Modeling Distributed Electricity Generation in the NEMS Buildings Models

by

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Distributed generation refers to the production of electricity in a decentralized facility—in the present context, a building. This "nontraditional" electricity source has the advantage of allowing the capture of the "waste" heat from generation, thereby offsetting the energy requirements of other end uses and potentially lowering total energy requirements across multiple end uses (i.e., the combined requirements for electric energy, space heating energy, and water heating energy). This paradigm contrasts with central generation, where waste heat is often a negative externality that is emitted directly into the biosphere. In addition to utilizing heat energy that would otherwise be wasted, on-site generation has the additional efficiency benefit of avoiding the transmission and distribution losses associated with centralized generation and, possibly, the need for upgrades to transmission and distribution grids. Currently, the National Energy Modeling System (NEMS) buildings models characterize several distributed generation technologies: conventional oil or gas engine generation, combustion turbine technologies, and newer, still developing technologies such as solar photovoltaics (PV), fuel cells, and microturbines. This paper describes the modeling techniques, assumptions, and results for the Annual Energy Outlook 2000 *reference case. In addition, a series of alternative simulations are described, and key results for distributed generation are presented.*

Introduction

Recently, distributed generation technologies have received much attention for the potential energy savings and reliability assurances that might be achieved as a result of their widespread adoption. Fueling the attention have been the possibilities of international agreements to reduce greenhouse gas emissions, electricity sector restructuring, high power reliability requirements for certain activities, and concern about easing transmission and distribution capacity bottlenecks and congestion.[1]

This paper presents the modeling methodology, projected market penetration, and impact of distributed generation with respect to offsetting future electricity needs and carbon dioxide emissions in the residential and commercial buildings sector in the *Annual Energy Outlook 2000* (*AEO2000*) reference case. Also, a series of alternate simulations are presented with key distributed generation results. These alternatives include more optimistic assumptions regarding the cost of the newer distributed technologies, favorable compensation rates for grid sales (net metering), and aggressive tax incentives for selected technologies. Projections of future levels of distributed generation and estimated impacts on fuel consumption and carbon dioxide emissions are presented.

Model Overview

The National Energy Modeling System (NEMS) is the primary midterm forecasting tool of the Energy Information Administration (EIA), used for the projections contained in EIA's *Annual Energy Outlook* (*AEO*) and numerous special studies for the U.S. Congress and the U.S. Department of Energy (DOE). NEMS, developed in the early 1990s (and subsequently refined), consists of a series of computer simulation models that represent all the major energy supply, demand, and conversion sectors of the U.S. economy, as well as general domestic macroeconomic conditions and world oil markets.[2] Within the NEMS buildings sector models (residential and commercial sectors), the use of distributed generation technologies is projected through 2020.

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[1] The value of transmission and distribution network savings and any benefits from reduced congestion are not estimated in this paper.

[2] For detailed information on the National Energy Modeling System (NEMS), see Energy Information Administration, *National Energy Modeling System: An Overview 2000*, DOE/EIA-0581(2000) (Washington, DC, April 2000), web site ftp://ftp.eia.doe.gov/pub/pdf/multi.fuel/0581(2000).pdf.

The modeling of distributed generation equipment was expanded in the NEMS residential and commercial building sector models for EIA's *Annual Energy Outlook 2000* (*AEO2000*).[3] Currently, NEMS projects electricity generation, fuel consumption, and water and space heating energy savings (from captured waste heat from thermal technologies) for 10 distributed generation technologies: photovoltaics (PV); natural-gas-fired fuel cells, reciprocating engines, turbines, and microturbines; diesel engines; coal-fired cogeneration; municipal solid waste and wood generators; and hydroelectric. Only PV and fuel cells are considered for the residential sector, but all of the technologies are considered for use in commercial buildings.

Forecasts of distributed generation technology penetration rates are based on forecasts of the economic returns from their purchase. Penetration rates, estimated by Census division and building type, vary depending on building vintage (newly constructed versus existing space). The number of years required for the investment to recoup its flow of costs determines the technology penetration rate in the model. The more quickly costs are recovered, the higher the penetration rate. As discussed below, penetration parameter assumptions vary by technology and are currently constrained to a maximum annual penetration of 30 percent for new construction when investments yield a cumulative positive cash flow (see below) in 1 year or less. In existing floorspace, penetration in a given year is assigned a comparatively lesser rate, given the complexities and costs of building retrofits.

In addition to the modeling of distributed generation equipment based on economic returns, the NEMS residential and commercial buildings models for *AEO2000* allow program-driven penetration of distributed generation technologies. Programs such as DOE's Million Solar Roofs and the Department of Defense fuel cell demonstration program, as well as various State and local incentives and programs, may result in the adoption of distributed generation technologies based on criteria that are not strictly economic. The model user has the ability to input these units exogenously by technology, Census division, and forecast year via the distributed generation technology input files. The exogenous penetration also provides a vehicle to account for existing units already in use, such as PV systems installed under the Sacramento Municipal Utility District's Pioneers programs. The *AEO2000* reference case includes existing PV and fuel cell units, using information provided by the responsible DOE program offices and an estimate of program-driven installations under the Administration's Million Solar Roofs program.

In terms of the NEMS projections for the overall economy, investments in distributed generation reduce purchases of electricity from the electricity supply sector of NEMS. In this case, energy input requirements for generating electricity are transferred from the generation sector to the buildings sector. By generating on site, transmission and distribution losses are avoided. When PV is selected as the generator, renewable energy replaces energy input to electric utilities for the electricity that is self-generated. When fuel cells or other fuel-consuming technologies are selected, consumption of fuel by the electricity generation sector is replaced by buildings sector fuel consumption. Fuel-consuming technologies also generate waste heat, which is partially captured and used to offset water and space heating energy use. For efficient fuel-using technologies and PV, the substitution of self-generation for central station generation decreases overall primary energy consumption, as shown in the comparisons below.

