Assessment of the Potential for Distributed Resources Using a New Modeling Framework

Subtask 3

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Background

Introduction

This *Results* Report follows up on a previous Report, *Implementation of Distributed Generation Analytic Framework Building Upon NEMS/POEMS*[1]. That *Implementation* Report detailed the preliminary distributed generation routines that were added to the demand models for the Annual Energy Outlook 2000 and then discussed and implemented a variety of model code changes and enhancements that might improve upon that foundation. The *Implementation* report then specifically addressed the NEMS residential model routine (which very directly parallels the NEMS commercial model routine) and discussed an alternative enhanced distributed generation model that used some alternative algorithms, but built upon the code and inputs that were already there. The *Implementation* report directly addressed model code changes and the implementation of a number of changes in the preliminary code for the NEMS residential model. The end result along with the report was a new, alternative residential distributed generation model that could be run and tested both in a standalone mode and in the full NEMS/POEMS system. This effort was made towards the goal of modeling distributed generation in the context of the National Energy Modeling System (NEMS) and the Policy Office Electricity Modeling System (POEMS).

Integrated Version of the Model for NEMS and POEMS

The National Energy Modeling System (NEMS)[2] is developed and maintained by the Energy Information Administration (EIA). NEMS is used by the EIA to develop the Annual Energy Outlook (AEO) projections and is also used by EIA to prepare analytical studies for the U.S. Congress and other offices within the Department of Energy. NEMS is a complex energy modeling system but is publicly available for other organizations to use. One example of an external organization working with NEMS is the extension of NEMS to create the Policy Office Electricity Modeling System (POEMS)[3] which substitutes a more detailed electricity model into NEMS. This electricity model, TradeElec, is related to the NEMS electricity model, but is designed specifically to analyze electricity restructuring issues with its much greater regional detail used for the modeling of electricity trading.

The projections in NEMS are developed with the use of a market-based approach to energy analysis. For each fuel and consuming sector, NEMS balances the energy supply and demand, accounting for the economic competition between the various energy fuels and sources. The time horizon of NEMS is the midterm period, approximately 20 years in the future.

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[1]This report was submitted as the second deliverable in this Task. It is dated October 29, 1999.

[2]For a more complete description see *The National Energy Modeling System: An Overview 1998*, DOE/EIA-0581(98), February 1998, Washington, DC. (This is available at www.eia.doe.gov.)

[3]For a more complete description see Policy Office Electricity Modeling System (POEMS) Model Documentation, In Support of the Department of Energy's Comprehensive Electricity Competition Plan, ONLOC-99-05, May 1999, Dunn Loring, Virginia. (This is available at www.onlocationinc.com.)

NEMS is organized and implemented as a modular system. The modules represent each of the fuel supply markets, conversion sectors, and end-use consumption sectors of the energy system. NEMS also includes macroeconomic and international modules. NEMS is a regional system, functioning and reporting at the nine Census division level. The end use demand models and some other components operate at the nine Census division level, but the supply and conversion models operate internally using a variety of other, sector-specific regional definitions. The primary flows of information between these modules are the delivered prices of energy to the end user and the quantities consumed by product, region, and sector. The information flows also include other data such as economic activity, domestic production activity, and international petroleum supply availability. The execution of each of the component modules is controlled by the integrating module which also tests for convergence.

The POEMS model is a version of the NEMS which substitutes an alternative electricity model (described above), but otherwise includes all of the other component modules and retains the same integrating module and execution system. For various purposes or analyses, some changes are made to various algorithms in some component modules. The discussion of proposals for and implementation of modeling changes for distributed generation in this *Results* report would be in the context of the NEMS and POEMS models and could be applied to one or the other or both.

The Approach in This Report

The previous *Implementation* report fully described and discussed changes that might improve and enhance the preliminary residential distributed generation model. These changes were made in the model code and some results were provided. In addition, the *Implementation* report fully described and discussed a new, alternative residential distributed generation model that included a methodology that competed the various technologies against each other and against the price of purchased electricity. This model code was implemented in the standalone residential model on the PC and a run was made using "optimistic" inputs that provided test results.

As noted in the *Implementation* report, although the NEMS buildings models, residential and commercial, are very different from each other in their approach and structure, they have a lot of similarities in the way that they use energy. They also have a lot of similarities with respect to distributed generation. The preliminary NEMS model is basically the same for each, except for the slate of technologies and their attributes. The alternative distributed generation model was built for the residential sector, but can easily be adapted to the commercial sector. Although the alternative residential sector distributed generation model is discussed in this *Results* report, the conclusions would also apply to a commercial sector distributed generation model.

Since the previous *Implementation* report was completed, the Annual Energy Outlook 2000 was released along with the models and inputs that went into producing it. We have examined the distributed generation model that was used and have compared it to the preliminary distributed generation model that we have been describing up to this point. The next section of this *Results* report details the few differences in code and inputs and describes how we have updated the alternative model to reflect these changes. This if followed by a section that discusses the creation of a "reference case" for the alternative distributed generation model and proceeds to examine a number of model sensitivities relative to the reference case. These are all done in a standalone version of the residential model without the full NEMS integration effects. The final section in this *Results* report discusses some runs of the model that were made in the full integrated NEMS/POEMS system.

AEO 2000 Distributed Generation Model

The work that was done for the previous *Description* report for Subtask1 and the *Implementation* report for Subtask 2 described and built upon the preliminary versions of the distributed generation models embedded in the NEMS demand models. These preliminary versions were being developed for use in the NEMS demand models for the AEO 2000. Since we submitted the *Implementation* report for Subtask 2 a few weeks ago, the models and input files that were used in the AEO 2000 have been released and are available. This provides the opportunity to examine the final versions of the distributed generation models that were used for AEO 2000 and to incorporate any changes that were made from the preliminary version into the alternative model. Since we have concentrated on the residential distributed generation model, the following discusses the changes in the final code and input file, and describes which of those changes we have incorporated into the alternative distributed generation model.

Changes to the Code

An examination of the AEO 2000 residential model code indicates that there were a few changes made to the residential distributed generation model code since the preliminary version.

Interest Rate. The interest rate in the preliminary model was given in the distributed generation input file. It is now passed through the variable *MC_RMMTGCCNS* from the macroeconomic model. This is described as the conventional commitment mortgage rate.

Electricity Price. The electricity prices that are being used for own use and for grid sales have been changed. Previously the same price was used for each and was equal to an average electricity price multiplied by a "net metering" factor.[4] The model now uses a separate price for own use and for sales to the grid. For own use the model uses the air conditioning price (the NEMS model has separate electricity prices for each end use) which is multiplied times an inflator to convert it to 1998 dollars (the model no longer uses the net meter adjustment factor variable). For grid sales the model now uses a price that is passed to it from the electricity model in the variable *PELME*. This is a new variable in the AEO 2000 and is described as a "grid sales price" and as a "marginal energy price".

Existing Housing. The preliminary version of the distributed generation model applied the distributed generation penetration rate for each technology only to new housing in each year. The AEO 2000 version of the model extends this to existing housing, too. The penetration rate for existing housing is based upon that solved for new housing. It is equal to either the new housing penetration rate divided by

[4]The price for sales to the grid would most likely be the generation price of electricity rather than the full retail price. The net metering factor in the model allows the retail price to be multiplied by a factor that represents the portion of it that is the generation price. In some cases, legislation or regulation might require the grid sales price to be equal to the retail price and the factor would be 1.0.

50 or the value of 0.0025, whichever is smaller.[5]

Results Provided to the Electricity Model. The distributed generation model used for the AEO 2000 provides its results to the electricity model in an integrated NEMS run. These include (disaggregated by fuel, region, and year) the generation capacity, the amount of electricity generated for own use and for sales to the grid, and the amount of energy consumed.[6]

Changes to the Input File

An examination of the AEO 2000 residential model distributed generation input file indicates that there were a few changes made to the values of some variables since the preliminary version.

Included Equipment. A technology slot was available and labeled for micro turbines in the preliminary distributed generation input file. This had a mixed set of values in it, with the end result that micro turbines were in effect not modeled. The AEO 2000 input file changes the name from micro turbines to "unused", making explicit what was previously implicit. The distributed generation model considers solar photovoltaics (pvs) and fuel cells.

Sizing and Operating Hours. The capacity sizes of the equipment and their operating hours are changed in the new input file. The capacity size of solar pvs is decreased from 2.75 kw to 2.0 kw and fuel cells from 7.0 kw to 5.0 kw. The annual operating hours for fuel cells is reduced from 8000 hours to 3000 hours.

Solar Insolation. The solar insolation values by region are slightly changed, with some higher and some lower.

Technology Attributes. A few of the technology description attributes for the two technologies have changed. For solar pvs, the middle technology description (there are five vintages) was moved forward by two years, the cost was significantly reduced in some of the later vintages, a small maintenance cost was added, the lifetime was extended from 20 to 30 years, and the electric loss factor was changed from 0.8 to 1.0. For fuel cells, a very slight reduction was made to the cost of the middle vintage, the electric loss factor was changed from 0.94 to 1.0, and the recovery efficiency was changed from 0.66 to 0.75.

