Appendix

Model Performance

This appendix discusses performance aspects of the Renewable Fuels Module (RFM). It is intended to present the pattern of response of the RFM to typical changes in its major inputs from other NEMS modules.

The overall approach of this document, with the particular statistics presented, is designed to be comparable with similar analyses conducted for all of the modules of NEMS. While not always applicable, the overall approach has been to produce analyses and statistics that are as comparable as possible with model developer's reports for other NEMS modules.[1] Those areas where the analysis is somewhat limited or constrained are discussed below.

Because the RFM consists of independent submodules, this appendix is broken down by submodule.

Convergence

All RFM submodules consist of deterministic formulas for the outputs in terms of the inputs: there is no iterative logic of any kind in any of the submodules. Therefore, convergence is not an issue, except insofar as the entire National Energy Modeling System (NEMS) iterates to a convergence that is dependent on the outputs from the RFM submodules. These issues are treated in documentation of the NEMS Integrating Module.

Sensitivity Analyses

The remainder of this appendix presents the results of sensitivity analyses executed to measure the responsiveness of RFM submodule outputs to inputs from the other NEMS modules. Only a limited number of the outputs of other NEMS modules are used as inputs by the RFM submodules; their effects are measured on the most important output variables from RFM. For this report, all outputs were examined for effects from changes in the inputs; any variables that do not change are not reported.

This section begins with general discussions of the submodule inputs and outputs analyzed, then presents the approach in general terms. The bulk of the section consists of discussion of the details of the sensitivity analyses that were performed for each submodule, along with tables of the specific

[1]Details of the approach, including the concept of "conditional sensitivity," were defined by Andy S. Kydes of the Office of Integrated Analysis and Forecasting in a memorandum dated December 13, 1993.

values that were modified and the resulting effects on the outputs.

Inputs

Table 1 shows the RFM submodules, along with their input variables. Only variables created by other NEMS modules are shown, as these are the dynamic inputs to the submodules. The Hydroelectric submodule does not use any NEMS variables. In addition, because the Wind submodule is sensitive to the amount of ‘‘windy land’’ made available exogenously to the submodule, this variable was added to the list to be analyzed.

In the sensitivity analysis, NEMS runs were submitted for each of these variables, in each of which the value of one of these variables was adjusted to a value 10 percent greater than the value used in the 12/21/93 NEMS base case, unless the base case value was zero. In the latter case, a suitable absolute value was chosen as the sensitivity case value.

Table 1. NEMS Variables Used by the Renewable Fuels Module.

RFM Submodule	Input Variable	Name (Dimensions)	COMMON
Wind	Utility Wind Generation Capacity	UCAPWNU(MNUMNR,MNUMYR)	UDATOUT
	Nonutility Wind Generation Capacity	UCAPWNN(MNUMNR,MNUMYR)	UDATOUT
Solar	Total Photovoltaic Additions	UADDPVT(MNUMNR,MNUMYR+10)	UECPOUT
	Total Solar Thermal Additions	UADDSTT(MNUMNR,MNUMYR+10)	UECPOUT
Ethanol	Price of Diesel Oil	PDSTR(MNUMCR,MNUMYR)	MPBLK
	Price of Natural Gas for Industrial	PNGIN(MNUMCR,MNUMYR)	MPBLK
	Yield on AA Utility Bonds	MC_RMPUAANS(MNUMYR)	MACOUT
Biomass	Quantity of Biomass Residential	QBMRS(MNUMCR,MNUMYR)	QBLK
	Price of Electricity for Commercial	PELCM(MNUMCR,MNUMYR)	MPBLK
	Price of Electricity for Industrial	PELIN(MNUMCR,MNUMYR)	MPBLK
Geothermal	Total Geothermal Additions	UADDGET(MNUMNR,MNUMYR+10)	UECPOUT
MSW	Real Gross Domestic Product	MC_GDP(MNUMYR)	MACOUT

Outputs

Most of the RFM submodules have the following outputs:

WCAteEL	Maximum Available Capacity,
WCCteEL	Capital Costs,
WOCteEL	Fixed Operating Costs, and
WVCteEL	Variable Operating Costs.