Cumulative Cash Flow Approach and Market Penetration

The residential and commercial modules of NEMS determine the amount of distributed generation purchased each year for each Census division, building type, and technology type. For each potential investment decision, a cash flow analysis covering 30 years from the date of investment is calculated. The cash flow calculations include both the costs (down payments, loan payments, maintenance costs, and fuel costs) and returns (energy cost savings, tax deductions, and tax credits) from the potential investment. Cumulative cash flow for distributed generation equipment starts out negative in value, representing the up-front investment costs, before any savings can accrue. In any given year of the 30-year analysis, the net of costs and returns can be either positive or negative. If the net return is positive, then the cumulative net cash flow increases. Thus, the technology under consideration always starts out with a negative initial cash flow, which will then either increase or decrease based on the net economic returns. This approach is related to, but different from, calculating the estimated "years to simple payback." Simple paybacks are merely the investment cost divided by estimated annual savings. The cumulative positive cash flow approach incorporates financing assumptions in the calculations and can yield payback estimates that are faster

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[3] For detailed information on distributed generation modeling in the NEMS residential and commercial buildings modules, see Energy Information Administration, *Residential Sector Demand Module of the National Energy Modeling System: Model Documentation 2000*, DOE/EIA-067(2000) (Washington, DC, January 2000), web site ftp://ftp.eia.doe.gov/pub/pdf/model.docs/m067(2000).pdf; and *Commercial Sector Demand Module of the National Energy Modeling System: Model Documentation 2000*, DOE/EIA-066(2000) (Washington, DC, January 2000), web site ftp://ftp.eia.doe.gov/pub/pdf/model.docs/m066(2000).pdf.

than what would be computed as the simple payback (it can also yield “infinite” paybacks if the cumulative cash flow never becomes positive).

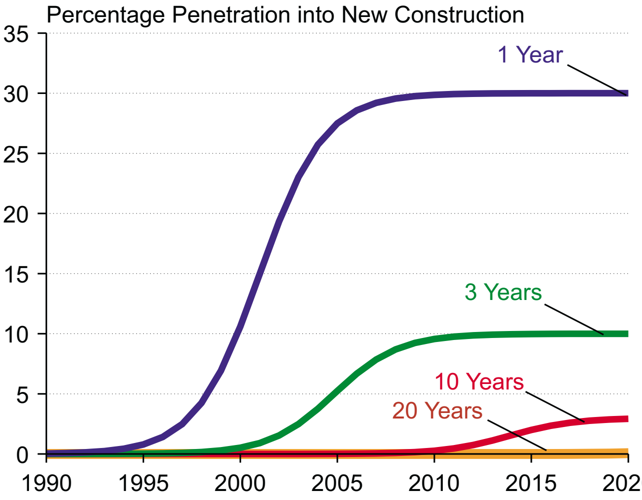
In NEMS, investment in distributed generation technologies in the buildings sector for new construction is added to the commercial loan or residential mortgage. In addition to energy savings, the timing and magnitude of tax effects are included in the cash flow calculation, thus allowing the modeling of simple tax incentives. If any tax credits apply, they are modeled as one-time payments in the second year of the investment, which assumes that a wait of 1 year is necessary to receive the credits.[4] Tax credits can have a major effect on the time required to achieve a positive cumulative net cash flow, depending on the size and timing of the tax credit. Once the 30-year analysis is complete, the number of years required to reach a positive cash flow is input to the penetration function for new construction, which in turn determines the amount of distributed generation technologies that the model estimates would be purchased in a particular year.

Penetration rates are modeled as a direct function of the number of years required to achieve a cumulative positive cash flow for the investment. The penetration function has a “logistic” shape that produces slow initial penetration followed by a period of more rapid growth and ending with a tapering-off effect. The endogenous driver for penetration is the number of years calculated until a positive cumulative cash flow is achieved. The result is that as economic returns improve, the period required to meet the positive cumulative cash flow requirement is shortened and penetration increases. In some cases, this may never occur, and for such cases the number of years is set to 30. Note that the technologies do not “compete” for a fixed distributed generation amount; rather, each technology has its own penetration possibilities based on the number of years required to achieve a positive cash flow in its particular niche.

Figure 1 represents the penetration function under a maximum assumed penetration of 30 percent. The maximum penetration assumption allows ample opportunity for growth in the adoption of existing and advanced distributed generation technologies in the buildings sectors. Currently, very little residential capacity for electricity generation exists. It consists primarily of emergency backup generators to provide electricity for minimum basic needs in the event of power outages, as well as solar PV systems in a few niche markets with very high electricity rates and / or subsidies that encourage the use of renewable energy sources. The commercial sector generating capacity is also primarily for emergency backup; however, some electricity supply and peak generation have been reported. EIA’s 1995 Commercial Buildings Energy Consumption Survey (CBECS) estimated that about 5 percent of commercial buildings, representing 23 percent of commercial floorspace, have some capability to generate electricity. However, 78 percent of those reporting generating capability also reported that their generators are used primarily for emergency backup generation. Another 21 percent of respondents either did not know or did not report the primary use for their generators. The remaining 1 percent reporting generating capability stated that their generators are primarily used to meet periods of peak demand or are operated continuously. This translates to about 0.05 percent of all commercial buildings (0.23 percent of all commercial floorspace) reporting use of generators for meeting peak demand or continuous operation.