Exogenous Penetration. The exogenous penetration for solar pvs was reduced overall to about one-half of that in the preliminary file. There were also even more significant shifts among regions. (Exogenous penetration for fuel cells remains at 0.)

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[5]In each year, a penetration rate is applied to new housing (a flow) and to existing housing (a stock). In new housing in each year the penetration rate is applied to a new set of new housing which is then summed over time. In existing housing, it appears that the penetration rate is being applied to the same stock each year and then summed over time. This may not be intended.

[6]Note that these variables are new for the AEO 2000. The alternative distributed generation model being used for this task is built around the AEO 1999 system and that system does not include these variables.

Changes Incorporated into the Alternative Model

We have incorporated most of the changes that were made in the final version of the distributed generation code and input file for the AEO 2000 into the alternative model. The alternative model runs in the AEO 1999 system so a couple of the changes for the AEO 2000 do not apply. Moreover, the alternative model has some differences so not all the changes relate to the alternative model.

Interest Rate. The source of the interest rate was changed from the input file to the macroeconomic model variable *MC_RMMTGCCNS*.

Electricity Price. The alternative model cannot use the new variable *PELME* for marginal prices from the electricity model since it is running in the AEO 1999 version (this can easily be changed as the version in updated). This variable is being used for the price for sales to the grid, but the price at which the sales are made may depend upon legislation or regulation. For this reason, it is desirable to retain the net meter factor as an input policy lever. The best approach would be to have the option of using either the marginal price or the retail prices or some combination of the two. For the valuation of electricity purchases that are avoided because of generation for own use the NEMS model uses the airconditioning end use price. As discussed later, the alternative model uses a price adjustment factor to lower the price of avoided purchased electricity because it is expected that the residential customer will eventually have to pay for the fixed component of price independent of the amount of electricity purchased.

Existing Housing. Penetration of distributed generation technologies in existing housing has already been added to the alternative model, along with the addition of all housing types. For existing housing, the accounting that the alternative model uses takes into account the fact that the technology penetration rate is applied against the stock of existing housing.

Results Provided to the Electricity Model. The alternative model cannot use the new variables for providing results to the electricity model since it is running in the AEO 1999 version (this can easily be changed as the version in updated).[7]

New Input File. In general, across the board, we have incorporated the new input assumptions. This means two technologies, lower solar pv costs, different solar insolation, alternative exogenous technology penetration, etc. In a couple of cases, as described later, we will make some further changes to some inputs that we think might be improved.

[7] As described later, for some test runs of the full integrated system in NEMS on the RISC machine we have created a version that will pass generation, capacity, and consumption information to the electricity model using existing variables.

Reference Case Version and Sensitivity to Various Assumptions

Introduction

The construction of an alternative distributed generation model, built upon the foundation of the NEMS distributed generation model, was described in the previous report. The alternative model accounted for housing vintages and housing types within a market segmentation accounting and used a methodology that competed the technologies against each other and against purchased electricity based upon a distribution of their costs. In general, fairly optimistic assumptions were used in that report so that the effects of the models could be seen. In this report we will attempt to choose somewhat more realistic assumptions to construct a "reference case". From that reference case we will show how the model reacts to reasonable changes in the values of some of the more basic assumptions. The assumptions that we will consider include:

- *Cost Distribution Function Parameter*. In the technology competition algorithm, *lamda* is a parameter that determines the width of the distribution.
- *Discount Rate Premium*. In the algorithm for levelized costs, a premium is added to the interest rate to account for a variety of consumer behavior including risk, lack of market knowledge, lack of foresight, market imperfections, etc.
- *Consumer Amortization Lifetime*. In the algorithm for levelized costs, the present discount value is calculated based upon the consumers perceived equipment lifetime rather than the actual lifetime of the equipment. This might generally be the period of time a typical consumer spends in the same housing unit.
- *Net Meter Price Adjustment*. Electricity that is sold back to the grid might typically be priced at the generation price level rather than at the full retail price level. However, legislation or regulation can be used to set this at or close to the retail price.
- *Price for Avoided Purchased Electricity Adjustment*. Electricity purchases might consist of a fixed component of cost and a variable component of cost. If this is the case, then electricity that is not purchased (avoided) because of generation and own use might actually be valued at less than the average price paid for electricity (the fixed component is now spread over the remaining use).
- *Own Use Versus Grid Sales*. The amount of electricity used for own use versus the amount sold to the grid has an effect upon the costs and choices for distributed generation.
- *System Capacity and Annual Operating Hours*. In the current model, the system capacity and the annual operating houses have an effect on the competition and choices because they impacts on the amount of own use versus the amount of sales.
- *Equipment and Installation Costs*. Equipment and installation costs affect the cost of electricity generated by the equipment.
- *Tax Policy*. Tax credits in effect reduce the cost of the equipment making the cost of the electricity generated less expensive.
- *Housing Vintages and Types Using the Market Segmentation Accounting*. This includes assumptions on market shares for each market segment within housing vintages and types along with assumptions about the distribution of interest rates, equipment costs, installation costs, and electricity price.
- *Purchased Energy Prices*. This includes the retail prices of electricity and of natural gas.

Reference Case

The reference case uses our estimates for reasonable values for all of the parameters discussed above. The values that are assumed are given by:

Penetration Function Parameters	
Cost Distribution Function Parameter	5.0
Discount Rate Premium	5.0 percent
Consumer Amortization Lifetime	7.0 years
Electricity Pricing and Sales	
Net Meter Price Adjustment	1.0 for solar pv, 0.5 for fuel cells
Price for Avoided Purchased Electricity	0.65
Own Use as Fraction of UEC	0.60
Equipment Capacity, Operating Hours, and Costs	
Capacity	3.0kw for solar pv, 5.0kw for fuel cells
Operating Hours	n/a for solar pv, 6000 hours for fuel cells
Costs	(see below)
Policy Parameters	
Tax Credit	none
Housing Vintages, Types, and Market Segmentation	
Market Segment Shares	(see below)
Relative Interest Rate	(see below)
Relative Equipment Costs	(see below)
Relative Electricity Prices	not used
Purchased Energy Prices	
Electricity	AEO99 base case
Natural Gas	AEO99 base case

The equipment costs vary over time (there are 5 representations for each of solar pvs and for fuel cells that change over time). These are given by:

	93-99	00-04	05-09	10-14	15-20
Solar PV	7370	5136	3814	2872	2151
Fuel Cells	5000	5000	2875	2300	1600

The market segment shares are assumed to be the same over time and for new and existing housing. They vary by single family and multi family as given below:

Interest Rate / Project Size	Single Family	Multi-Family
Low Rate / Large Project	0.20	0.50
Average Rate / Small Project	0.50	0.20
Average Rate / Large Project	0.20	0.20
High Rate / Small Project	0.10	0.10

The market segment interest rate adjustment factors are assumed to be the same over time and for new and existing housing. They are also the same by single family and multi family as given below:

Interest Rate / Project Size	Single Family	Multi-Family
Low Rate / Large Project	0.75	0.75
Average Rate / Small Project	1.00	1.00
Average Rate / Large Project	1.00	1.00
High Rate / Small Project	1.33	1.33

The market segment equipment and installation cost adjustment factors are assumed to be the same over time and for new and existing housing. Equipment cost are the same by single family and multi family while installation costs vary as given below:

	Equipment Costs		Installation Costs	
Interest Rate / Project Size	Single Family	Multi-Family	Single Family	Multi-Family
Low Rate / Large Project	0.60	0.60	0.60	0.60
Average Rate / Small Project	1.00	1.00	1.00	1.00
Average Rate / Large Project	0.60	0.60	0.60	0.60
High Rate / Small Project	1.00	1.00	1.00	1.00

A variety of other inputs and assumptions are used in the reference case, but are considered to be less central or sensitive. Many of the assumptions apply only to the alternative model and not to the NEMS model. However, there is some overlap and we have made different assumptions for a couple of them. We have assumed that the capacity for solar pvs is 3.0 kw instead of 2.0 kw, closer to the original NEMS assumption. We have also assumed that the operating hours for fuel cells will be 6000 hours rather than the 3000 hours NEMS has assumed. This is much closer to the original assumption of 8000 hours and to the level used in the commercial model. (As discussed in detail later, this also causes some sales to the grid as the amount of generation crosses the threshold level between own use and sales.) In the following discussion we will be looking at sensitivities of the above variables.

The reference case model is run using the inputs described above along with the macroeconomic, price, and other inputs for the Annual Energy Outlook 1999 reference case. The model is a standalone version of the residential model running in Windows on a PC that has the alternative distributed generation model coded into it. Since this is a standalone model not running in the integrated system, there are no feedback effects from the other models. For example, although we may have an increase in natural gas consumption, there is no feedback effect from a change in natural gas price. The next chapter describes some scenarios that use the same model but run in the full integrated NEMS modeling system in UNIX on a RISC machine in order to capture feedback effects.

