2010	2222.44	50.50	2.55	2.07	0.00	27.97	0.21
2025	2889.99	50.66	3.35	2.56	0.00	20.77	0.27
Oil							
2002	95.00	2.49	4.63	0.077	56.04	2.05	3.79
2010	110.47	2.51	5.46	0.091	57.88	1.88	6.50
2025	148.00	2.59	6.48	0.120	66.37	1.70	100.00
Gas							
2002	691.00	18.11	4.31	0.30	8.48	10.95	1.45
2010	878.37	19.96	4.57	0.36	11.98	11.04	1.85
2025	1401.96	24.58	4.71	0.52	24.34	11.85	3.32
Nuclear							
2002	780.00	20.44	1.35	0.00	0.00	6.64	0.00
2010	797.04	18.11	1.43	0.00	0.00	6.26	0.00
2025	830.00	14.55	1.57	0.00	0.00	5.58	0.00
Wind							
2002	10.35	0.27	0.81	0.00	0.00	0.09	0.00
2010	15.74	0.36	2.88	0.00	0.00	0.12	0.00
2025	34.52	0.61	4.61	0.00	0.00	.23	0.00
Solar PV							
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	.33	0.007	24.74	0.00	0.00	0.002	0.00
2025	.96	0.02	22.01	0.00	0.00	.066	0.00
Solar Thermal							
2002	.55	0.01	1.74	0.00	0.00	.0046	0.00
2010	.67	0.02	5.52	0.00	0.00	.0052	0.00
2025	.99	0.02	9.16	0.00	0.00	.0065	0.00
Other Renew							
2002	305.37	8.00	-	-	-	-	-
2010	392.90	8.55	-	-	-	-	-
2025	434.19	6.97	-	-	-	-	-
Portfolio							
2002	3509.90	92.00	2.12	2.25	2.93	53.43	0.45
2010	4025.07	91.45	2.85	2.53	4.20	47.27	0.70
2025	5306.42	93.03	3.53	3.20	8.26	40.13	3.82

These reference case numbers are generated to provide a benchmark for users to explore alternative portfolios and compare those portfolios against the reference portfolio for the selected criteria. The following sections provide two concrete examples of EPSim's capabilities. In the first example, coal is eventually eliminated as an option in an attempt to limit environmental impacts. The second example attempts to minimize energy dependence.

Example 1: Zero Coal Portfolio

In this first example, coal is removed from the overall portfolio in an attempt to minimize environmental impacts. This is in sharp contrast to the reference case, in which coal generation is the largest source of emissions, Figure 6.



	C02	V0C	N0x	C0	S02	PM10	PM25	OTHER
COAL	2057.233	0.029	4.471	0.258	10.357	0.555	0.434	0.016
PETROLEUM	90.14	0.004	0.132	0.014	0.402	0.015	0.011	0.0004
N. GAS	362.285	0.007	0.412	0.102	0.085	0.009	0.008	0.003

Figure 6. Portfolio Environmental Impacts Screen

For this example, coal's market share was reduced to zero percent in 2010. Coal's share is redistributed to the other technologies in proportion to their market share, Table 8.

Table 8. Base Case Market Shares Compared With Zero Coal Portfolio Market Shares in 2010

	Coal	Petroleum	Natural Gas	Nuclear	Wind	Solar PV	Solar Thermal
Base (%)	50.50	2.51	19.96	18.11	0.36	0.007	0.02
No Coal (%)	0.00	5.51	40.07	45.22	0.59	0.02	0.04

With coal removed, combined cycle natural gas and nuclear technologies take up most of the difference. Petroleum combustion, wind, solar PV and solar thermal technologies all increase, but account for less than 6.5% of electricity generation. EPSim's market share graph, Figure 7, provides a good visual understanding of the re-adjusted shares. In this case, coal has been removed in 2010 and nuclear and natural gas generation has picked up most of the coal's share.