Most distributed generation technologies considered for the commercial sector provide useful heat as well as electricity, providing the potential for use as combined heat and power (CHP) systems. The capture and use of heat to satisfy water heating and space heating needs often make CHP systems more economically attractive than systems that are used exclusively for electricity generation. However, the inadequacy of thermal loads or the seasonal nature of heating needs, together with limited hours of operation in some types of commercial buildings, can reduce the ability to use the heat provided by CHP systems. High and / or fairly constant thermal loads and a high number of operating hours per year

Figure 1. Distributed Generation Technology Penetration Functions for Investments with Varying Years Until Positive Cumulative Cash Flows



Source: Office of Integrated Analysis and Forecasting, *AEO2000* modeling assumptions.

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[4] For building sector distributed generation investments in *AEO2000*, the only tax credit incorporated in the forecast is a business energy tax credit for PV units of 10 percent of the installed purchase costs up to $25,000 in any one year, as provided in the Energy Policy Act of 1992.

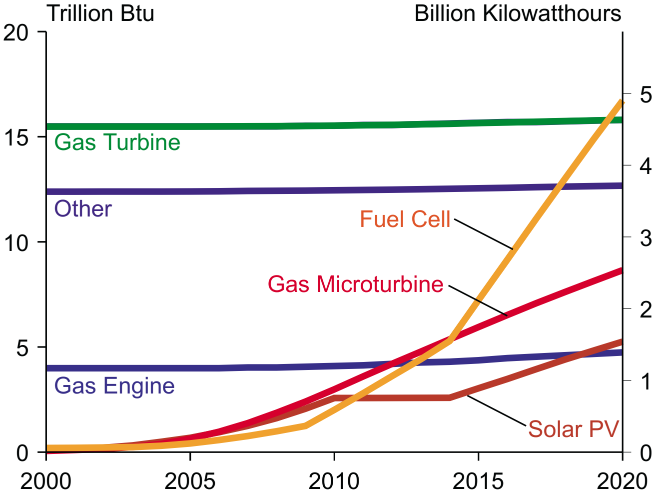
characterize the commercial applications favorable to CHP, such as for hospitals or lodging. Based on consideration of electric and thermal loads in conjunction with available CHP technologies, a recent report prepared for EIA estimated that the technical market potential for commercial CHP applications is only about 5 percent of the existing commercial buildings in the U.S., based on current technologies.[5]

Current market penetration of commercial CHP applications is well below the technical market potential, as illustrated by the CBECS estimates provided above. The possibility also exists to expand the market potential of CHP. Advanced technologies can expand the economic applications of CHP to building types that do not currently have adequate thermal needs. In addition, the development of cost-effective CHP systems in smaller sizes could also expand the potential market and increase the application of CHP in the commercial sector. Setting the maximum penetration at 30 percent for new construction allows for expanded market potential through advanced technologies and nontraditional applications, while ensuring that technology penetration is not projected to occur in buildings unsuited to utilizing distributed generation technologies.

AEO2000 Reference Case Results

The *AEO2000* reference case includes projections of the penetration of distributed generation technologies, energy use, and carbon dioxide emissions for the U.S. economy under conditions of moderate improvement in technology costs and performance (especially for emerging technologies), current energy policies, and consumer behavior that is similar to historical behavior. For distributed generation, this translates into a moderate increase in penetration over the forecast horizon. Although the emerging distributed generation technologies (PV, fuel cells and microturbines) exhibit cost declines throughout the projection period, the cost declines are not large enough to spur significant projected gains in penetration over the next 20 years under the reference case conditions. Figure 2 summarizes the penetration of the various distributed generation technologies into the buildings sector through 2020. Natural gas turbine technology is projected to maintain the largest share of distributed generation until the very end of the period, with little change from present levels. Fuel cells gain the most in terms of market share, due largely to projected declines in cost over time, as this technology is currently in the demonstration phase and just entering the era where a shift toward mass market production methods could significantly reduce costs. Solar PV, while small relative to other technologies, gains market share as well, based primarily on projected continuation of historical cost declines and policies to promote installations.[6]

Figure 2. Buildings Sector Electricity Generation by Selected Distributed Resources in the *AEO2000* Reference Case, 2000-2020



Source: AEO2000 National Energy Modeling System, run AEO2K.D100199A.

Table 1 shows the projected costs (equipment and installation costs only, no operating or maintenance costs) and electrical conversion efficiencies for several of the distributed generation technologies characterized in the NEMS buildings sector models. Note that cost declines are projected only for emerging technologies. The costs for more mature technologies are assumed to be constant in real terms. Thus, the costs of the emerging technologies decline relative to those of conventional technologies.

Table 2 presents *AEO2000* reference case levels for buildings sector energy use and carbon dioxide emissions for 2010 and 2020. The levels shown in this table will serve as the reference point for the changes in energy and carbon dioxide emissions for the alternative distributed generation cases to be presented.

Alternative Cases for Distributed Generation

To investigate the projected deployment of distributed generation in the buildings sector, two general sets of alternative cases were examined. The first set consists of

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[5] For detailed information on the distributed generation market, see ONSITE SYCOM Energy Corporation, *The Market and Technical Potential for Combined Heat and Power in the Commercial/Industrial Sector* (Washington, DC, January 2000).

[6] For example, DOE's Million Solar Roofs program is a voluntary program that aims at enlisting utility and State agency participation in demonstrating the efficacy of solar power.