Here, *te* represents the particular technology. These are the most important outputs of the submodules because they are the key inputs for each technology in the Electricity Market Module. Because the Ethanol submodule, which interacts only with the Petroleum Market Module (PMM), does not produce the four variables listed above, the analysis instead focuses on the supply curves used by the PMM. A few other submodule outputs are influenced by changes in the NEMS variables; these are discussed under each submodule.

The sensitivity analyses therefore measure the sensitivity of the output variables to variations imposed on the input variables listed in Table 1, and, in the case of the Wind Submodule, to the windy land area variable.

Approach

This subsection describes the general objectives of the approach used in this analysis; the details of the procedures used for each submodule are described in separate subsections below.

In order to measure the sensitivity of each output to changes in each input, *ceteris paribus*, the RFM was executed ‘‘standalone,’’ that is, with all other modules switched off, to prevent their influencing the NEMS convergence process. This analysis therefore measures sensitivity of the outputs to changes in the inputs as solved in the 1994 NEMS base case published in the *Annual Energy Outlook 1994*. Each input variable can potentially change any one of the important outputs, so there were separate NEMS runs for each of the input variables, in which the variable’s 2005 value in each region is increased by 10 percent, or by an absolute value, as described for the individual analyses, when the initial value was zero. 2005 was chosen as the analysis year because it is well beyond the period covered by construction lags and other effects that depend on history. The sensitivities are the impacts of each change on the output variables’ 2005 values. In a few cases, submodules carry the effects of one year’s NEMS variable to other forecast years; these cases are discussed below.

In the remaining sections of this appendix, tables show the results of the analyses for each of the submodules. Separate tables show the absolute values of the variables, the percentage changes and the sensitivities. For the purpose of this study, the sensitivity tables represent ‘‘conditional sensitivities’’ as the ratio between percent change in the output variable and percent change in the input variable. Many RFM outputs (those not shown in the tables below) are insensitive to all inputs from NEMS.

Where a variable has been calculated as zero in the NEMS base case, the conditional sensitivity concept is meaningless. In these cases, the ratio called simply ‘‘sensitivity’’ is the ratio between the absolute (rather than percent) values of the changes in the output and input variables.

Hydroelectric Submodule

All data that is sent to NEMS by the Hydroelectric submodule is obtained from external sources, rather than calculated within the submodule. Because utilities plan their capacity additions far in advance of needs, and because there are scant opportunities for further hydroelectric development, the Hydroelectric submodule returns to NEMS only the utilities’ plans for capacity expansion, as reported in their responses to EIA surveys. The survey data are read from an external file by the Hydroelectric submodule, and are therefore insensitive to inputs from other NEMS modules.

Wind Submodule

Table 2 summarizes the sensitivity analysis for the Wind submodule. It presents the base case values for the input and output variables, the adjusted values for the input variables, and the resulting values for the output variables. Tables 3 and 4 show values calculated from Table 1.

In the tables, it should be noted that the Windy Land input variable is the only variable in the sensitivity analysis that is not input from another NEMS module. It is included here, even though it is entirely exogenous to NEMS, because it is so important for determining the maximum available wind capacity. One factor that influences the potential for wind generation is the perception that there will be negative environmental impacts, some of which are aesthetic. The Pacific Northwest Laboratories, in their assessment of the potential for wind generation[2], created four scenarios that represent the amount of land that would be available for wind development, given alternative degrees of restrictions. Their ‘‘moderate environmental exclusions’’ case was used in the Wind submodule for the NEMS AEO94 Base Case. For this sensitivity analysis, we compared with the most pessimistic of the PNL cases, ‘‘severe environmental exclusions,’’ which, as Tables 2 and 3 show, allows the submodule to use about half the amount of land used in the moderate case.

Table 2. Wind Submodule Sensitivity Analysis, National Totals.

