The Potential Impact of Distributed Generation Technologies on Future Energy Use and Carbon Emissions in the United States: Scenario Analysis Using the National Energy Modeling System (NEMS)

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ABSTRACT

Distributed generation has the potential to dampen future increases in carbon emissions attributable to electric generation, as well as to possibly reduce some of the high costs of upgrading the electric power grid. On-site generation has the advantage of allowing the capture of the "waste" heat from generation, lowering total energy requirements (e.g., combined electric, heating, and water heating energy) compared with remote generation where waste heat is generally emitted directly into the atmosphere. Also, by generating electric power on site, electricity transmission and distribution losses are avoided.

Currently, the National Energy Modeling System (NEMS) includes up to ten distributed generation technologies in the residential and commercial buildings sectors. These include conventional oil or gas engine and turbine technologies, as well as newer, still-developing technologies such as solar photovoltaic (PV), fuel cells, and micro-turbines. This paper analyzes the potential nationwide impact of distributed generation on energy consumption and carbon emissions by varying assumptions regarding the cost, availability, and tax treatments for distributed generation technologies, as well as alternative energy price scenarios, as forecasted using NEMS.

Introduction

Recently, distributed generation has received much attention for the potential energy savings and reliability assurances that might be achieved with widespread adoption of these technologies. Fueling the fervor have been the possibility of an international climate treaty, which would require the U.S. to substantially change the current electricity generation fuel mix, and electricity restructuring, which may bring about decreased reliability and less investment and concern about maintaining and expanding the electric grid. This paper analyzes the potential role of distributed generation with respect to offsetting future electricity needs and carbon emissions in the residential and commercial buildings sector under various assumptions regarding technology cost and availability, energy prices, and tax policy.

Model Overview

The NEMS is the primary mid-term 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 United States Congress and the Department of

Energy (DOE). The NEMS, developed in the early 1990s (and subsequently refined), consists of a series of computer simulation models that represent all of the major energy supply, demand, and conversion sectors of the U.S. economy, as well as general domestic macroeconomic conditions and world oil markets.[1] Within the NEMS buildings sector models (residential and commercial sectors), projections for the use of distributed generation technologies are estimated for the next two decades.

The modeling of distributed generation equipment has been expanded for the NEMS residential and commercial buildings models for EIA's Annual Energy Outlook (AEO) 2000.[2] 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. The characterized technologies include: PV; natural gas-fired fuel cells, reciprocating engines, turbines, and microturbines; diesel engines; coal fired co-generation; municipal solid waste and wood generators; and hydroelectric. Of these ten technologies, only PV and fuel cells are considered for the residential sector, while all technologies are applied to commercial buildings.

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

In terms of the NEMS projections for the overall economy, investments in distributed generation reduce purchases of electricity from the "supply-side" of NEMS. In this case, energy input requirements for generating electricity are transferred from the utility 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 self-generated amounts. When fuel cells or other fuel-consuming technologies are selected, utility consumption of fuel 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 utility generation decreases overall primary energy consumption, which will be shown in the scenario comparisons section.

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[1] For detailed information on the National Energy Modeling System (NEMS), see Energy Information Administration, *National Energy Modeling System: An Overview 2000*, DOE/EIA-058(2000), Washington, DC, April 2000.

[2] For detailed information on the distributed generation modeling within 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, and *Commercial Sector Demand Module of the National Energy Modeling System Model Documentation 2000*, DOE/EIA-060(2000), Washington, DC, January 2000. Copies of the EXCEL spreadsheet version of the distributed generation module available from the authors upon request.

Cumulative Cash Flow Approach and Market Penetration

As NEMS executes for a given projection year, the residential and commercial modules each invoke their sub-modules that determine the amount of distributed generation purchased each year. These calculations are made separately 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 (tax deductions, tax credits, and energy cost savings) 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 either be 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 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, for new construction, investment in distributed generation technologies is always added to the 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 tax policies. 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 one year is necessary to receive the credits.[3] NEMS modeling has shown that tax credits can have a major effect on increasing the rapidity of achieving a positive cumulative net cash flow. 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 newly constructed floor space, which in turn determines the amount of distributed generation technologies 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. In many cases, this may never occur, and for such cases the number of years is set to 30. The result is that as economic returns improve, the period required to meet the positive cumulative cash flow requirement is shortened and penetration increases. Figure 1 represents the penetration function under a maximum assumed penetration of 30 percent. A recent report prepared for EIA estimated that the technical market potential for combined heat and power applications is only about 5 percent of the existing commercial buildings in the U.S., based on current

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[3] For AEO 2000, the only tax credit is a business energy tax credit under EPACT for PV units of 10 percent of the installed purchase costs up to $25,000 in any one year.

technologies.[4] Setting the maximum penetration at 30 percent for new construction allows for expanded market potential through advanced technologies and non-traditional applications, while ensuring that technology penetration does not occur in buildings unsuited to distributed generation technologies.