In the reference case, by the year 2020 there is a very small penetration of solar pvs and a somewhat larger penetration of fuel cells. Although the penetration of fuel cells is small at about 1.3 percent of residential housing units, the amount of electricity generated is significant at 170 trillion Btu, of which 147 trillion Btu is saved for own use, implying sales of about 23 trillion Btu. The solar pv generation of 4 trillion Btu plus the fuel cell generation of 147 trillion Btu translates into a reduction of electricity purchases from the AEO 99 reference case of about 151 trillion Btu. This also leads to an increase in natural gas consumption of about 423 trillion Btu. This is almost a 10 percent increase in natural gas consumption for the residential sector.

Distributed Generation Reference Case Results (in Standalone Version without Feedbacks)

	2005	2010	2015	2020
Solar PV				
Endogenous Penetration (units)	3.7	25.0	107.6	129.4
Exogenous Penetration (units)	7.8	63.7	63.7	63.7
Total Penetration (units)	11.4	88.7	171.3	193.1
Total Penetration Rate (fraction)	0.0001	0.0008	0.0014	0.0015
Electricity Generation (TBtu)	0.3	2.0	3.7	4.2
Electricity Own Use (TBtu)	0.3	2.0	3.7	4.2
Fuel Cells				
Endogenous Penetration (units)	119.3	463.9	1444.5	1745.6
Exogenous Penetration (units)	0.0	0.0	0.0	0.0
Total Penetration (units)	119.3	463.9	1444.5	1745.6
Total Penetration Rate (fraction)	0.0011	0.0039	0.0117	0.0134
Electricity Generation (TBtu)	11.6	45.1	140.5	169.8
Electricity Own Use (TBtu)	10.2	39.7	121.7	147.1
Overall Consumption (TBtu)				
Electricity Consumption in AEO99	4311.6	4588.5	4945.9	5323.7
Electricity Consumption in Reference Case	4301.7	4546.6	4820.7	5172.6
Change from AEO99	-9.9	-41.9	-125.2	-151.1
Natural Gas Consumption in AEO99	5309.8	5519.2	5776.9	5939.9
Natural Gas Consumption in Reference Case	5335.3	5619.2	6090.5	6319.0
Change from AEO99	25.5	100.0	313.6	379.1

Penetration Function Parameters

Share Parameter

The alternative residential distributed generation model competes the distributed generation technologies against each other and against electricity based upon levelized costs. Rather than use a point estimate for costs, a distribution for costs is used to calculate relative shares. As described in the previous report, a number of factors go into the annualized cost calculation, taking into account a variety of costs, prices, policies, etc. In general, however, a weight (representing a level of utility) is calculated based upon the levelized cost of each technology and the cost for avoided purchased electricity. A very general representation of that calculation is given by the following function:

Weight for OptionA = Levelized Cost for OptionA ^ (-ShareParameter) .

The weights are then summed up and the share of each technology or of electricity is its weight divided by the total.

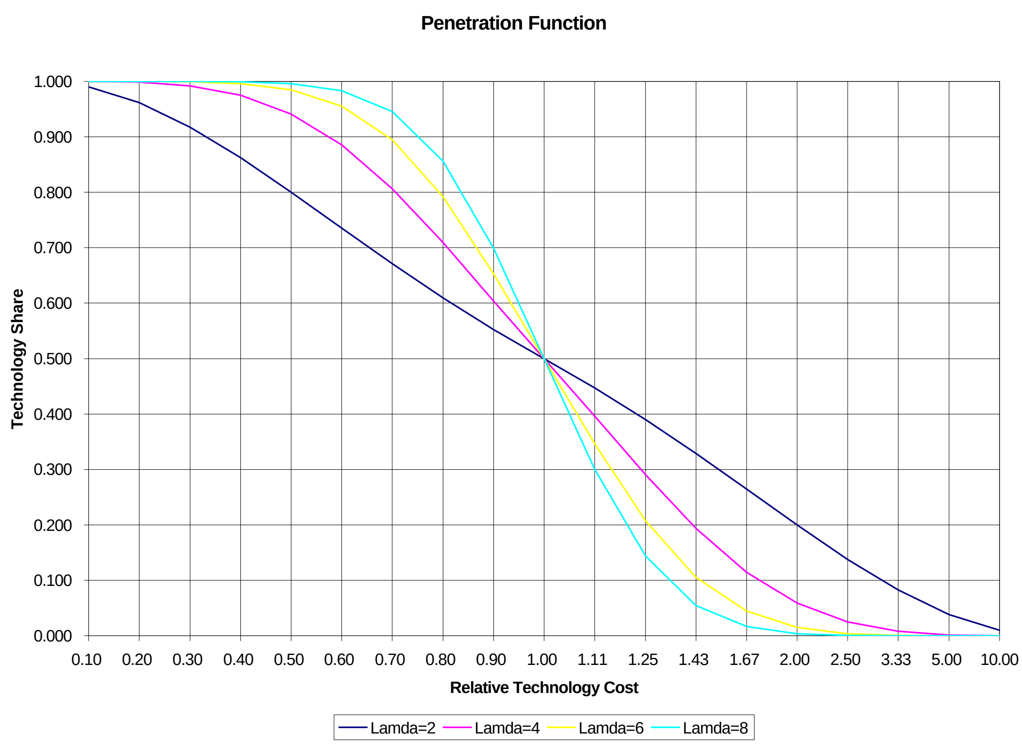
Share for OptionA = Weight for OptionA / Total of Weights for All Options .

The distribution of the shares is determined by the relative costs and the size of the share parameter. As the share parameter gets larger, the distribution is narrowed so that share for any particular technology becomes smaller if it has a cost disadvantage or becomes larger if it has a cost advantage. The actual relationship is shown in the accompanying figure, which shows the shares for an example technology at various relative costs with share parameters of 2, 4, 6, and 8.

In the reference case a share parameter of 5 is assumed, which is in the middle of those illustrated in the following figure. The following table shows the results relative to the reference case when a share parameter of 4 and a share parameter of 7 are used. Since the distributed generation technologies are generally at a cost disadvantage to electricity, the smaller share parameter increases their penetration and the larger share parameter decreases their penetration.

The result for the larger parameter (lamda = 7) is that the distributed generation resources barely penetrate, with solar pvs determined almost solely by the exogenous penetration and fuel cells having a penetration rate of only about 0.003 by 2020. The cost difference between the technologies and the cost of electricity is large enough that with the larger parameter virtually none of the technologies are chosen. The purchase of electricity and natural gas are almost back to the AEO99 level.

On the other hand, the result for the smaller parameter (lamda = 4) is that the distributed generation resources penetrate more than before. By the year 2020, the penetration rate for solar pvs is still small at 0.3% of all housing units, but for fuel cells is considerably larger at 3.8%. The purchase of electricity declines by an additional 153 trillion Btu (beyond the reference case) and the consumption of natural gas increases by 444 trillion Btu. This is a substantial amount of change from the AEO99 level, one that would be expected to have significant feedback effects in a full integrated model run.



Penetration Function Parameter Lamda Results

	Lamda = 4		Reference Case		Lamda = 7	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
Solar PV						
Endogenous Penetration (units)	105.8	447.7	25.0	129.4	1.5	11.7
Exogenous Penetration (units)	63.7	63.7	63.7	63.7	63.7	63.7
Total Penetration (units)	169.4	511.3	88.7	193.1	65.2	75.3
Total Penetration Rate	.0014	.0039	.0008	.0015	.0006	.0006
Electricity Generation (TBtu)	3.7	10.9	2.0	4.2	1.5	1.7
Electricity Own Use (TBtu)	3.7	10.9	2.0	4.2	1.5	1.7
Fuel Cells						
Endogenous Penetration (units)	1128.9	3570.3	463.9	1745.6	81.4	406.4
Exogenous Penetration (units)	.0	.0	.0	.0	.0	.0
Total Penetration (units)	1128.9	3570.3	463.9	1745.6	81.4	406.4
Total Penetration Rate	.0096	.0275	.0039	.0134	.0007	.0031
Electricity Generation (TBtu)	109.8	347.2	45.1	169.8	7.9	39.5
Electricity Own Use (TBtu)	94.8	293.9	39.7	147.1	7.2	35.1
Overall Consumption (TBtu)						
Electricity Consumption	4489.9	5019.2	4546.6	5172.6	4579.6	5287.2
Change from Reference Case	-56.7	-153.4	.0	.0	33.0	114.6
Natural Gas Consumption	5764.3	6716.9	5619.2	6319.0	5535.8	6026.9
Change from Reference Case	145.1	397.9	.0	.0	-83.4	-292.1

Discount Rate Premium

A discount rate premium is added on top of the market interest rate in the algorithm for calculating annualized costs. The premium is used to account for a variety of consumer behavior or other factors that might not be included in the algorithm such as risk, lack of market knowledge, lack of foresight, market imperfections, etc. A higher premium (higher discount rate) implies a higher present value for a stream of future costs, while a lower premium implies a lower present value. The two technologies each have a fixed capital cost and fuel cells have a stream of future costs consisting of maintenance costs and fuel costs. Purchased electricity consists solely of a stream of future costs. In this case, when the future costs become less important in the total annualized cost (higher discount rate), the total annualized cost becomes more dependent upon the fixed component. Therefore, the technologies with the capital cost component become less favorable and the penetration of solar pvs and fuel cells becomes less. On the other hand, with a lower discount rate, the penetration of solar pvs and fuel cells becomes greater.