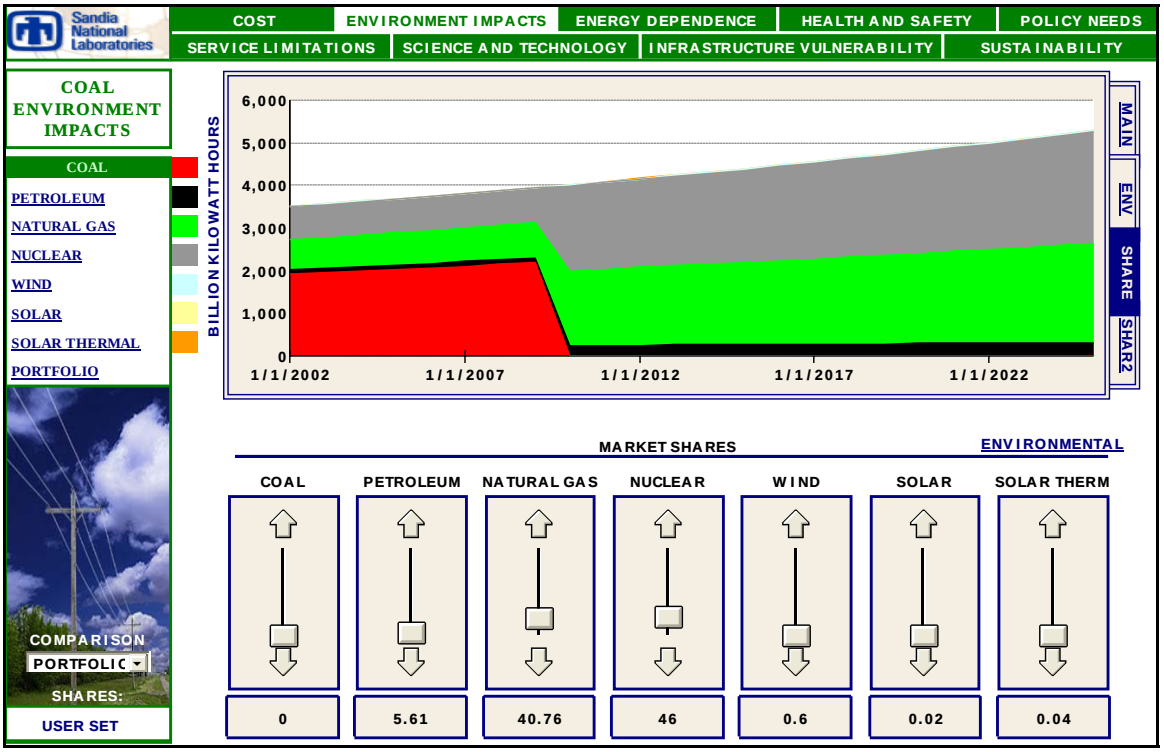


Figure 7. Share Graph Showing Total Portfolio with Coal Removed in 2010

The impacts of removing coal from the portfolio are summarized in Table 9 and illustrated in Figure 8.

Table 9. Summary of 2010 Portfolio Characteristics for Base Case and Zero Coal Portfolios

	Cost (Cents/kWhr)	Environmental Impacts (Trillion Tons)	Dependency (% Imported)	Health and Safety (Worker Deaths)	Sustainability (% of Reserves Used)
Base	2.85	2.53	4.20	47.27	0.70
No Coal	4.35	0.87	16.27	41.66	1.41
Difference	1.50	-1.66	12.07	-5.61	0.71