	Case	Base	High Utility Generation	High Non-Utility Generation	Severe Environmental Restrictions
Input Variable	Utility Wind Generation Capacity (MW)	***39***	43	39	39
	Non-Utility Wind Generation Capacity (MW)	***1938***	1938	2132	1938
	Windy Land (km^2)	***438138***	438138	438138	199739
Output Variable	Maximum Available Capacity (MW)	***821803***	821799	821609	454454

Note: ***Bold italic*** values are from the NEMS base case.

Table 3. Wind Submodule Percent Changes, National Averages.

	Case	High Utility Generation	High Non-Utility Generation	Severe Environmental Restrictions
Input Variable	Utility Wind Generation Capacity	10	0	0
	Non-Utility Wind Generation Capacity	0	10	0
	Windy Land	0	0	-54
Output Variable	Maximum Available Capacity	-.0005	-.02	-45

[2] Elliott, D. L., et al., *An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States*, Pacific Northwest Laboratories (PNL-7789), August 1991.

Table 4. Wind Submodule Conditional Sensitivities, National Average.

Case	High Utility Generation	High Non-Utility Generation	Severe Environmental Restrictions
Maximum Available Capacity	-.00005	-.002	.82

The apparent extreme insensitivity of available capacity for wind to changes in generation capacity is strictly a numerical phenomenon: as shown in Table 2, an increase in installed capacity leads to an identical decrease in available capacity. The small percent changes are merely due to the extremely large amounts of available windy land, in comparison to the increments of newly-installed capacity.

A decrease in the available windy land results in a somewhat smaller decrease in available capacity because the land excluded for environmental reasons tends to be the less energetic Class 3 land. In any case, the available wind resource, even in the severe exclusions case, is still relatively unlimited, as its 454 GW level is on the order of total US capability from all energy sources.

Solar Submodule

The Solar submodule is insensitive to changes in the inputs from NEMS. The submodule was originally designed to reduce capital costs in response to industrial experience (learning curve effect) in manufacturing solar collectors; however, because the value of the coefficient of capacity manufactured to date is set at zero, the submodule is presently unresponsive to inputs from NEMS. In future versions of NEMS, the learning curve will be handled in a separate module located outside of the RFM.

Biomass (Ethanol) Submodule

Only one set of variables is calculated by the Ethanol submodule: the supply curve (WPETOH). There are five steps on the supply curve, so the output variable for this sensitivity analysis is the five steps. Furthermore, the supply curve is calculated only for PADD 2, where all ethanol plants are assumed to be located, so the sensitivity case represents the price of ethanol at the conversion plant gate only in PADD 2, with no transportation costs for finished product. Table 5 summarizes the sensitivity analysis for the Ethanol submodule. It presents the base case values for the input and output variables, the adjusted values for the input variables, and the resulting values for the output variables. Tables 6 and 7 are calculated from Table 5.

As noted in the tables, the Ethanol submodule makes use of fuel prices in a lagged linear formulation: the price of ethanol is subject to the previous year's prices for diesel oil (a cost component of agricultural production of corn) and natural gas (a surrogate for the price of energy at the conversion plant), which is reflected in the sensitivities. Sensitivity of ethanol prices to diesel fuel price is considerably larger than that for natural gas price, since the cost of energy to run the conversion plant is a comparatively small component of the production cost for ethanol. Neither price has strong influence on ethanol prices.

Table 5. Ethanol Submodule Sensitivity Analysis.

			Case	Base	High Diesel Price[1]	High Plant Energy Price[1]	High Interest Rate
Input Variable	1995 Diesel Oil Price (1987 $/MMBtu)			***8.43***	9.28	8.43	8.43
	1995 Natural Gas Price (1987 $/MMBtu)			***3.62***	3.62	3.98	3.62
	1995 AA Bond Rate (%)			***8.47***	8.47	8.47	9.32
Output Variable	Price of Ethanol (1987 $/Bbl)	1995[1]	Step 1	***48.83***	48.83	48.83	49.44
			Step 2	***50.06***	50.06	50.06	50.67
			Step 3	***51.29***	51.29	51.29	51.91
			Step 4	***52.53***	52.53	52.53	53.14
			Step 5	***53.76***	53.76	53.76	54.37
		1996[1]	Step 1	***49.12***	50.61	49.78	49.12
			Step 2	***50.35***	51.84	51.02	50.35
			Step 3	***51.58***	53.08	52.25	51.58
			Step 4	***52.82***	54.31	53.48	52.82
			Step 5	***54.05***	55.54	54.72	54.05

[1] Changes in NEMS prices in year t affect ethanol prices in year t+1.
Note: ***Bold italic*** values are from the NEMS base case.