The following table shows the results. With a lower discount rate and a higher penetration of solar pvs and fuel cells, we have a decrease in the amount of purchased electricity because more electricity is being generated and used for own use. The consumption of natural gas is greater, due to the increased use of fuel cells.

Discount Rate Premium Results

	Premium = 0.0		Reference Case		Premium = 0.15	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
Solar PV						
Endogenous Penetration (units)	56.7	285.5	25.0	129.4	5.9	32.0
Exogenous Penetration (units)	63.7	63.7	63.7	63.7	63.7	63.7
Total Penetration (units)	120.3	349.2	88.7	193.1	69.6	95.7
Total Penetration Rate	.0010	.0027	.0008	.0015	.0006	.0007
Electricity Generation (TBtu)	2.7	7.5	2.0	4.2	1.6	2.1
Electricity Own Use (TBtu)	2.7	7.5	2.0	4.2	1.6	2.1
Fuel Cells						
Endogenous Penetration (units)	735.8	2523.2	463.9	1745.6	190.7	828.8
Exogenous Penetration (units)	.0	.0	.0	.0	.0	.0
Total Penetration (units)	735.8	2523.2	463.9	1745.6	190.7	828.8
Total Penetration Rate	.0063	.0194	.0039	.0134	.0016	.0064
Electricity Generation (TBtu)	71.6	245.4	45.1	169.8	18.5	80.6
Electricity Own Use (TBtu)	62.7	210.9	39.7	147.1	16.4	70.5
Overall Consumption (TBtu)						
Electricity Consumption	4523.0	5105.6	4546.6	5172.6	4570.3	5251.3
Change from Reference Case	-23.6	-67.0	.0	.0	23.7	78.7
Natural Gas Consumption	5678.5	6488.5	5619.2	6319.0	5559.6	6119.0
Change from Reference Case	59.3	169.5	.0	.0	-59.6	-200.0

Consumer Amortization Lifetime

The discount rate is used in the algorithm for calculating annualized costs, but the calculation must look at the stream of costs over a period of years. For these calculations, the number of years that is being used is 7, representing the average amount of time that a resident remains in a single housing unit. The greater the number of years that are used in the calculation, the larger the variable cost component becomes, giving it a greater weight versus the fixed cost component. Therefore, with a greater number of years in the calculation, the distributed generation technologies become more favorable.

The table below shows the results for a consumer amortization lifetime of 4 years and 10 years versus the reference case with 7 years. With a shorter amortization period, the penetration rate for the solar pvs and for fuel cells becomes smaller and with a longer amortization period, the penetration rate becomes greater.

Consumer Amortization Lifetime Results

	Lifetime = 4		Reference Case		Lifetime = 10	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
Solar PV						
Endogenous Penetration (units)	3.3	18.2	25.0	129.4	73.1	355.7
Exogenous Penetration (units)	63.7	63.7	63.7	63.7	63.7	63.7
Total Penetration (units)	66.9	81.8	88.7	193.1	136.7	419.3
Total Penetration Rate	.0006	.0006	.0008	.0015	.0012	.0032
Electricity Generation (TBtu)	1.5	1.9	2.0	4.2	3.0	9.0
Electricity Own Use (TBtu)	1.5	1.9	2.0	4.2	3.0	9.0
Fuel Cells						
Endogenous Penetration (units)	128.0	592.0	463.9	1745.6	843.2	2781.6
Exogenous Penetration (units)	.0	.0	.0	.0	.0	.0
Total Penetration (units)	128.0	592.0	463.9	1745.6	843.2	2781.6
Total Penetration Rate	.0011	.0046	.0039	.0134	.0072	.0214
Electricity Generation (TBtu)	12.4	57.6	45.1	169.8	82.0	270.5
Electricity Own Use (TBtu)	11.1	50.5	39.7	147.1	71.7	231.9
Overall Consumption (TBtu)						
Electricity Consumption	4575.7	5271.7	4546.6	5172.6	4513.6	5083.1
Change from Reference Case	29.1	99.1	.0	.0	-33.0	-89.5
Natural Gas Consumption	5546.0	6067.4	5619.2	6319.0	5701.9	6544.9
Change from Reference Case	-73.2	-251.6	.0	.0	82.7	225.9

Electricity Pricing and Sales

Net Meter Price Adjustment

The net meter price adjustment affects the price of the electricity that is sold back to the grid. Electricity that is sold to the grid might more typically be priced at the generation price level (the marginal price level) which would be considerably less than the full retail price (which also includes transmission and distribution costs). However, legislation or regulation might require various price levels depending upon certain policy goals. This is particularly true of solar pvs, where various policy goals have encouraged the use of solar pvs by requiring that the price of electricity generated by solar pvs and sold to the grid be priced at the full retail price.

This net meter adjustment is handled in the distributed generation model by using an adjustment factor that is applied to the full retail price of electricity. In the case of solar pvs it is set at 1.0 and in the case of fuel cells it is set to 0.5. Therefore electricity generated by solar pvs and sold to the grid is sold at the full retail price, while that generated by fuel cells and sold to the grid is sold at only one-half of the full retail price. The table below shows the effect for two different cases (rather than a lower and higher value). The first case is when the adjustment factor for solar pvs is decreased from 1.0 to 0.75, and the second case is when the adjustment factor for fuel cells is increased from 0.5 to 0.75.

When the net meter adjustment for solar pvs is decreased from 1.0 to 0.75, the price at which electricity generated by solar pvs is sold to the grid is decreased. There is no effect in the model. This is because in the model, none of the electricity generated by solar pvs is sold to the grid. The reason that no electricity is sold is because the capacity size of the solar pv means that the amount of electricity generated by a typical housing unit with solar pvs is not an amount that crosses the threshold for sales to the grid. The model has a factor that determines the fraction of the electricity unit energy consumption that is own use versus that sold to the grid (this is discussed below). All electricity generated up to this amount is for own use. Sales to the grid occur only when the amount generated passes this threshold amount.

When the net meter adjustment for fuel cells is increased from 0.5 to 0.75, the price at which electricity generated by fuel cells is sold to the grid is increased. In the case of fuel cells, the capacity size and hours of use is such that the amount of electricity generated crosses the threshold so that some of the electricity is sold to the grid. Since the grid sales price is greater, fuel cells penetrate a little more in the model. The effect is modest, because the amount of sales to the grid is a modest percent of the total amount of fuel cell electricity generation.

Net Meter Price Adjustment Results

	Solar = 0.75		Reference Case		Fuel Cell = 0.75	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
Solar PV						
Endogenous Penetration (units)	25.0	129.4	25.0	129.4	25.0	128.7
Exogenous Penetration (units)	63.7	63.7	63.7	63.7	63.7	63.7
Total Penetration (units)	88.7	193.1	88.7	193.1	88.6	192.3
Total Penetration Rate	.0008	.0015	.0008	.0015	.0008	.0015
Electricity Generation (TBtu)	2.0	4.2	2.0	4.2	2.0	4.2
Electricity Own Use (TBtu)	2.0	4.2	2.0	4.2	2.0	4.2
Fuel Cells						
Endogenous Penetration (units)	463.9	1745.6	463.9	1745.6	532.0	2064.4
Exogenous Penetration (units)	.0	.0	.0	.0	.0	.0
Total Penetration (units)	463.9	1745.6	463.9	1745.6	532.0	2064.4
Total Penetration Rate	.0039	.0134	.0039	.0134	.0045	.0159
Electricity Generation (TBtu)	45.1	169.8	45.1	169.8	51.7	200.7
Electricity Own Use (TBtu)	39.7	147.1	39.7	147.1	44.2	168.2
Overall Consumption (TBtu)						
Electricity Consumption	4546.6	5172.6	4546.6	5172.6	4542.1	5151.6
Change from Reference Case	.0	.0	.0	.0	-4.5	-21.0
Natural Gas Consumption	5619.2	6319.0	5619.2	6319.0	5634.1	6388.5
Change from Reference Case	.0	.0	.0	.0	14.9	69.5

Price for Avoided Purchased Electricity

The adjustment to the price for avoided purchased electricity affects the price of the electricity that would have been consumed, but is now *avoided* (not purchased) because of own use consumption of generated electricity. This price is of interest in the model because we need to compare the cost of the purchased electricity we avoid to the cost of the electricity generated by the technologies we are considering. It might be thought that the price of this avoided electricity purchase would be the retail price of electricity, but this model allows it to be a factor of the retail price of electricity. This is because the price of purchased electricity consists of a variable component and a fixed component. If residential customers decide to generate a greater amount of electricity on their own, and purchase less electricity, the fixed component becomes a greater proportion of the purchased electricity cost. It is expected that at some point these costs will become unbundled and passed to the customer. In that case, the price of the avoided purchased electricity in effect becomes less than the full retail price. In the reference case we have set the avoided purchased electricity price adjustment factor to 0.65.[8]

The table below shows the effect of decreasing the avoided purchased electricity price adjustment factor to 0.5 and of increasing the factor to 0.9. When the factor is less, we are saying that the price of the purchased electricity that is avoided is less than the full retail price. This means that the value of the savings we get from avoiding the purchase of that electricity is less, meaning that the value of the electricity generated is less. With a lower price for avoided electricity purchases, the distributed generation technology becomes less valuable and the penetration is less. When the price of avoided purchased electricity is higher, the value of the savings for the same amount of generation becomes higher and the distributed generation technologies penetrate more. This can have a fairly large impact upon the results as shown in the table.