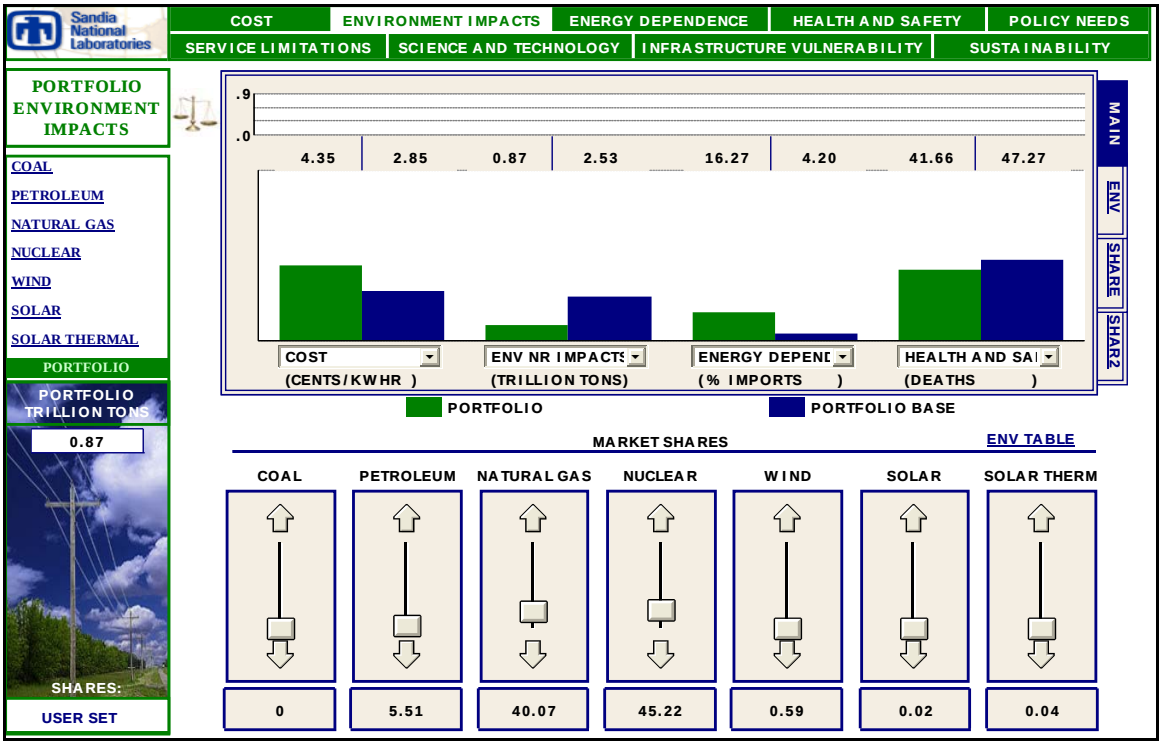


Figure 8. Portfolio Environmental Impacts Screen for Zero Coal Portfolio

By comparing the two bars in the main graph, the changes that occurred as a result of removing coal from the portfolio are clear. The green bar represents the portfolio averages after the shares have been changed, while the blue bars represent the portfolio averages when shares are held consistent with AEO data. The changes can be viewed in greater detail by looking at a specific fuel's section of the model.

The main effects of removing coal combustion from the portfolio in 2010 are cost; the overall portfolio generation cost increases from 2.85 cents/kWhr to 4.35 cents/kWhr, total emissions drop by 1.66 trillion tons, and dependency increases from 4.2% to 16.27%. The portfolio also becomes slightly safer, though less sustainable. The increase in cost is explained by the relatively lower cost of electric power generation from coal (2.55 cents/kWhr) being replaced by the more expensive technologies of natural gas combined cycle (4.87 cents/kWhr) and nuclear (3.65 cents/kWhr). Although nuclear was the least cost alternative in the base case (based only on operating, maintenance and fuel cost), the average cost of nuclear generation increased (from 1.43 to 3.65 cents/kWhr) as new capacity requiring new capital investment was added, because of coal's removal, at a cost of 5.13 cents/kWhr. These figures are shown in Table 3; the percentages of old and added capacity are in Table A-1.

In terms of the main objective of this example, reducing emissions, this swap of coal for natural gas and nuclear is effective; emissions drop from 2.53 to 0.87 trillion tons.[11] In the base case, coal combustion accounts for 2.07 of the 2.53 trillion tons of emissions. Although emissions as a result of petroleum combustion and combined cycle natural gas rise as a result of increased capacity, the rise is far less significant than the drop caused by replacing coal with natural gas and nuclear generation.

Dependence on imports of fossil fuels increases as a result of eliminating coal, due to the large increase in generation using combined cycle natural gas plants and the U.S.'s increased dependence on foreign imports of natural gas. Overall dependence increases from 11.98% in the reference case to 29.03% (Table 10).

[11] As mentioned earlier, total emissions can be misleading if not viewed in terms of the individuals pollutants. For this example, individual pollutants are reduced by (in billion tons): CO_2 , 1,643; VOC, 0.018; NOx, 3.725; CO, 0.139; SO2, 9.527; PM10, 0.547; and PM2.5, 0.43.