Table 1. Installed Cost and Electrical Conversion Efficiency for Distributed Generation Technologies by Year of Introduction, 2000-2020

Technology	2000-2004		2005-2009		2010-2014		2015-2020	
	Cost (1998 Dollars per Kilowatt)	Efficiency (Percent)	Cost (1998 Dollars per Kilowatt)	Efficiency (Percent)	Cost (1998 Dollars per Kilowatt)	Efficiency (Percent)	Cost (1998 Dollars per Kilowatt)	Efficiency (Percent)
PV	5,529	14	4,158	16	3,178	18	2,426	20
Fuel Cell	3,625	40	3,000	40	2,425	40	1,725	40
Gas Turbine	900	29	900	29	900	29	900	29
Gas Engine	900	35	900	35	900	35	900	35
Gas Microturbine	800	27	700	27	700	27	700	27
Conventional Oil	500	33	500	33	500	33	500	33

Note: Fuel cells are not yet available in sizes and configurations appropriate for the residential sector. The first marketed units are expected around 2003.

Sources: **Solar PV:** U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, and Electric Power Research Institute, *Renewable Energy Technology Characterizations*, EPRI-TR-109496 (Washington, DC, December 1997). **Technologies other than Fuel Cells and Solar PV:** Electric Power Research Institute, *Quantifying the Market for Distributed Resource Technologies*, EPRI-TR-111962 (Palo Alto, CA, December 1998). **Fuel Cells:** Energy Information Administration, *Technology Forecast Updates—Residential and Commercial Building Technologies—Advanced Adoption Case* (Arthur D. Little, Inc., September 1998).

Table 2. Buildings Sector Distributed Electricity Generation, Primary Energy Consumption, and Carbon Dioxide Emissions in the Reference Case, 2010 and 2020

Projection	2010	2020
Total Electricity Generation		
Trillion Btu	40	64
Billion Kilowatthours	12	19
Photovoltaics	1	2
Fuel Cells	1	5
Microturbines	1	3
Other Distributed Generation	9	10
End-Use Electricity Consumption		
Trillion Btu	9,068	10,016
Billion Kilowatthours	2,658	2,936
Solar Energy Use (Trillion Btu)	32	35
Natural Gas Use (Trillion Btu)	9,039	9,611
Electricity Losses (Trillion Btu)	18,968	19,172
Total Primary Energy Use (Trillion Btu)	37,107	38,835
Carbon Dioxide Emissions (Million Metric Tons Carbon Equivalent)	635	683

Note: Totals may not equal sum of components due to independent rounding.

Source: AEO2000 National Energy Modeling System, run BASE.D061900A.

three cases in which the technology cost assumptions and the compensation price for sales to the grid were altered, singly and in combination. A second set of cases was used to investigate tax incentives for distributed generation technologies.

Advanced Technology Cost Assumptions Case

The technology cost and performance assumptions illustrated in Table 1 include projected declines in cost for the newer, emerging technologies. For *AEO2000*, a more optimistic view of future costs for emerging technologies was included as part of the advanced technology case, in recognition of the considerable uncertainty surrounding estimates of future costs. Efficiencies were assumed to be the same as for the reference case. The cost assumptions are illustrated in Table 3.

Under the advanced technology assumptions shown in Table 3, the projected cost reductions relative to the reference case vary in percentage terms across the technologies. PV costs are assumed to show a rapid decline after 2015, and the projections for PV in the advanced technology case show dramatic increases in penetration after 2015 relative to the reference case projections. For fuel cells and microturbines, the assumed cost reductions are more uniform over the forecast period, leading to earlier projections of higher penetration.[7]

To isolate the implications for distributed generation technologies, the advanced technology case cost assumptions were combined with the other inputs and assumptions set at reference case values. The results, summarized in Table 4, indicate a mild stimulation of

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[7] The differences between the cost decline assumptions stem partly from the level of maturity of each technology. Commercially applicable fuel cells have been tested and marketed only in the past few years, and building-size microturbines are in the demonstration phase. PV technology, in contrast, has been deployed commercially for more than 15 years and, thus, is less likely to experience near-term cost declines.

Table 3. Total Installed Costs for Distributed Generation Technologies in the Advanced Technology Case by Year of Introduction, 2000-2020

Technology	2000-2004		2005-2009		2010-2014		2015-2020	
	Cost (1998 Dollars per Kilowatt)	Percent Difference from Reference Case	Cost (1998 Dollars per Kilowatt)	Percent Difference from Reference Case	Cost (1998 Dollars per Kilowatt)	Percent Difference from Reference Case	Cost (1998 Dollars per Kilowatt)	Percent Difference from Reference Case
PV	5,529	—	3,840	-8	3,000	-6	1,750	-28
Fuel Cell	3,625	—	2,400	-20	1,940	-20	1,293	-25
Gas Microturbine	800	—	560	-20	560	-20	560	-20

Sources: Office of Integrated Analysis and Forecasting. PV costs approximate the industry "road map." Fuel cells costs are approximately 20 to 25 percent lower than reference case levels based on industry projections. Microturbine estimates are by assumption.

Table 4. Projections for Buildings Sector Distributed Generation in the Advanced Technology Case, 2010 and 2020
(Difference from Reference Case)

Projection	2010	2020
Total Electricity Generation		
Trillion Btu	3	20
Billion Kilowatthours	1	6
Photovoltaics	0	2
Fuel Cells	1	3
Microturbines	0	1
Other Distributed Generation	0	0
End-Use Electricity Consumption		
Trillion Btu	-3	-18
Billion Kilowatthours	-1	-5
Solar Energy Use (Trillion Btu)	0	7
Natural Gas Use, Net (Trillion Btu)	6	23

Note: Totals may not equal sum of components due to independent rounding.

Source: AEO2000 National Energy Modeling System, runs ADVTECH.D061900A and BASE.D061900A.

distributed generation. Net natural gas usage includes natural gas for generation, less savings for space and water heating.