[8]The model uses an adjustment factor on the retail price of electricity to model the price of avoided purchased electricity. It is clear from the discussion above that this is a fairly simplistic way of representing this price. An enhanced version might explicitly take into account the fixed and varible components of the bill.

Avoided Purchased Electricity Price Result

	Factor = 0.5		Reference Case		Factor = 0.9	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
Solar PV						
Endogenous Penetration (units)	6.8	35.5	25.0	129.4	121.7	615.2
Exogenous Penetration (units)	63.7	63.7	63.7	63.7	63.7	63.7
Total Penetration (units)	70.4	99.1	88.7	193.1	185.4	678.8
Total Penetration Rate	.0006	.0008	.0008	.0015	.0016	.0052
Electricity Generation (TBtu)	1.6	2.2	2.0	4.2	4.1	14.5
Electricity Own Use (TBtu)	1.6	2.2	2.0	4.2	4.1	14.5
Fuel Cells						
Endogenous Penetration (units)	127.2	495.7	463.9	1745.6	2137.0	6744.7
Exogenous Penetration (units)	.0	.0	.0	.0	.0	.0
Total Penetration (units)	127.2	495.7	463.9	1745.6	2137.0	6744.7
Total Penetration Rate	.0011	.0038	.0039	.0134	.0182	.0519
Electricity Generation (TBtu)	12.4	48.2	45.1	169.8	207.8	655.9
Electricity Own Use (TBtu)	10.9	42.0	39.7	147.1	180.3	546.8
Overall Consumption (TBtu)						
Electricity Consumption	4575.8	5279.8	4546.6	5172.6	4404.0	4762.6
Change from Reference Case	29.2	107.2	.0	.0	-142.6	-410.0
Natural Gas Consumption	5545.8	6046.3	5619.2	6319.0	5984.1	7409.3
Change from Reference Case	-73.4	-272.7	.0	.0	364.9	1090.3

Own Use as a Fraction of UEC

The electricity that is generated can be used for a combination of own use or of sales to the grid. Following the original NEMS model, this alternative model assumes that all electricity generated is used for own use up to some threshold level. All generation above this threshold level is sold to the grid. In the original model the threshold level was a fixed, exogenous amount. The alternative model first determines the amount of the unit energy consumption of electricity for the particular housing unit, and then sets the threshold level as a fraction of the unit energy consumption. In the reference case this fraction is set to be 0.60, so that if the unit energy consumption were, for example, 40 million Btu, then the threshold level for sales to the grid would be 24 million Btu. Because electricity use is not uniform throughout a year or a day, the distributed technology cannot meet all the electricity demand unless it were sized to meet the peak demand and to sell substantial amounts.

The table below shows the effect on the model results when this factor is decreased to 0.5 and increased to 0.75. To calculate the value of the electricity displaced by the generation, there are two distinct components; the value of the electricity for own use and the value of the electricity that is sold to the grid. Each of these has a different price associated with it (the two items discussed above) and in general the electricity that is sold to the grid will have a lower price and a lower value. Therefore, the greater the proportion of the electricity that is own use versus the amount that is sold to the grid, the greater the value of the electricity savings (the value of the distributed generation technology). This is true, of course, only when some of the electricity generation is sold to the grid. In the case of solar pvs, the amount of generation is small enough that even with the lower factor, none of the generation is sold to the grid. Therefore, the change in this factor has no effect on solar pvs, other than a very small feedback effect.[9] However, for fuel cells, some of the generation is sold to the grid in all cases. When the sales factor is increased to 0.75 this increases the value of the fuel cell generation and increases its penetration as shown in the table. When the sales factor is decreased to 0.5 this decreases the value of the fuel cell

[9]The technologies are competed against each other and against purchased electricity, so anything that affects one will affect the others. However, since the penetration rates are so small for the technologies, a change in one has only very slight changes in the others.

generation and decreases its penetration. The effects are fairly modest because the amount of sales is also a modest proportion of the total generation by fuel cells.

Own Use Fraction of UEC Results

	Factor = 0.5		**Reference Case**		**Factor = 0.75**	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
Solar PV						
Endogenous Penetration (units)	25.2	130.6	25.0	129.4	24.9	128.0
Exogenous Penetration (units)	63.7	63.7	63.7	63.7	63.7	63.7
Total Penetration (units)	88.8	194.2	88.7	193.1	88.5	191.7
Total Penetration Rate	.0008	.0015	.0008	.0015	.0008	.0015
Electricity Generation (TBtu)	2.0	4.2	2.0	4.2	2.0	4.2
Electricity Own Use (TBtu)	2.0	4.2	2.0	4.2	2.0	4.2
Fuel Cells						
Endogenous Penetration (units)	253.0	1026.2	463.9	1745.6	666.0	2431.8
Exogenous Penetration (units)	.0	.0	.0	.0	.0	.0
Total Penetration (units)	253.1	1026.2	463.9	1745.6	666.0	2431.8
Total Penetration Rate	.0022	.0079	.0039	.0134	.0057	.0187
Electricity Generation (TBtu)	24.6	99.8	45.1	169.8	64.8	236.5
Electricity Own Use (TBtu)	18.4	73.7	39.7	147.1	59.8	217.4
Overall Consumption (TBtu)						
Electricity Consumption	4567.9	5246.0	4546.6	5172.6	4526.5	5102.4
Change from Reference Case	21.3	73.4	.0	.0	-20.1	-70.2
Natural Gas Consumption	5573.2	6162.1	5619.2	6319.0	5663.3	6468.6
Change from Reference Case	-46.0	-156.9	.0	.0	44.1	149.6

Equipment Capacity, Operating Hours, and Costs

Equipment Capacity

The equipment capacity in the original model and in this alternative model is fixed in size and is read in from an input file. Equipment capacity, as used in the model, affects only the amount of electricity generated by the equipment (the number of operating hours also effects the amount of electricity generated).[10] The table below shows the effect of different equipment capacities. In the reference case the capacities were 3.0 kw for solar pvs and 5.0 kw for fuel cells. In the smaller capacity case below, the capacities are 2.0 and 3.0 respectively, and in the larger capacity case they are 5.0 and 7.0. The capacity changes do not have any direct effect (but have a small feedback effect) on the penetration of solar pvs because in either case the amount of electricity generated by solar pvs does not reach the threshold where the valuation of electricity changes (and since there are no fuel costs, this also has no effect). However, the capacity changes do have an effect on the amount of electricity generated by solar pvs, because with a higher capacity the same piece of equipment generates more electricity.

[10]For a given equipment capacity size, as the technology is used more and more (and more electricity is generated), the equipment costs are allocated over a larger base and the fuel costs remain the same per unit, so the unit cost of the technology becomes less and less. However, when the amount of electricity generated gets to a threshold level between own use and sales to the grid, the value of the electricity generated changes because of the difference between the price of avoided purchased electricity and the net meter price of electricity. The price of avoided purchased electricity is generally higher than the net meter price, so as more electricity is generated past the threshold point (due to increased use or hours), the value of this marginal electricity is reduced. Depending upon the level of fuel costs and of the “grid sales” price, the lowest overall cost may be at the level of generation that is equal to the threshold between own use and sales to the grid. Both the NEMS and the alternative models would be improved if the amount of own use versus sales to the grid were endogenous, as well as the equipment capacity and equipment operating hours.

The capacity changes do have a significant effect upon the penetration of fuel cells, where there are fuel costs and where the amount of generation is typically above the threshold point. In the reference case the fuel cell capacity is large enough that some of the electricity generated is sold to the grid. Sales to the grid receive less than the price for avoided purchased electricity, so they are less valuable. When the capacity size is reduced so that there are no sales to the grid and all generation is for own use, the technology becomes more valuable and the penetration increases. In this case, the increased penetration apparently outweighs the decrease in capacity so that the total generation by fuel cells increases. In the case where the capacity size of fuel cells is increased the economics become worse than in the base case because all of the additional electricity generated is sold to the grid, so the penetration becomes less.