Table 10. Summary of Zero Coal Portfolio Results

	Generation		Cost (Cents /kWhr)	Environment Impacts (Trillion Tons)	Depend-ency (% Imported)	Health and Safety (Worker Deaths)	Sustainability (% of Reserves Used)
	(Billion kWhrs)	(%)					
Coal							
2002	1933.00	50.66	1.87	1.87	0.00	33.71	0.18
2010	0.00	0.00	-	-	-	-	0.02
2025	0.00	0.00	-	-	-	-	0.02
Oil							
2002	95.00	2.49	4.63	0.077	56.04	2.05	3.79
2010	242.72	5.51	6.23	0.19	58.92	4.00	6.66
2025	319.57	5.61	6.73	0.26	67.25	3.60	100.00
Gas							
2002	691.00	18.11	4.31	0.30	8.48	10.95	1.45
2010	1763.54	40.07	4.87	0.67	29.03	21.81	2.29
2025	2321.88	40.76	4.88	0.84	36.92	19.57	4.42
Nuclear							
2002	780.00	20.44	1.35	0.00	0.00	6.64	0.00
2010	1990.14	45.22	3.65	0.00	0.00	15.63	0.00
2025	2623.69	46.00	3.97	0.00	0.00	17.63	0.00
Wind							
2002	25.97	0.27	0.81	0.00	0.00	0.09	0.00
2010	34.20	0.59	3.91	0.00	0.00	0.20	0.00
2025	34.20	0.60	4.60	0.00	0.00	0.23	0.00
Solar PV							
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.90	0.02	23.95	0.00	0.00	.0069	0.00
2025	1.18	0.02	23.09	0.00	0.00	.0078	0.00
Solar Thermal							
2002	0.55	0.01	1.74	0.00	0.00	.0046	0.00
2010	1.79	0.04	10.60	0.00	0.00	0.01	0.00
2025	2.36	0.04	11.66	0.00	0.00	0.02	0.00
Other Renew							
2002	305.37	8.00	-	-	-	-	-
2010	392.90	8.55	-	-	-	-	-
2025	434.19	6.97	-	-	-	-	-
Portfolio							
2002	3509.90	92.00	2.12	2.25	2.93	53.43	0.45
2010	4025.07	91.45	4.35	0.87	16.27	41.66	1.41
2025	5306.42	93.03	4.55	1.11	20.23	41.05	7.97

Example 2: Zero Dependence Portfolio

U.S. dependence on energy imports is an issue of ongoing importance. The purpose of this example is to explore the affect on other criteria if all electricity is produced from domestic resources. Completing this example requires some simplifying assumptions. For example, as U.S. sources account for a large percentage of its total natural gas consumption (about 91.5% in 2010), at least some electricity could still come from natural gas in 2010 without requiring imports. Based on the reference assumptions about natural gas supply in 2010, EPSim suggests that the share of electricity from natural gas could remain around 8%, or about half the share in the reference case. For petroleum, since most of U.S. oil consumption is used in the transportation sector, this example assumes that petroleum cannot be used for electricity generation in 2010. These share changes are illustrated in Figure 9.

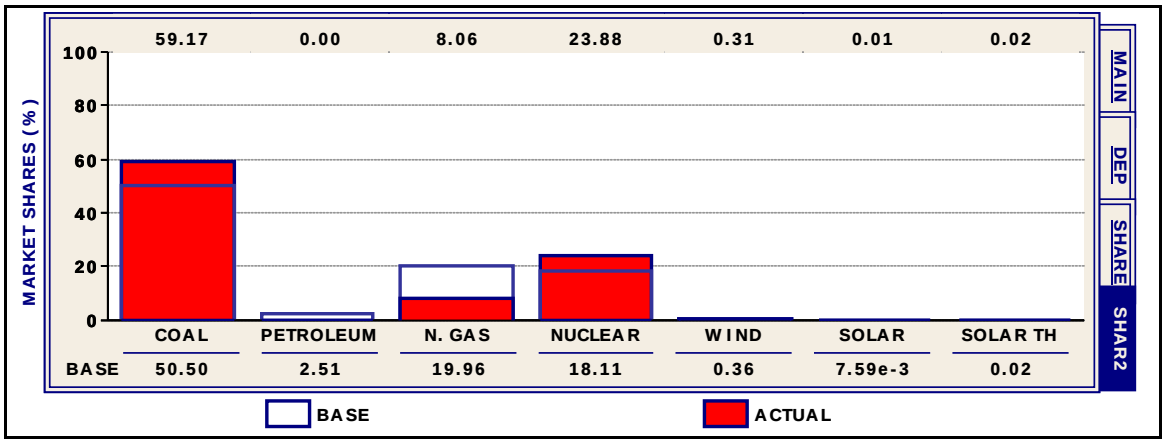


Figure 9. Market Shares for the Zero Dependence Case

Figure 10 illustrates the resulting effect on total U.S. dependency after adjusting the shares of petroleum and natural gas to achieve zero dependence in the electricity sector (Figure 9). Despite the elimination of any imported fuel for use in the electricity sector, U.S. imports of petroleum are barely affected; removing all petroleum from the electricity sector only decreases U.S. oil import rate from 57.9% to 56.9%. The results also suggest that this strategy has little on the average cost, Table 11. The sustainability criterion is improved as electricity from nuclear, domestic coal, and renewables increases. Total deaths fall slightly, from 47.27 to 45.48. Table 12 summarizes the complete results of the Zero dependence portfolio.