In the advanced technology case, distributed generation is projected to supply an additional 20 trillion Btu of end-use energy in the buildings sector relative to the reference case in 2020. The increased supply comes either from PV, fuel cells, or microturbines, because the other technology costs remain at reference case levels. End-use electricity consumption is projected to decline by 18 trillion Btu relative to the reference case, with the difference between the generation increase and the consumption decline being modeled as grid sales from the buildings sector to electric utilities. Solar PV supplies 2 billion kilowatthours of the total 6 billion kilowatthour change from the reference case (fuel cells supply 3 billion kilowatthours and microturbines 1 billion kilowatthours). All the differences occur after 2010, when the costs for PV and fuel cells ultimately decline to less than half their current estimated values. The change in natural gas consumption in the buildings sector is the net of the increase in natural gas requirements for generation and any reductions in gas usage for water and/or space heating resulting from waste heat capture. The estimated overall average efficiency of fuel cell generation is total generation from fuel cells divided by the net natural gas usage change, or 53 percent in 2020. The overall efficiency is greater than the electrical efficiency of 40 percent (see Table 1 for electrical efficiencies) because of the capture and use of part of the waste heat. Total fuel cell efficiency, if all waste heat were captured and used effectively, would approach 85 percent.

The increased generation in the advanced technology case represents 0.2 percent of the projected total electricity demand for the buildings sector. This rather modest change from the reference case can be attributed to several factors:

- The technology costs decline; however, the reference case also includes declining technology costs. Comparing Table 3 with Table 1 shows that the cost differences between cases are larger for fuel cells and PV toward the end of the projection period. There is some additional stimulation, primarily after 2010.
- The projected real electricity price in the reference case decreases on average by 0.5 percent and 0.9 percent per year for residential and commercial buildings, respectively, between 2000 and 2020. Thus, the electricity price component of the financial incentive to deploy distributed resources is expected to weaken over the projection interval.
- For fuel cells and other natural-gas-using technologies, the projected natural gas price is fairly stable, ranging from a decline of 0.2 percent per year for residential customers to essentially constant prices for commercial customers. In both cases, however, the gap between the benefit of reduced electricity bill expenditures and increased gas bill expenditures widens in the reference case, somewhat reducing the

expected incentives for natural-gas-based generation toward the end of the projection period, when technology costs are the lowest.

Net Metering Case with Reference Technology Assumptions

Currently, electricity generated by distributed generation technologies, with the exception of PV, is valued at less than retail rates when sold to the grid. An alternative assumption is to value grid sales at the retail electricity rate, also referred to as "net metering." This would increase the returns from distributed generation for those fuel-based technologies that result in more generation than can be used on site. Net metering is modeled to determine how much additional distributed generation might occur as a result.

For PV, *AEO2000* assumed that net metering would be available. For grid sales from fuel-based generation technologies, *AEO2000* assumed that any projected grid sales would be valued at the estimated marginal cost of generation (in NEMS the price is modeled dynamically by the electricity generation module and passed to the building sector models). These lower-than-retail prices for electricity reduce the incentive for any generation in excess of on-site needs. As of 1997, the last historical year for cogeneration data in *AEO2000*, the commercial sector sold about 25 percent of the electricity it generated to utilities; therefore, the compensation price is a relevant issue. Also, for smaller buildings, a "standard-sized" fuel cell can generate more than their annual electricity requirements (and can also produce more heat than is required).[8]

Table 5. Projections for Buildings Sector Distributed Generation in the Net Metering Case with Reference Technology Assumptions, 2010 and 2020
(Difference from Reference Case)

Projection	2010	2020
Total Electricity Generation		
Trillion Btu	7	56
Billion Kilowatthours	2	16
Photovoltaics	0	0
Fuel Cells	1	14
Microturbines	1	1
Other Distributed Generation	0	1
End-Use Electricity Consumption		
Trillion Btu	-3	-25
Billion Kilowatthours	-1	-7
Solar Energy Use (Trillion Btu)	0	0
Natural Gas Use, Net (Trillion Btu)	16	122

Note: Totals may not equal sum of components due to independent rounding.

Source: AEO2000 National Energy Modeling System, runs NMREF.D061900D and BASE.D061900A.

Table 5 shows the results of the net metering case for fuel-based technologies. Total distributed generation in the buildings sector is projected to increase by 56 trillion Btu from the reference case in 2020, with most of the increase occurring after 2010. The net metering assumption produces a greater change than do the advanced technology cost assumptions alone, representing approximately 0.6 percent of total buildings electricity consumption. No change from reference case PV generation is projected, because net metering was assumed for PV in the reference case. Due to their increased return, grid sales account for a larger share of generation, at more than half of the increment over the reference case.

Net Metering Case with Advanced Technology Assumptions

The net metering case with advanced technology assumptions combines the two previous cases to develop projected impacts for distributed generation under more optimistic assumptions for capital costs and a higher benefits stream for installing fuel-based generation. The effects are not linear for fuel cells; that is, the separate effects of the two cases cannot merely be added. They are, however, additive for PV, because net metering was incorporated in the reference case. For fuel cells and microturbines, cash flow is affected by both the net metering and advanced technology cost assumptions. Thus, new simulations of cash flow produce new estimated intervals to reach positive cash flow, resulting in combined effects that are greater than the sum of the separate effects.

Table 6 summarizes the results for the net metering case with advanced technology assumptions. Fuel-based generation in the buildings sector would increase from its value of 56 trillion Btu in the net metering case to 115 trillion Btu. As mentioned above, PV reaches a level 7 trillion Btu above the reference case, as was also projected in the advanced technology case. Grid sales are approximately one-half of the incremental generation from gas-using technologies. Generation increases for a wide range of distributed resources in this case: conventional oil, gas turbines, gas engines, microturbines, fuel cells, and PV.