Equipment Capacity Results

	Smaller Capacity		Reference Case		Larger Capacity	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
Solar PV						
Endogenous Penetration (units)	24.6	125.0	25.0	129.4	25.2	131.3
Exogenous Penetration (units)	63.7	63.7	63.7	63.7	63.7	63.7
Total Penetration (units)	88.2	188.6	88.7	193.1	88.9	195.0
Total Penetration Rate	.0008	.0015	.0008	.0015	.0008	.0015
Electricity Generation (TBtu)	1.3	2.7	2.0	4.2	3.3	7.1
Electricity Own Use (TBtu)	1.3	2.7	2.0	4.2	3.3	7.1
Fuel Cells						
Endogenous Penetration (units)	1079.2	3935.5	463.9	1745.6	133.8	558.9
Exogenous Penetration (units)	.0	.0	.0	.0	.0	.0
Total Penetration (units)	1079.2	3935.5	463.9	1745.6	133.8	558.9
Total Penetration Rate	.0092	.0303	.0039	.0134	.0011	.0043
Electricity Generation (TBtu)	63.0	229.6	45.1	169.8	18.2	76.1
Electricity Own Use (TBtu)	63.0	229.5	39.7	147.1	11.7	48.5
Overall Consumption (TBtu)						
Electricity Consumption	4524.0	5091.8	4546.6	5172.6	4573.3	5268.3
Change from Reference Case	-22.6	-80.8	.0	.0	26.7	95.7
Natural Gas Consumption	5648.5	6413.9	5619.2	6319.0	5560.2	6114.5
Change from Reference Case	29.3	94.9	.0	.0	-59.0	-204.5

Equipment Operating Hours

The level of operating hours for equipment applies only to the fuel cells. An increase in the operating hours for fuel cells causes more electricity to be generated. Solar pvs are on all the time and their amount of generation (for a given amount of insolation, conversion efficiency, etc.) is determined solely by their capacity size. However, there may also be a slight feedback effect on solar pvs from a change in operating hours for fuel cells.

The table below shows the effects of lower and higher operating hours for fuel cells. In the reference case there already are some sales to the grid because the amount of electricity generated is greater than the threshold point between own use and sales. Because the reference case is already above this threshold level, when the operating hours are increased, all of the increment in generation goes to sales. Sales have less value than own use, so the competitiveness of the technology decreases as there are more sales. This causes the penetration of the fuel cell to decrease. In the case shown in the table, the increment in generation due to the increase in hours is greater than the decrement in generation due to the decrease in penetration so the total amount of generation by fuel cells increases.

When the operating hours are decreased, the amount of generation moves below the threshold point, so that all generation is for own use. The amount of generation is far enough below the threshold level to cause the competitiveness of the fuel cell to be worse than in the reference case, leading to a decrease in penetration. At 3000 hours of operation, fuel cell penetration and generation of electricity is significantly reduced.

Equipment Operating Hours Results

	Hours = 3000		Reference Case		Hours = 8000	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
Solar PV						
Endogenous Penetration (units)	25.2	131.1	25.0	129.4	25.1	130.0
Exogenous Penetration (units)	63.7	63.7	63.7	63.7	63.7	63.7
Total Penetration (units)	88.9	194.8	88.7	193.1	88.7	193.6
Total Penetration Rate	.0008	.0015	.0008	.0015	.0008	.0015
Electricity Generation (TBtu)	2.0	4.2	2.0	4.2	2.0	4.2
Electricity Own Use (TBtu)	2.0	4.2	2.0	4.2	2.0	4.2
Fuel Cells						
Endogenous Penetration (units)	117.6	550.8	463.9	1745.6	385.5	1402.7
Exogenous Penetration (units)	.0	.0	.0	.0	.0	.0
Total Penetration (units)	117.6	550.8	463.9	1745.6	385.5	1402.7
Total Penetration Rate	.0010	.0042	.0039	.0134	.0033	.0108
Electricity Generation (TBtu)	5.7	26.8	45.1	169.8	50.0	181.9
Electricity Own Use (TBtu)	5.7	26.8	39.7	147.1	33.5	119.9
Overall Consumption (TBtu)						
Electricity Consumption	4580.6	5292.9	4546.6	5172.6	4552.8	5199.9
Change from Reference Case	34.0	120.3	.0	.0	6.2	27.3
Natural Gas Consumption	5529.4	5991.4	5619.2	6319.0	5633.3	6357.8
Change from Reference Case	-89.8	-327.6	.0	.0	14.1	38.8

Equipment Costs

In the reference case each technology has five different equipment costs that represent the technology at five different points in time. In the lower cost case we have multiplied all these reference case costs by a factor of 0.85. In the higher cost case we have multiplied all these reference case costs by a factor of 1.15.

The effect on the model is very straightforward. When the costs are decreased, the penetration of each technology increases and the amount of generation increases. When the costs are increased, the penetration of each technology decreases and the amount of generation decreases.

Equipment Costs Results

	Factor = 0.85		Reference Case		Factor = 1.15	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
Solar PV						
Endogenous Penetration (units)	49.6	250.6	25.0	129.4	13.7	72.1
Exogenous Penetration (units)	63.7	63.7	63.7	63.7	63.7	63.7
Total Penetration (units)	113.3	314.2	88.7	193.1	77.3	135.8
Total Penetration Rate	.0010	.0024	.0008	.0015	.0007	.0010
Electricity Generation (TBtu)	2.5	6.8	2.0	4.2	1.8	3.0
Electricity Own Use (TBtu)	2.5	6.8	2.0	4.2	1.8	3.0
Fuel Cells						
Endogenous Penetration (units)	702.3	2425.4	463.9	1745.6	316.2	1277.4
Exogenous Penetration (units)	.0	.0	.0	.0	.0	.0
Total Penetration (units)	702.3	2425.4	463.9	1745.6	316.2	1277.4
Total Penetration Rate	.0060	.0187	.0039	.0134	.0027	.0098
Electricity Generation (TBtu)	68.3	235.9	45.1	169.8	30.7	124.2
Electricity Own Use (TBtu)	59.8	202.9	39.7	147.1	27.1	108.3
Overall Consumption (TBtu)						
Electricity Consumption	4525.9	5114.3	4546.6	5172.6	4559.4	5212.7
Change from Reference Case	-20.7	-58.3	.0	.0	12.8	40.1
Natural Gas Consumption	5671.2	6467.2	5619.2	6319.0	5587.0	6216.8
Change from Reference Case	52.0	148.2	.0	.0	-32.2	-102.2

Policy Parameters

Tax Credit

A tax credit pays for part of the cost of a technology and the consequence is to reduce the cost of the technology to the consumer. In this model, the full amount of the tax credit is rebated through taxes (rather than the tax percentage amount). However, the tax credit is rebated in a later period so it is discounted. In the reference case there is no tax credit. The table below shows a tax credit for solar and a tax credit for fuel cells, each separately. The tax credit in each case is 20 percent of the cost, up to a maximum of $5000. In each case the results are very straightforward, with an increase in penetration for the technology that has a tax credit. There is a very small indirect feedback effect on the other technology.

Tax Credit Results

	Solar Credit		Reference Case		Fuel Cell Credit	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
Solar PV						
Endogenous Penetration (units)	53.0	263.8	25.0	129.4	24.9	128.4
Exogenous Penetration (units)	63.7	63.7	63.7	63.7	63.7	63.7
Total Penetration (units)	116.6	327.4	88.7	193.1	88.5	192.1
Total Penetration Rate	.0010	.0025	.0008	.0015	.0008	.0015
Electricity Generation (TBtu)	2.6	7.1	2.0	4.2	2.0	4.2
Electricity Own Use (TBtu)	2.6	7.1	2.0	4.2	2.0	4.2
Fuel Cells						
Endogenous Penetration (units)	463.6	1740.6	463.9	1745.6	710.9	2410.1
Exogenous Penetration (units)	.0	.0	.0	.0	.0	.0
Total Penetration (units)	463.6	1740.6	463.9	1745.6	710.9	2410.1
Total Penetration Rate	.0039	.0134	.0039	.0134	.0061	.0185
Electricity Generation (TBtu)	45.1	169.3	45.1	169.8	72.8	246.7
Electricity Own Use (TBtu)	39.7	146.7	39.7	147.1	61.2	203.0
Overall Consumption (TBtu)						
Electricity Consumption	4546.0	5170.2	4546.6	5172.6	4525.2	5116.8
Change from Reference Case	-.6	-2.4	.0	.0	-21.4	-55.8
Natural Gas Consumption	5619.1	6317.9	5619.2	6319.0	5682.2	6494.7
Change from Reference Case	-.1	-1.1	.0	.0	63.0	175.7

Housing Vintages and Types and Market Segmentation

Market Segment Shares

The effect of changes in the market segment shares is relatively straightforward. The table below shows the effects of increasing the shares of the smaller projects and the effects of increasing the shares of the larger projects. In each case about 20 percent of the shares were shifted between the two smaller and the two larger projects. Smaller projects generally have higher costs so their penetration is less than larger projects. If the share of smaller projects is increased then the effect is to decrease the overall penetration rate of distributed generation technologies. The decrease in the penetration rate means that less electricity is generated, causing an increase in the amount of purchased electricity and a decrease in the natural gas consumption. The effect is the opposite if the share of larger projects is increased.