Table 6. Ethanol Submodule Percent Changes.

		Case	High Diesel Price	High Plant Energy Price	High Interest Rates
Input Variable	Diesel Oil Price		10	0	0
	Natural Gas Price		0	10	0
	AA Bond Rate		0	0	10
Output Variable	Price of Ethanol	Step 1	3.4[1]	1.9[1]	.7
		Step 2	3.6[1]	1.9[1]	.6
		Step 3	3.5[1]	1.9[1]	.6
		Step 4	3.4[1]	1.8[1]	.6
		Step 5	3.3[1]	1.8[1]	.6

[1] Next-year changes.

Table 7. Ethanol Submodule Conditional Sensitivities.

	Case	High Diesel Price	High Plant Energy Price	High Interest Rates
Price of Ethanol	Step 1	.34[1]	.19[1]	.07
	Step 2	.36[1]	.19[1]	.06
	Step 3	.35[1]	.19[1]	.06
	Step 4	.34[1]	.18[1]	.06
	Step 5	.33[1]	.18[1]	.06

[1] Next-year sensitivities.

Biomass (Wood) Submodule

Table 8 summarizes the sensitivity analysis for the Wood submodule. It presents the base case values for the input and output variables, the adjusted values for the input variables, and the resulting values for the output variables. Tables 9 and 10 are calculated from Table 8. In addition to the output variables shown in the tables, the Wood submodule also calculates the price of wood by sector.

The sensitivities of the output variables to changes in the input variables are straightforward. In each case, the submodule applies a simple factor to the input variable to calculate the output variable. The commercial and industrial cogeneration revenues reflect the fact that wood is used primarily in cogeneration situations where the byproduct electricity is considered to be a net benefit. Capital and fixed operating costs and the availability and price of wood for electricity generation are not influenced by any inputs from NEMS.

Table 8. Wood Submodule Sensitivity Analysis.

	Case	Base	High Commercial Price	High Industrial Price	High Residential Biomass Consumption
Input Variables	Commercial Electricity Price (1987 $/MMBtu)	***18.95***	20.85	18.95	18.95
	Industrial Electricity Price (1987 $/MMBtu)	***12.68***	12.68	13.95	12.68
	Residential Biomass Consumption (TBtu)	***627***	627	627	690
Output Variables	Commercial Cogeneration Revenue (1987 $/MMBtu)	***1.00***	1.10	1.00	1.00
	Industrial Cogeneration Revenue (1987 $/MMBtu)	***0.70***	0.70	0.77	0.70
	Residential Biomass Available Capacity (TBtu)	***1604***	1604	1604	1764

Note: ***Bold italic*** values are from the NEMS base case.

Table 9. Wood Submodule Percent Changes.

	Case	High Commercial Price	High Industrial Price	High Residential Biomass Consumptio n
Input Variables	Commercial Electricity Price	10	0	0
	Industrial Electricity Price	0	10	0
	Residential Biomass Consumption	0	0	10
Output Variables	Commercial Cogeneration Revenue	10.00	0	0
	Industrial Cogeneration Revenue	0	10.00	0
	Residential Biomass Available Capacity	0	0	10.00

Table 10. Wood Submodule Conditional Sensitivities.