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[8] Currently, fuel cells are most frequently available in packaged units of 200 kilowatts. Thus, for buildings with smaller average demand, there is a potential to supply electricity to the grid if the price received is high enough to compensate for the costs of generating the electricity.

Average fuel cell generation efficiency in 2020 is projected to fall to 49 percent, compared with 60 percent in the reference case, because the range of applications increases as conditions for deploying distributed resources become more favorable. In the reference case, only installations using relatively large amounts of waste heat find fuel cells economical; but with enhanced incentives, installations using smaller amounts of waste heat are projected to be economical as well.

CCTI Incentives Case

The assumptions underlying the CCTI incentives case were developed for EIA's analysis of the Administration's proposed Climate Change Technology Incentive (CCTI) for fiscal year 2001.[9] Among the various provisions, three provide incentives to deploy additional distributed generation resources—two are tax credits (fuel cells and rooftop PV), and the third allows accelerated depreciation of distributed generation capital costs. The proposed tax credit for fuel cells would equal 20 percent of the installed cost, with a limit of $500 per kilowatt of capacity, for purchases made between 2001 and 2004. For PV, the proposed tax credit would equal 15 percent for systems installed between 2001 and 2007 with a limit of $2,000 in total. The proposed depreciation change affects the number of years required to achieve a positive cash flow by moving tax savings from depreciation to earlier periods and would apply to all future years. Table 7 illustrates the results of this case for 2010 and 2020.

The CCTI tax credits produce relatively small effects in comparison with the other cases analyzed, because the financial incentives either are not strong enough or are assumed to expire before the end of the model's time horizon. The three cases below explore more aggressive tax credits with no limits on the size of the incentive and no expiration.

40% Tax Credit Case for Fuel Cells and PV with Advanced Technology Assumptions

Tax incentives have been used in the past to encourage the adoption of energy-efficient technologies. In the early 1980s, a 40-percent tax credit for the purchase of solar hot water heaters helped create a small market for these technologies while the tax credit was in effect. In order to analyze the effect of a more widespread adoption of distributed generation technologies, PV and fuel cells were targeted with a hypothetical 40-percent tax credit with no limit on the dollar amount of the credit and lasting from 2000 through 2020. These two technologies were selected because they have been targeted by the CCTI tax proposals designed to foster advanced technologies. The advanced technology case cost assumptions are employed here because the resulting penetrations that a 40-percent tax credit is projected to

Table 6. Projections for Buildings Sector Distributed Generation in the Net Metering Case with Advanced Technology Assumptions, 2010 and 2020
(Difference from Reference Case)

Projection	2010	2020
Total Electricity Generation		
Trillion Btu	18	115
Billion Kilowatthours	5	34
Photovoltaics	0	2
Fuel Cells	4	28
Microturbines	1	2
Other Distributed Generation	0	1
End-Use Electricity Consumption		
Trillion Btu	-10	-60
Billion Kilowatthours	-3	-18
Solar Energy Use (Trillion Btu)	0	7
Natural Gas Use, Net (Trillion Btu)	41	234

Note: Totals may not equal sum of components due to independent rounding.

Source: AEO2000 National Energy Modeling System, runs NMADV.D061900A and BASE.D061900A.

Table 7. Projections for Buildings Sector Distributed Generation in the CCTI Incentives Case, 2010 and 2020
(Difference from Reference Case)

Projection	2010	2020
Total Electricity Generation		
Trillion Btu	5	13
Billion Kilowatthours	1	4
Photovoltaics	0	0
Fuel Cells	1	3
Microturbines	0	0
Other Distributed Generation	0	0
End-Use Electricity Consumption		
Trillion Btu	-4	-11
Billion Kilowatthours	-1	-3
Solar Energy Use (Trillion Btu)	0	1
Natural Gas Use, Net (Trillion Btu)	9	23

Note: Totals may not equal sum of components due to independent rounding.

Source: AEO2000 National Energy Modeling System, runs CCTI2.D062900A and BASE.D061900A.

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[9] For a more detailed discussion of these and other components of the incentives, see Energy Information Administration, *Analysis of the Climate Change Technology Initiative: Fiscal Year 2001*, SR/OIAF/2000-01 (Washington, DC, April 2000).

stimulate should also lead to further improvements in production techniques.

Table 8 shows the effects of the tax credits on buildings sector distributed generation, energy consumption, and carbon dioxide emissions relative to the reference case. In 2020, almost 360 trillion Btu of electricity is projected to be generated in the buildings sector for self-use or sales to the grid. This represents nearly 4 percent of the total projected buildings sector electricity use for 2020 in the *AEO2000* reference case.

With the adoption of fuel cells, energy consumption is transferred from the generation sector (shown in the reduction of electric losses) to the buildings sector in the form of increased natural gas usage. The energy savings resulting from this transfer include transmission and distribution savings as well as the efficiency gain from the use of fuel cells with recovery of waste heat. The amount of carbon dioxide emissions avoided annually is projected to be about 4 million metric tons carbon equivalent by 2010, remaining at about that same level through 2020.

Table 8. Projections for Buildings Sector Distributed Generation in the 40% Tax Credit Case for PV and Fuel Cells with Advanced Technology Assumptions, 2010 and 2020

(Difference from Advanced Technology Case)

Projection	2010	2020
Total Electricity Generation		
Trillion Btu	152	360
Billion Kilowatthours	45	106
Photovoltaics	6	14
Fuel Cells	38	92
Microturbines	0	0
Other Distributed Generation	0	0
End-Use Electricity Consumption		
Trillion Btu	-107	-252
Billion Kilowatthours	-31	-74
Solar Energy Use (Trillion Btu)	21	47
Natural Gas Use, Net (Trillion Btu)	265	637
Electricity Losses (Trillion Btu)	-380	-573
Total Primary Energy Use (Trillion Btu)	-200	-141
Carbon Dioxide Emissions (Million Metric Tons Carbon Equivalent)	-4	-4

Note: Totals may not equal sum of components due to independent rounding.