Market Segment Shares Results

	Smaller Projects		Reference Case		Larger Projects	
	2010	2020	2010	2020	2010	2020
Solar PV						
Endogenous Penetration (units)	17.4	94.9	25.0	129.4	31.6	159.5
Exogenous Penetration (units)	63.7	63.7	63.7	63.7	63.7	63.7
Total Penetration (units)	81.1	158.5	88.7	193.1	95.3	223.1
Total Penetration Rate	.0007	.0012	.0008	.0015	.0008	.0017
Electricity Generation (TBtu)	1.8	3.5	2.0	4.2	2.1	4.8
Electricity Own Use (TBtu)	1.8	3.5	2.0	4.2	2.1	4.8
Fuel Cells						
Endogenous Penetration (units)	350.5	1402.2	463.9	1745.6	564.4	2043.4
Exogenous Penetration (units)	.0	.0	.0	.0	.0	.0
Total Penetration (units)	350.6	1402.2	463.9	1745.6	564.4	2043.4
Total Penetration Rate	.0030	.0108	.0039	.0134	.0048	.0157
Electricity Generation (TBtu)	34.1	136.4	45.1	169.8	54.9	198.7
Electricity Own Use (TBtu)	30.0	118.5	39.7	147.1	48.3	171.9
Overall Consumption (TBtu)						
Electricity Consumption	4556.4	5202.0	4546.6	5172.6	4537.9	5147.2
Change from Reference Case	9.8	29.4	.0	.0	-8.7	-25.4
Natural Gas Consumption	5594.5	6244.0	5619.2	6319.0	5641.1	6383.9
Change from Reference Case	-24.7	-75.0	.0	.0	21.9	64.9

Market Segment Interest Rates and Relative Costs

The effects of interest rates and of equipment costs on the penetration of distributed generation technologies were each described above. Applied to market segments, the effect is basically the same and is fairly straightforward. The only difference is that the effects apply to separate market segments and the overall result depends upon the segments the change is applied to and the overall shares for the market segments..

Purchased Energy Prices

Electricity Prices

The relationship between distributed generation technologies and electricity price is not simple and has been described above. The distributed generation technologies are competing against the cost of purchased electricity. The value of displacing purchased electricity and the value of electricity sold to the grid are different and are both likely to be less than the full retail price of electricity. The level of these two prices in absolute terms and relative to each other has a strong impact on the penetration of distributed generation technologies in the model. In this model both of these prices are tied in a functional form to the retail price of electricity, so if that price changes both of these also change.

The table below shows the effects of decreasing and increasing the retail price of electricity by 25 percent. Lower electricity prices decrease the value of the savings from avoiding purchased electricity and decrease the value of selling electricity to the grid, both of which decrease the value of the distributed generation technologies. Therefore, lower electricity prices cause a lower penetration of distributed generation technologies along with less electricity generation. The effect of higher electricity prices is just the opposite, with a greater penetration of distributed generation technologies along with more electricity generation.

Electricity Price Results

	Lower El. Price 2010	Lower El. Price 2020	Reference Case 2010	Reference Case 2020	Higher El. Price 2010	Higher El. Price 2020
Solar PV						
Endogenous Penetration (units)	6.1	31.4	25.0	129.4	74.2	377.1
Exogenous Penetration (units)	63.7	63.7	63.7	63.7	63.7	63.7
Total Penetration (units)	69.7	95.0	88.7	193.1	137.8	440.8
Total Penetration Rate	.0006	.0007	.0008	.0015	.0012	.0034
Electricity Generation (TBtu)	1.6	2.1	2.0	4.2	3.0	9.4
Electricity Own Use (TBtu)	1.6	2.1	2.0	4.2	3.0	9.4
Fuel Cells						
Endogenous Penetration (units)	108.9	412.5	463.9	1745.6	1432.8	4933.3
Exogenous Penetration (units)	.0	.0	.0	.0	.0	.0
Total Penetration (units)	108.9	412.5	463.9	1745.6	1432.8	4933.3
Total Penetration Rate	.0009	.0032	.0039	.0134	.0122	.0379
Electricity Generation (TBtu)	10.6	40.1	45.1	169.8	139.3	479.7
Electricity Own Use (TBtu)	9.5	35.4	39.7	147.1	120.3	401.0
Overall Consumption (TBtu)						
Electricity Consumption	4577.3	5286.4	4546.6	5172.6	4465.0	4913.5
Change from Reference Case	30.7	113.8	.0	.0	-81.6	-259.1
Natural Gas Consumption	5541.8	6028.2	5619.2	6319.0	5830.5	7014.2
Change from Reference Case	-77.4	-290.8	.0	.0	211.3	695.2

Natural Gas Prices

The relationship between distributed generation technologies and natural gas price is fairly straightforward. Solar pvs do not consume natural gas, so natural gas prices have no direct effect upon their cost effectiveness (there are very small feedback effects). Fuel cells consume natural gas in this model in a linear relationship. With lower natural gas prices, the variable cost component for generating electricity with fuel cells is reduced and with higher natural gas prices it becomes greater. Therefore lower natural gas prices cause a larger penetration of fuel cells along with an increased amount of generation. Higher natural gas prices cause a smaller penetration of fuel cells along with a decreased amount of generation.

Natural Gas Price Results

	Lower NG. Price 2010	Lower NG. Price 2020	Reference Case 2010	Reference Case 2020	Higher NG. Price 2010	Higher NG. Price 2020
Solar PV						
Endogenous Penetration (units)	24.8	126.8	25.0	129.4	25.2	130.7
Exogenous Penetration (units)	63.7	63.7	63.7	63.7	63.7	63.7
Total Penetration (units)	88.4	190.5	88.7	193.1	88.8	194.4
Total Penetration Rate	.0008	.0015	.0008	.0015	.0008	.0015
Electricity Generation (TBtu)	2.0	4.2	2.0	4.2	2.0	4.2
Electricity Own Use (TBtu)	2.0	4.2	2.0	4.2	2.0	4.2
Fuel Cells						
Endogenous Penetration (units)	821.6	3256.8	463.9	1745.6	279.6	992.6
Exogenous Penetration (units)	.0	.0	.0	.0	.0	.0
Total Penetration (units)	821.6	3256.8	463.9	1745.6	279.6	992.6
Total Penetration Rate	.0070	.0250	.0039	.0134	.0024	.0076
Electricity Generation (TBtu)	79.9	316.7	45.1	169.8	27.2	96.5
Electricity Own Use (TBtu)	69.4	268.8	39.7	147.1	24.1	84.8
Overall Consumption (TBtu)						
Electricity Consumption	4516.9	5051.0	4546.6	5172.6	4562.2	5235.0
Change from Reference Case	-29.7	-121.6	.0	.0	15.6	62.4
Natural Gas Consumption	5697.2	6648.6	5619.2	6319.0	5579.0	6154.7
Change from Reference Case	78.0	329.6	.0	.0	-40.2	-164.3

NEMS/POEMS Integrated Model Results

Introduction

All of the runs that have been described up to this point have been run in a standalone version of the residential model that uses the base case AEO99 inputs and runs on a PC. A standalone run does not include the feedback effects that would take place in a full integrated run of the NEMS or POEMS model with other sector models running.[11] For example, these feedback effects would include the impact from the electricity model due to the residential model purchasing less electricity and selling some electricity to the grid. This would require less generation from the conventional electricity model sources causing changes in generation mix, changes in prices, changes in emissions, etc. These feedback effects would also include the impacts from the natural gas model due to the residential model purchasing more natural gas to fuel the fuel cells.[12]

In the standalone Reference Case, distributed generation technologies lead to a moderate decline in electricity consumption along with a small amount of sales to the grid. There is also a significant increase in natural gas consumption. The same Reference Case parameters and inputs are used in the first integrated model run. The second integrated model run is a case in which there is a larger decline in electricity consumption along with a greater amount of sales to the grid and a large increase in natural gas consumption. To create this case we have simply reduced the penetration function parameter, *lamda*, to 4 instead of 5.

Reference Case in the Integrated System

A Reference Case run in the standalone system was described and the results shown earlier in this report. This same run is made in the integrated system because it is a good representation of a likely outcome and also so that the effects can be compared.

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[11]In the following model results and discussion, the NEMS AEO99 model was used as the base integrating system. The integrating system and the distributed generation model implementation would be the same for the POEMS. It is also expected that the results would be essentially the same for POEMS, due to the type and extent of the distributed generation model changes.

[12]In the NEMS system up through the AEO 1999 there has been no generation of electricity by the residential sector. As a consequence there is no variable or method for reporting own use and sales of generated electricity from the residential sector to the electricity sector. The preliminary NEMS distributed generation model that is being used as the framework for this report and the previous two reports is designed for the AEO 2000, where new variables have been added for this reporting. Since we have been doing this work ahead of the AEO 2000 we have incorporated the alternative distributed generation model into the AEO 1999. For an integrated model run it is necessary to pass the residential generation to the electricity model, so we have created some new variables that collect the necessary residential values and put them into existing variables that are already being reported out of the commercial sector model for use in the electricity model.