This analysis shows that the electricity sector has a very limited effect on the United State's dependence on fuel imports because the major sources of energy used in electricity generation are produced domestically.

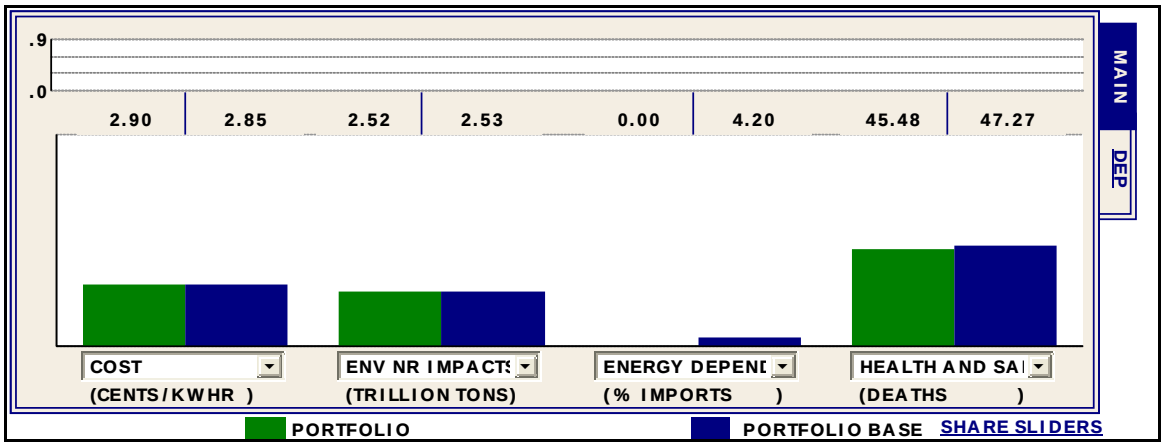


Figure 10. Main Graph Displaying Results of Zero Dependence Portfolio

Table 11. Summary of 2010 Portfolio Characteristics for Base Case and Zero Dependence Portfolios

	Cost (Cents/kWhr)	Environmental Impacts (Trillion Tons)	Dependency (% Imported)	Health and Safety (Worker Deaths)	Sustainability (% of Reserves Used)
Base	2.85	2.53	4.20	47.27	0.70
No Coal	2.90	2.52	0.00	45.48	0.30
Difference	0.05	0.01	-4.20	-1.79	-0.40

Table 12. Summary of Zero Dependence Portfolio Results

	Generation		Cost (Cents /kWhr)	Environment Impacts (Trillion Tons)	Depend-ency (% Imported)	Health and Safety (Worker Deaths)	Sustainability (% of Reserves Used)
	(Billion kWhrs)	(%)					
Coal							
2002	1933.00	50.66	1.87	1.87	0.00	33.71	0.18
2010	2609.40	59.17	2.83	2.39	0.00	32.70	0.24
2025	3424.89	60.19	3.51	3.00	0.00	24.59	0.32
Oil							
2002	95.00	2.49	4.63	0.077	56.04	2.05	3.79
2010	0.00	0.00	-	-	56.91	-	6.35
2025	0.00	0.00	-	-	65.54	-	100.00
Gas							
2002	691.00	18.11	4.31	0.30	8.48	10.95	1.45
2010	354.69	8.06	5.10	0.13	0.00	4.41	1.58
2025	467.27	8.20	5.06	0.17	4.70	3.96	2.45
Nuclear							
2002	780.00	20.44	1.35	0.00	0.00	6.64	0.00
2010	1050.84	23.88	2.33	0.00	0.00	8.25	0.00
2025	1385.37	24.29	2.97	0.00	0.00	9.31	0.00
Wind							
2002	25.97	0.27	0.81	0.00	0.00	0.09	0.00
2010	13.71	0.31	3.18	0.00	0.00	0.11	0.00
2025	18.05	0.32	4.19	0.00	0.00	0.12	0.00
Solar PV							
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.47	0.01	24.38	0.00	0.00	0.004	0.00
2025	0.62	0.01	23.41	0.00	0.00	0.004	0.00
Solar Thermal							
2002	0.55	0.01	1.74	0.00	0.00	0.0046	0.00
2010	0.95	0.02	7.86	0.00	0.00	0.007	0.00
2025	1.24	0.02	10.07	0.00	0.00	0.008	0.00
Other Renew							
2002	305.37	8.00	-	-	-	-	-
2010	392.90	8.55	-	-	-	-	-
2025	434.19	6.97	-	-	-	-	-
Portfolio							
2002	3509.90	92.00	2.12	2.25	2.93	53.43	0.45
2010	4025.07	91.45	2.90	2.52	0.00	45.48	0.30
2025	5306.42	93.03	3.51	3.17	0.41	37.99	0.42