Source: AEO2000 National Energy Modeling System, runs FCTAX.D061900A and ADVTECH.D061900A.

The carbon dioxide savings from 2010 through 2020 level out in the face of increasing distributed generation due to the potential displacement of more efficient generation resources in 2020 than in 2010 and a slight decline in fuel cell efficiency by 2020.[10] For fuel cells purchased in 2010, the overall efficiency (electrical efficiency plus waste heat used to offset other natural gas usage) in the reference case is 62 percent. For the tax credit case, fuel cells purchased in 2010 have an average efficiency of 50 percent. For fuel cells purchased in 2020, the reference case efficiency is 58 percent (the average reference case efficiency for all fuel cells in 2020 is 60 percent). For the fuel cell and PV tax credit case, fuel cells purchased in 2020 remain at their 2010 efficiency of 50 percent.

The estimated reduction in carbon dioxide emissions reflects the integrated analysis of the buildings sector models with the electricity generation and renewable fuel modules of NEMS. Thus, as the buildings sector purchases lower amounts of electricity (compared with the reference case), the generation sector dispatches fewer resources, generates less electricity, and possibly builds less capacity over the forecast horizon. The amount of carbon dioxide emissions avoided by this transfer of generation depends on the efficiency of the building sector's generation assets relative to those that would have been deployed in the absence of the shift. Fuel cells have the potential for high efficiency, and the "carbon dioxide efficiency" of generation resources varies greatly. Thus, it is difficult to make an accurate *a priori* estimate as to how much lower carbon dioxide emissions might be.

It is possible to calculate "standalone" carbon dioxide emissions reductions using only the buildings sector modules by assuming that the generation sector avoids average carbon dioxide emissions for the electricity not generated relative to the reference case in a particular instance. However, this would ignore potential changes in generation dispatch and capacity expansion. In the current case, the estimated savings from the analysis of the buildings modules are equal to 4 million metric tons carbon equivalent in 2010, the same as the integrated result. For 2020, however, the standalone savings are estimated to be 9 million metric tons carbon equivalent, double their estimated value in the integrated run. The difference results from the reduced use of relatively carbon-efficient technologies in the integrated case as central station generation requirements relative to the reference case are lowered by the buildings sector self-generation. The fact that the difference can be so near the integrated result (as it was in 2010) or so different from it (as for 2020) highlights the importance of considering the impacts on the generation sector when estimating the carbon dioxide emissions reduction

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[10] Lower capital costs prompt adoption by consumers with smaller electric and thermal loads, leading to less efficient fuel cell use.

potential of significant deployment of distributed resources.

Another factor that greatly affects the amount of the carbon dioxide emissions reduction resulting from the use of distributed resources is the amount of PV deployed. Because PV has no direct carbon dioxide emissions, any electricity generated by PV will result in a reduction in carbon dioxide emissions.[11] In this case, PV accounts for about 13 percent of generation from the incrementally deployed resources. The effect of the technology mix on reductions in carbon dioxide emissions is investigated in the next case.

40% Tax Credit Case for Fuel Cells Only with Advanced Technology Assumptions

This case is designed to show the differential effects on carbon dioxide emissions of a different mix of distributed generation resources. By targeting only fuel cells with the tax credit, less PV is deployed than in the previous case, and there is a steep drop in the projected carbon dioxide emissions reductions. Whereas in the previous case carbon dioxide emissions reductions were 4 million metric tons carbon equivalent in 2010 and 2020, the values in this case are reduced to 2 million metric tons carbon equivalent in 2010 and 2020 (Table 9).

40% Tax Credit Case for PV and All Gas-Fired Generating Technologies with Advanced Technology Assumptions

A final case illustrates the effects of stimulating all natural gas generation technologies along with PV, coupled with the advanced technology cost assumptions. The purpose of this case is to show that some of the more conventional technologies also have the ability to penetrate when given tax advantages similar to those previously assumed only for emerging technologies.

As shown in Table 10, this case projects an increase in total distributed generation in the buildings sector of 496 trillion Btu in 2020—136 trillion Btu, or about 38 percent, higher than the increase in the case providing tax credits only to fuel cells and PV. By targeting all of the natural gas technologies with the hypothetical tax credit,

Table 9. Projections for Buildings Sector Distributed Generation in the 40% Tax Credit Case for Fuel Cells Only with Advanced Technology Assumptions, 2010 and 2020

(Difference from Advanced Technology Case)

Projection	2010	2020
Total Electricity Generation		
Trillion Btu	130	313
Billion Kilowatthours	38	92
Photovoltaics	0	0
Fuel Cells	38	92
Microturbines	0	0
Other Distributed Generation	0	0
End-Use Electricity Consumption		
Trillion Btu	-85	-205
Billion Kilowatthours	-25	-60
Solar Energy Use (Trillion Btu)	0	0
Natural Gas Use, Net (Trillion Btu)	265	636
Electricity Losses (Trillion Btu)	-288	-475
Total Primary Energy Use (Trillion Btu)	-108	-44
Carbon Dioxide Emissions (Million Metric Tons Carbon Equivalent)	-2	-2

Note: Totals may not equal sum of components due to independent rounding.