Case	High Commercial Price	High Industrial Price	High Residential Biomass Consumptio n
Commercial Cogeneration Revenue	1.00	0	0
Industrial Cogeneration Revenue	0	1.00	0
Residential Available Capacity	0	0	1.00

Geothermal Submodule

Table 11 summarizes the sensitivity analysis for the Geothermal submodule. It presents the base case values for the input and output variables, the adjusted values for the input variables, and the resulting values for the output variables. Tables 12 and 13 show values calculated from Table 11. In the NEMS base case, Geothermal Capacity Additions (UADDGET) from the Electricity Market Module (EMM), was zero GW in all forecast years, because the high cost of geothermal plants precluded EMM from selecting them in competition with other resources. In order to create a sensitivity case, the analysis therefore assumes a 1 GW capacity addition in each of the 15 EMM regions in 2005. As shown in Table 11, the potential national total of the additions created was therefore 15 GW. The design of the Geothermal submodule, however, allows geothermal facilities only in regions determined *a priori* to have geothermal potential: i.e., those four that are west of the Rocky Mountains, including Hawaii. The available capacity therefore increases by only about 4 GW over the entire nation. Realized capacity is somewhat less, however, due to the fact that the potential plants available do not sum to exactly the additional capacity requested.

Because the value of the input variable was zero in the Base Case, as discussed above, it is impossible to calculate the percent change measures presented for the other RFM resources, as division by zero would result. The tables therefore present instead absolute changes and simple, rather than conditional, sensitivities.

In the tables, the fact that a change in the input variable in a single year causes changes in the solution over a period of years, some before the year of change, is reflective of the fact that the Geothermal submodule, unlike the other RFM submodules, contains a detailed simulation of the investment decision-making process. In order to implement an increase in installed capacity in a certain year, the utility must begin planning prior to the on-line year, and take some years to build and calibrate the installation. Figure 1 shows this phenomenon for data from Table 11.

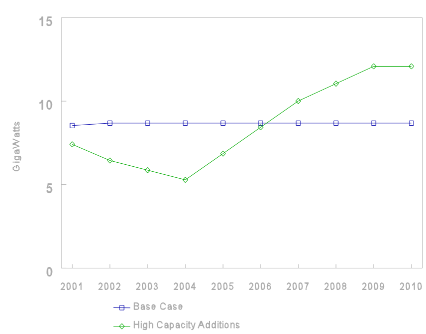

Figure 1. Maximum Utility Geothermal Capacity: Case Comparison.

Table 11. Geothermal Submodule Sensitivity Analysis.

		Case	Base	High Capacity Additions
Input Variable	Geothermal Capacity Additions (GW)		***0***	15
Output Variables	Maximum Utility Geothermal Capacity (GW)	2001	***8.534***	7.414
		2002	***8.684***	6.444
		2003	***8.684***	5.864
		2004	***8.684***	5.284
		2005	***8.684***	6.859
		2006	***8.684***	8.434
		2007	***8.684***	10.009
		2008	***8.684***	11.044
		2009	***8.684***	12.079
		2010	***8.684***	12.079
	Fixed Operating Costs (1987 $/KW)	2001	***57.01***	58.94
		2002	***56.86***	61.21
		2003	***56.86***	62.95
		2004	***56.86***	65.05
		2005	***56.86***	60.33
		2006	***56.86***	57.26
		2007	***56.86***	55.07
		2008	***56.86***	53.88
		2009	***56.86***	52.89
		2010	***56.86***	52.89
	Average Heat Rate (Btu/KWh)	2001	***28833***	28700
		2002	***28847***	28551
		2003	***28847***	28562
		2004	***28847***	28578
		2005	***28847***	29400
		2006	***28847***	29728
		2007	***28847***	29959
		2008	***28847***	30080
		2009	***28847***	30181
		2010	***28847***	30181
	CO_2 Emissions (lb/MMBtu)	2005	***14.625***	11.939
		2006	***14.625***	11.939
		2007	***14.625***	11.939
		2008	***14.625***	11.939
		2009	***14.625***	11.939
		2010	***14.625***	11.939

Note: ***Bold italic*** values are from the NEMS base case.

Table 12. Geothermal Submodule Absolute Changes.