Future Work

The objective of developing this preliminary Electricity Portfolio Simulation Model (EPSim) is to help energy planners, policy makers, and energy students better understand the tradeoffs associated with some of the key characteristics of alternative electricity portfolios. The present preliminary version of EPSim allows the user to explore competing electricity portfolios from 2002 to 2025 in terms of five different criteria: cost, environmental impacts, energy dependence, health and safety, and sustainability. Four other criteria have been identified as another part of this LDRD (Kuswa et al. 2005) and have placeholders in the existing model: infrastructure vulnerability, service limitations, policy needs and science and technology needs.

In addition to adding these four additional criteria, several model enhancements would strengthen EPSim. Specific suggestions for enhancements include:

- Review and refinement of the data, methodology and assumptions used in the current five criteria.
- Addition of risk and uncertainty to cost criterion.
- Inclusion of additional environmental factors in calculation of the environmental criterion, such as nuclear handling and waste issues, land use requirements, and overall level of visibility to the general public (e.g., windmills).
- Inclusion of additional health and safety factors other than worker deaths, including some aspect of public health impact (increased respiratory ailments, lost work days, increased cancer incidence).
- An automated optimization section allowing users to automatically seek portfolios that more closely match their criteria weighting.

To enhance the credibility and methodological approach of this model credibility, it should be subjected to one or more external peer reviews. Such reviews could include participation by up to 12 “experts” in a day long exercise, following pre-review of the model and its methodologies, which also could include a prioritization of suggested additional model capabilities.

Finally, following peer review and modification, as needed, of the current preliminary EPSim version, it should be tested on a variety of groups to test, evaluate and improve the pairwise comparison methodology.

References

Bureau of Labor Statistic (BLS). 2005. *Census of Fatal Occupational Injuries 1992 – 2002*, U.S. Department of Labor.

Drennen, T., W. Kamery, and A. Baker. 2005. *Electricity Generation Cost Simulation Model (GenSim)*. SAND2002-3376, updated 2005, Sandia National Laboratories.

Energy Information Administration (EIA). 2005. *Annual Energy Outlook 2005*, U.S. Department of Energy.

Energy Information Administration (EIA). 2003. *Annual Energy Review 2002*, U.S. Department of Energy.

Engi, D. and J. Glicken. 1995. *The Vital Issues Process: Strategic Planning for a Changing World*. SAND95-0845, Sandia National Laboratories.

Hobbs, B. And P. Meier. 2000. *Energy Decisions and the Environment: A Guide to the Use of Multicriteria Methods*. Kluwer Academic Publishers.

Kuswa, G., J. Zuffranieri, J. Brewer, S. Jones, M. Valdez, O. Paananen, and T. Drennen. 2005. *Multi-attribute Criteria Applied to Electric Generation: Energy Systems Analysis LDRD*, SAND2005-**XXXX**, Sandia National Laboratories.

U.S. Department of Energy. 2000. GRPA2000 Excel Spreadsheet, Office of Energy Efficiency and Renewable Energy.

U.S. Environmental Protection Agency. 2005. *Air Pollutant Emissions Trends Data and Estimation Procedures*, National Emissions Inventory (NEI). U.S. Environmental Protection Agency.