Source: AEO2000 National Energy Modeling System, runs FCTAX.D061900A and ADVTECH.D061900A.

Table 10. Projections for Buildings Sector Distributed Generation in the 40% Tax Credit Case for PV and All Gas-Fired Generating Technologies with Advanced Technology Assumptions, 2010 and 2020

(Difference from Advanced Technology Case)

Projection	2010	2020
Total Electricity Generation		
Trillion Btu	216	496
Billion Kilowatthours	63	145
Photovoltaics	6	14
Fuel Cells	38	91
Microturbines	6	13
Other Distributed Generation	12	27
End-Use Electricity Consumption		
Trillion Btu	-159	-367
Billion Kilowatthours	-46	-108
Solar Energy Use (Trillion Btu)	22	47
Natural Gas Use, Net (Trillion Btu)	419	961
Electricity Losses (Trillion Btu)	-485	-796
Total Primary Energy Use (Trillion Btu)	-202	-155
Carbon Dioxide Emissions (Million Metric Tons Carbon Equivalent)	-4	-5

Note: Totals may not equal sum of components due to independent rounding.

Source: AEO2000 National Energy Modeling System, runs DGALLCREDIT.D061900A and ADVTECH.D061900A.

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[11] This is of course not the case for fuel-consuming, carbon-dioxide-emitting distributed generation. If the carbon dioxide efficiency and transmission and distribution loss savings of the distributed resource do not exceed the marginal carbon dioxide emissions of utility generation resources, distributed generation can increase carbon dioxide emissions.

resources projected to be somewhat less efficient than fuel cells are also stimulated. The change in emphasis causes changes in reductions of carbon dioxide emissions less than proportional to the generation changes, now 4 and 5 million metric tons carbon equivalent in 2010 and 2020, respectively. Contributing to the smaller estimated reductions in carbon dioxide emissions per unit of generation is the targeting of additional technologies, all of which have lower potential overall efficiencies than those of fuel cells. In this analysis, the average overall efficiency of gas-fueled deployed resources through 2020 is projected to be 46 percent instead of 48 percent.

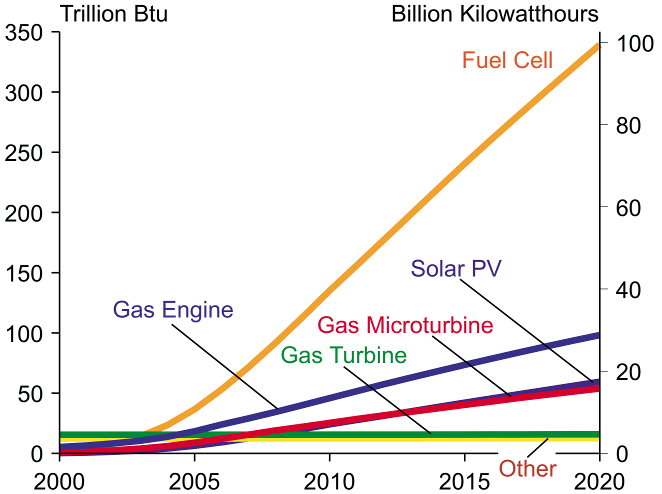
Figure 3 shows projected generation from the deployed resources over the projection period. Fuel cells supply nearly 350 trillion Btu by 2020, followed by gas engines at nearly 100 trillion Btu, and PV and microturbines at just over 50 trillion Btu each.

Conclusions

Distributed generation technologies, particularly fuel cells and PV, have received a great deal of attention from the energy community regarding their potential to save energy, increase the reliability of electricity supply, and decrease the cost of extending the current electrical grid. The tax incentive cases with resulting high penetrations also demonstrate the potential for distributed generation technologies with waste heat recovery to lower total carbon dioxide emissions from combined buildings and utility electricity generation. While the reductions in carbon dioxide emissions are not large enough to make what could be characterized as a major contribution toward stabilizing greenhouse gas emissions, distributed generation can contribute to that goal by helping to offset projected growth. Other conclusions are:

- The role of new, emerging technologies (PV, fuel cells, and microturbines) is critical to the projected growth of distributed resources. However, if given similar incentives, more traditional gas-fired technologies would also contribute.
- Technology cost reductions, as assumed in the advanced technology case for PV and fuel cells, lead to projected increases in total distributed generation in the buildings sector of more than 25 percent compared with the reference case projections by 2020.
- Net metering implemented in the model has a larger effect on the projections than that for the advanced technology cost case.

Figure 3. Buildings Sector Electricity Generation by Selected Distributed Resources in the 40% Tax Credit Case for PV and All Gas-Fired Generating Technologies with Advanced Technology Assumptions, 2000-2020



Source: AEO2000 National Energy Modeling System, run DGALLCREDIT.D061900A.

- Purchase incentives (including tax credits, lowered installed costs, and net metering) tend to reduce the projected marginal generation efficiency of installed distributed resources. These incentives increase the applicability of distributed generation by easing the requirements for utilizing waste heat and thus spur penetration into additional applications.
- The potential for distributed generation to mitigate carbon dioxide emissions depends on two key elements. First is the efficiency of displaced central station generation units: the more efficient the central station units are, the smaller will be the reduction in carbon dioxide emissions as a result of increases in distributed generation. The second is the efficiency of the distributed generation technology: PV makes direct carbon dioxide reductions with no offsets, whereas fuel-based distributed generation technologies create carbon dioxide emissions that depend on total efficiency, which can vary widely.
- “Standalone” estimates of reductions in carbon dioxide emissions derived from analysis of the buildings sector only (i.e., isolated from the electricity supply sector) should be avoided. Such estimates do not include the impacts of increased distributed generation on the central station generation and can overstate the amount of savings.