Higher Technology Penetration Case in the Integrated System

Many of the sensitivity runs that were made earlier resulted in a higher distributed generation technology penetration. However, many of these runs had effects that were more complex, especially those that affected the proportion of own use versus sales and their price valuations. A simple, clean way to effect a higher penetration of distributed generation technologies for testing purposes in the model is to lower the value of the penetration function parameter, *lamda*. This sensitivity was implemented and discussed earlier in this report. In that case the value of lamda was lowered from 5 to 4 and the impact on the penetration of the technologies substantial. This would make a good test run for the integrated system, providing a substantial change in electricity and natural gas. This case is named the High DG Case.

Results from the Integrated Model Runs

Below are two tables that show the results. The first table compares the results of the standalone runs to the results of the respective integrated runs in the year 2020. This table shows the feedback effects of the integration on the results. The second table shows various results comparing the three integrated runs, the base AEO 99, the Reference Case and the High DG Case in the year 2020.

Comparison of Standalone Results to Full Integrated Results in 2020

	Reference Case		High DG Case	
	Standalone	**Integrated**	**Standalone**	**Integrated**
Technology Results				
Solar PVs				
Amount of Penetration (Thousand)	193	193	511	517
Penetration Rate	0.002	0.002	0.004	0.004
Electricity Generation (TBtu)	4.2	4.2	10.9	11.0
Electricity Own Use (TBtu)	4.2	4.2	10.9	11.0
Fuel Cells				
Amount of Penetration (Thousand)	1746	1833	3570	3835
Penetration Rate	0.013	0.014	0.028	0.030
Electricity Generation (TBtu)	169.8	178.3	347.2	372.9
Electricity Own Use (TBtu)	147.1	155.0	293.9	316.4
Residential Consumption and Prices				
Electricity Purchases (Quads)	5.17	5.18	5.02	5.00
Electricity Price (97$/MBtu)	20.69	20.74	20.69	20.73
Natural Gas Consumption (Quads)	6.32	6.36	6.72	6.83
Natural Gas Price (97$/MBtu)	5.75	5.69	5.75	5.61
Natural Gas Wellhead Price (dollars per Mcf)	2.66	2.70	2.66	2.70

Comparison of Standalone Cases to the Integrated Cases

A comparison of the standalone cases to the integrated cases in the table indicates that the feedbacks due to the integration cause moderate changes to the results. In the Reference Case there are only very small differences. The differences are larger in the High DG Case simply because the changes from the Base Case are greater, but even then they are small. Note that in each case we are looking at two sets of changes. First, the distributed generation model increases the consumption of natural gas and decreases the purchases of electricity in the residential sector. In a standalone run, these have no consequence. In an integrated run, these are passed to the natural gas model and to the electricity model and the models react to the changes by changing their prices. Second, the changes in prices for natural gas and for electricity are passed back to the residential model and its distributed generation model, which react to the changes. This continues in an iterative process until the changes between iterations are minimal.

In the High DG Case, the increased consumption of natural gas in the residential sector causes the wellhead price of natural gas to increase. However, the distribution margin for the residential sector is reduced by more than the increase in the wellhead price so the delivered gas price is decreases. On the other hand, the price of natural gas to the electric utility sector increases (not shown in the above table). As a consequence, the price of electricity increases slightly, causing a somewhat greater penetration of distributed generation from the standalone model result. This can be seen clearly in the increase of the number of fuel cells that penetrate.

Comparison of Integrated Model Results for the Three Cases

A comparison of the integrated model results for the three cases (AEO99, Reference Case, and High DG Case) is shown in the second table. The key difference between the cases, of course, is that distributed generation is added at two different levels. Since the High DG Case shows the largest differences, that is the case that will be discussed. In the High DG Case there is a small amount of solar pvs with a small amount of generation and a significant amount of fuel cells with a significant amount of generation. Most of this generation is used for own use with a small amount of it sold to the grid. A substantial amount of natural gas is consumed by the fuel cells.

Consumption and Prices

In the High DG Case as compared to the AEO99 Base Case, residential purchases of electricity decrease by about 340 trillion Btu, while residential purchases of natural gas increase by about 890 trillion Btu. Electric utility consumption of natural gas decreases by about 690 trillion Btu, leading to a net increase in overall natural consumption of about 210 trillion Btu. Despite the increase in residential natural gas consumption, the price of natural gas to the residential sector decreases by 0.12 dollars (97 dollars per million Btu). However, the overall price of natural gas has increased as seen in the increase in the wellhead price, and although not shown in the table, the price of natural gas to the utility sector also increases.

Electric Utilities

Since residential purchases of electricity have decreased, and since some residential generation is sold to the grid, total generation of electricity by electric utilities decreases by about 141 billion Kwh. This is made up primarily of a decrease in generation by natural gas (108 billion Kwh) but there is also a significant decrease in generation by coal (30 billion Kwh). There is also a very small decrease in generation by renewables (3 billion Kwh).

The residential sector generation for own use is shown in the table as the increase in “cogeneration” for own use of 98 billion Kwh. This relates directly to the decrease in sales by electric utilities to the residential sector of 98 billion Kwh. The smaller amount of residential sector sales to the grid shows up as the “cogeneration” sales increase of 16 billion Kwh.

Full Integrated Runs for AEO, Reference Case, and High DG Case in 2020

	AEO99	Reference Case		High DG Case	
	Result	**Result**	**Change**	**Result**	**Change**
Technology Results					
Solar PVs					
Amount of Penetration (Thousand)	0	193		517	
Penetration Rate	0.000	0.002		0.004	
Electricity Generation (TBtu)	0.0	4.2		11.0	
Electricity Own Use (TBtu)	0.0	4.2		11.0	
Fuel Cells					
Amount of Penetration (Thousand)	0	1833		3835	
Penetration Rate	0.000	0.014		0.030	
Electricity Generation (TBtu)	0.0	178.3		372.9	
Electricity Own Use (TBtu)	0.0	155.0		316.4	
Consumption and Prices					
Electricity					
Residential Purchases (Quads)	5.34	5.18	-0.16	5.00	-0.34
Residential Price (97$/MBtu)	20.70	20.74	0.04	20.73	0.03
Natural Gas					
Residential Consumption (Quads)	5.94	6.36	0.42	6.83	0.89
Electric Utility Consumption (Quads)	9.36	9.13	-0.23	8.67	-0.69
Other Consumption (Quads)	17.88	17.87	-0.01	17.89	0.01
Overall Consumption (Quads)	33.18	33.36	0.18	33.39	0.21
Residential Price (97$/MBtu)	5.73	5.69	-0.04	5.61	-0.12
Gas Wellhead Price (dollars per Mcf)	2.66	2.70	0.04	2.70	0.04
Electric Utility Sector					
Generation by Fuel Type (Billion Kwh)					
Coal	2307	2283	-24	2277	-30
Petroleum	23	24	1	23	0
Natural Gas	1349	1307	-42	1241	-108
Nuclear Power	359	359	0	359	0
Renewable and Pumped Storage	420	417	-3	417	-3
Total Generation	4458	4389	-69	4317	-141
Cogeneration - Sales (Billion Kwh)	183	189	6	199	16
Cogeneration - Own Use (Billion Kwh)	183	231	48	281	98
Residential Sales (Billion Kwh)	1564	1517	-47	1466	-98
Total Sales (Billion Kwh)	4352	4306	-46	4259	-93
Carbon Emissions					
Residential - Natural Gas (MMT/yr)	85.6	91.6	6.0	98.4	12.8
Residential - Electricity (MMT/yr)	268.4	260.5	-7.9	251.5	-16.9
Residential - Overall Total (MMT/yr)	376.2	374.4	-1.8	372.1	-4.1
Total over All Sectors (MMT/yr)	1976	1975	-1	1973	-3
Electric Generators (MMT/yr)	746.7	739.4	-7.3	730.8	-15.9

Carbon Emissions

Carbon emissions have been shifted from the electric utility sector to the residential sector, but with a slight net decrease. There is an increase in carbon emissions from residential natural gas of 12.8 million metric tons per year (MMT/yr) which is being consumed to generate electricity. At the same time there is a decrease in the carbon emissions from electric utilities of 16.9 MMT/yr because the residential sector purchases less electricity. The net change due to the residential sector is a decrease in carbon emissions of 4.1 MMT/yr. However, because of feedback effects in the full integrated modeling system, other sectors are consuming more or less of various other energy sources. The net result is that the overall change in carbon emissions is a small decrease of about 3 MMT/yr.

Note that there are a variety of things that go into the change in carbon emissions and determine whether there is a net increase or a net decrease. The most central factor is the relative conversion efficiency of producing electricity by natural gas in the residential sector versus the electric utility sector. However, this is also affected by the change in the fuel mix used by electric utilities; not all of the displaced generation will be taken out of natural gas. Another important factor is that the residential sector distributed generation model provides for a limited amount of the waste heat to be used to heat water and to offset the consumption of natural gas for water heating in the residential sector. This “cogeneration” effect can significantly improve the net conversion efficiency of the natural gas.