		Case	High Capacity Additions
Input Variable	Geothermal Capacity Additions (GW)		15
Output Variables	Maximum Utility Geothermal Capacity (GW)	2001	-1.120
		2002	-2.240
		2003	-2.820
		2004	-3.400
		2005	-1.825
		2006	-.250
		2007	1.325
		2008	2.360
		2009	3.395
		2010	3.395
	Fixed Operating Costs (1987 $/KW)	2001	1.93
		2002	4.35
		2003	6.09
		2004	8.19
		2005	3.47
		2006	.40
		2007	-1.79
		2008	-2.98
		2009	-3.97
		2010	-3.97
	Average Heat Rate (Btu/KWh)	2001	-137
		2002	-296
		2003	-285
		2004	-269
		2005	553
		2006	881
		2007	1112
		2008	1233
		2009	1334
		2010	1334
	CO_2 Emissions (lb/MMBtu)	2005	-2.686
		2006	-2.686
		2007	-2.686
		2008	-2.686
		2009	-2.686
		2010	-2.686

Table 13. Geothermal Submodule Sensitivities.

	Case	High Capacity Additions
Maximum Utility Geothermal Capacity (GW/GW)	2001	-.075
	2002	-.149
	2003	-.188
	2004	-.227
	2005	-.122
	2006	-.017
	2007	.088
	2008	.157
	2009	.226
	2010	.226
Fixed Operating Costs (1987 $/KW/GW)	2001	.13
	2002	.29
	2003	.41
	2004	.55
	2005	.23
	2006	.03
	2007	-.12
	2008	-.20
	2009	-.26
	2010	-.26
Average Heat Rate (Btu/KWh/GW)	2001	-9
	2002	-20
	2003	-19
	2004	-18
	2005	37
	2006	59
	2007	74
	2008	82
	2009	89
	2010	89
CO_2 Emissions (lb/MMBtu/GW)	2005	-.179
	2006	-.179
	2007	-.179
	2008	-.179
	2009	-.179
	2010	-.179

Furthermore, the Geothermal submodule works with a database of specific potential geothermal sites, each characterized by certain parameters, such as capacity, costs and efficiency characteristics. Accordingly, the addition of a certain amount of capacity entails the choice of a certain facility, or group of facilities, that most closely match(es) the desired additional capacity. The newly added facilities in our sensitivity analysis, because they employ improved technology expected by 2005, are somewhat less expensive to operate, and have better efficiency and environmental characteristics than existing plants.

Municipal Solid Waste Submodule

Table 14 summarizes the sensitivity analysis for the Municipal Solid Waste submodule. It presents the base case values for the input and output variables, the adjusted values for the input variables, and the resulting values for the output variables. Tables 15 and 16 show values calculated from Table 14.

In the Municipal Solid Waste submodule, production of waste is assumed to be a linear function of GDP. Fixed proportions of the waste stream in any year are assumed to be available to be burned as fuel in each sector. These assumptions in combination result in the virtually identical sectoral capacity sensitivities shown in the tables.

Table 14. Municipal Solid Waste Submodule Sensitivity Analysis.

	Case	Base	High GDP
Input Variable	Gross Domestic Product (1987 $B)	***6736***	7410
Output Variables	Maximum Utility MSW Capacity (MW)	***4431***	4849
	Maximum Commercial MSW Capacity (TBtu/yr)	***60.20***	65.88
	Maximum Industrial MSW Capacity (TBtu/yr)	***76.88***	84.14

Note: ***Bold italic*** values are from the NEMS base case.

Table 15. Municipal Solid Waste Submodule Percent Changes.

	Case	High GDP
Input Variable	Gross Domestic Product	10
Output Variables	Maximum Utility MSW Capacity	9.5
	Maximum Commercial MSW Capacity	9.4
	Maximum Industrial MSW Capacity	9.4

Table 16. Municipal Solid Waste Submodule Conditional Sensitivities.

Case	High GDP
Maximum Utility MSW Capacity	.95
Maximum Commercial MSW Capacity	.94
Maximum Industrial MSW Capacity	.94