Appendix A

Table A-1 contains detailed assumptions about market shares for the base (or reference case), zero coal, and zero dependence scenarios. Table A-2 summarizes cost and performance assumptions for the various generation technologies**.**

Table A-1. Pre-2002 and Added Capacity Shares for Base, Zero Coal, and Zero Emissions Portfolios

	Pre 2002 (%)			Added (%)		
Coal	Base	Zero Coal	Zero Dependence	Base	Zero Coal	Zero Dependence
2002	100.00	100.00	100.00	0.00	0.00	0.00
2010	74.00	-	63.14	3.24	-	17.43
2025	42.03	-	35.37	2.60	-	2.63
Petroleum						
2002	100.00	100.00	100.00	0.00	0.00	0.00
2010	73.16	33.30	-	3.38	56.03	-
2025	40.33	18.65	-	2.79	2.29	-
Gas						
2002	100.00	100.00	100.00	0.00	0.00	0.00
2010	66.93	33.34	18.10	4.36	52.36	10.79
2025	30.97	18.68	10.14	3.76	2.29	3.80
Nuclear						
2002	100.00	100.00	100.00	0.00	0.00	0.00
2010	97.86	39.19	74.23	0.27	60.06	24.36
2025	93.98	29.73	56.30	0.27	1.91	1.91
Wind						
2002	100.00	100.00	100.00	0.00	0.00	0.00
2010	55.96	33.90	49.47	6.24	43.20	7.16
2025	18.84	18.99	27.71	5.49	2.30	2.65
Solar						
2002	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	12.50	67.38	38.22
2025	0.00	0.00	0.00	4.35	1.91	1.91
Solar Thermal						
2002	100.00	100.00	100.00	0.00	0.00	0.00
2010	69.35	26.12	49.47	3.94	63.82	31.47
2025	39.91	14.63	27.71	3.24	2.21	2.48

Table A-2. Cost and Performance Assumptions for New Generating Plants (2003 $)

	Capital ($/kW)	Fixed O&M ($/kW)	Variable O&M ($/kWhr)	Heat Rate (Mbtu/ kWhr)	Plant Life (yrs)	Years to Construct	Average Capacity Factor
Coal							
Pre 2002	0	24.36	0.00406	8844.00	20	4	85%
<2002	1134.00	24.36	0.00406	8844.00	20	4	85%
2010	1110.80	24.36	0.00406	8693.85	20	4	85%
2025	1067.29	24.36	0.00406	8600.00	20	4	85%
Petroleum							
Pre 2002	0	9.31	0.0028	9183	20	2	30%
<2002	356	9.31	0.0028	9183	20	2	30%
2010	356	9.31	0.0028	8550	20	2	30%
2025	356	9.31	0.0028	8550	20	2	30%
Natural Gas							
Pre 2002	0	10.35	0.00177	6752.00	20	3	85%
<2002	517.00	10.35	0.00177	6752.00	20	3	85%
2010	493.37	10.35	0.00177	6494.15	20	3	85%
2025	449.07	10.35	0.00177	6333.00	20	3	85%
Nuclear							
Pre 2002	0	60.06	0.00044	10400	20	6	90%
<2002	1694.00	60.06	0.00044	10400	20	6	90%
2010	1635.10	60.06	0.00044	10400	20	6	90%
2025	1524.68	60.06	0.00044	10400	20	6	90%
Wind							
Pre 2002	0	26.81	0	10280	20	3	38%
<2002	1060.00	26.81	0	10280	20	3	38%
2010	1056.17	26.81	0	10280	20	3	38%
2025	1049.00	26.81	0	10280	20	3	38%
Solar PV							
Pre 2002	0	10.34	0	10280	20	2	24.6%
<2002	3868.00	10.34	0	10280	20	2	24.6%
2010	3431.83	10.34	0	10280	20	2	24.6%
2025	2614.00	10.34	0	10280	20	2	24.6%
Solar Thermal							
Pre 2002	0	50.23	0	10280	20	3	33%
<2002	2515.00	50.23	0	10280	20	3	33%
2010	2329.96	50.23	0	10280	20	3	33%
2025	1983.00	50.23	0	10280	20	3	33%

Distribution:

1	MS-0123	LDRD office (1011)
1	MS-0612	Review & Approval Desk (9612) for DOE/OSTI
1	MS-0749	Baker, Arnie (6010)
5	MS-0749	Drennen, Tom (6010)
1	MS-0749	Klotz, Richard (6010)
2	MS-0899	Technical Library (9616)
1	MS-9018	Central Technical File, (8945-1)