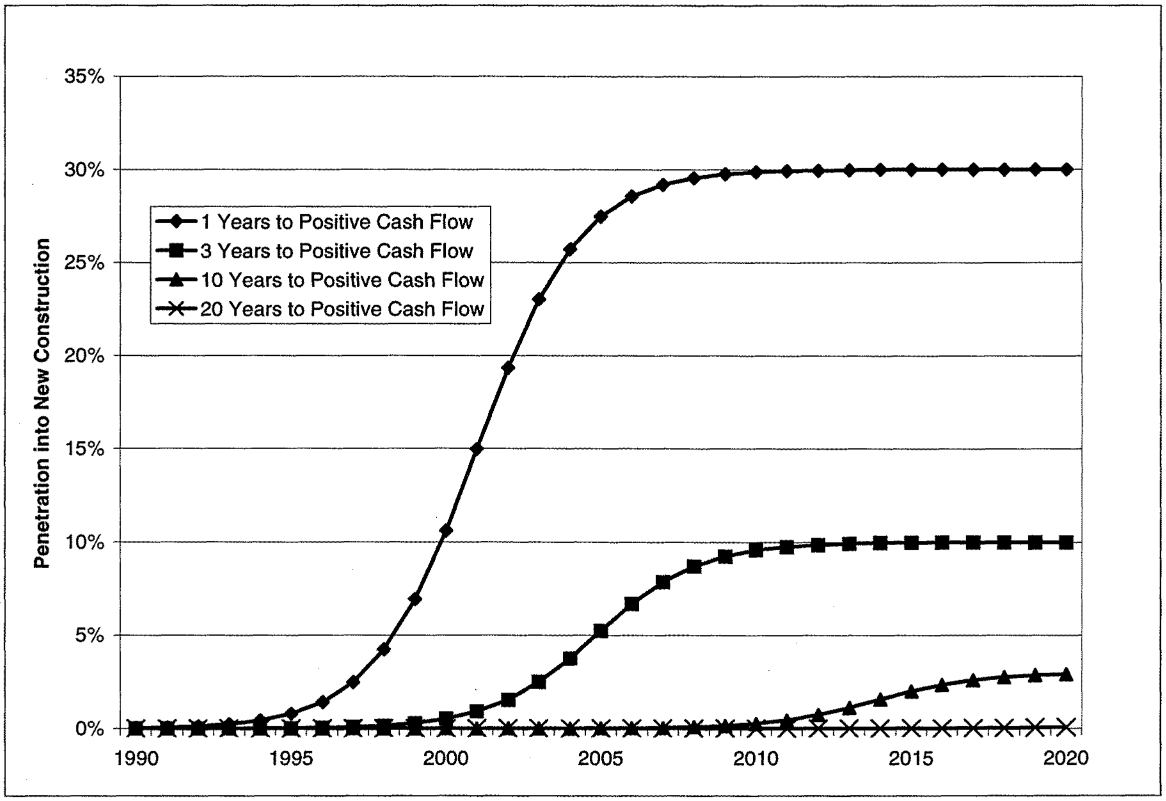

Figure 1. Distributed Generation Technology Penetration Rates Relative to Years to Positive Cumulative Cash Flow

Scenario Comparisons

To analyze the impacts that distributed generation may have on energy consumption and carbon emissions, several scenarios were established within the NEMS modeling framework[5]. This section details the results obtained from individually and cumulatively varying key parameters that affect the penetration of distributed generation technologies in the buildings sector of NEMS. The key parameters identified for this study include the installed cost of distributed generation technologies, tax credit availability, and energy prices. The final scenario described in this section details the effects of forcing the penetration of

[4] 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.

[5] The carbon accounting for the first three scenarios does not include the results of changes in electric utility capacity expansion and dispatch.

both PV and fuel cells to meet all future growth (post-2000) in electricity demand in the buildings sector. Although not all electricity growth in the buildings sector is attributable to new construction, this scenario provides insight into a potential "maximum" impact that distributed generation can provide over the next two decades with respect to primary energy consumption and carbon emissions in the buildings sector of the United States.

AEO 2000 Reference Case Results

The AEO 2000 reference case projects energy use and carbon emissions for the U.S. under a "business as usual regime." In this context, energy policy is projected to remain at its current status and no major breakthroughs in the cost and performance of technologies are assumed. For distributed generation, this translates into less favorable investment criteria, relative to conventional technologies, since penetration rates are low and system costs are relatively high. Although the distributed generation technologies exhibit gains in relative costs through the projection period, the advances are not large enough to spur significant gains in penetration over the next 20 years. Figure 2 depicts AEO 2000 reference case levels for buildings sector energy use and carbon emissions for 2010 and 2020. The levels shown in Figure 2 will serve as the reference point for the changes in energy and carbon emissions in the distributed generation scenarios that follow.

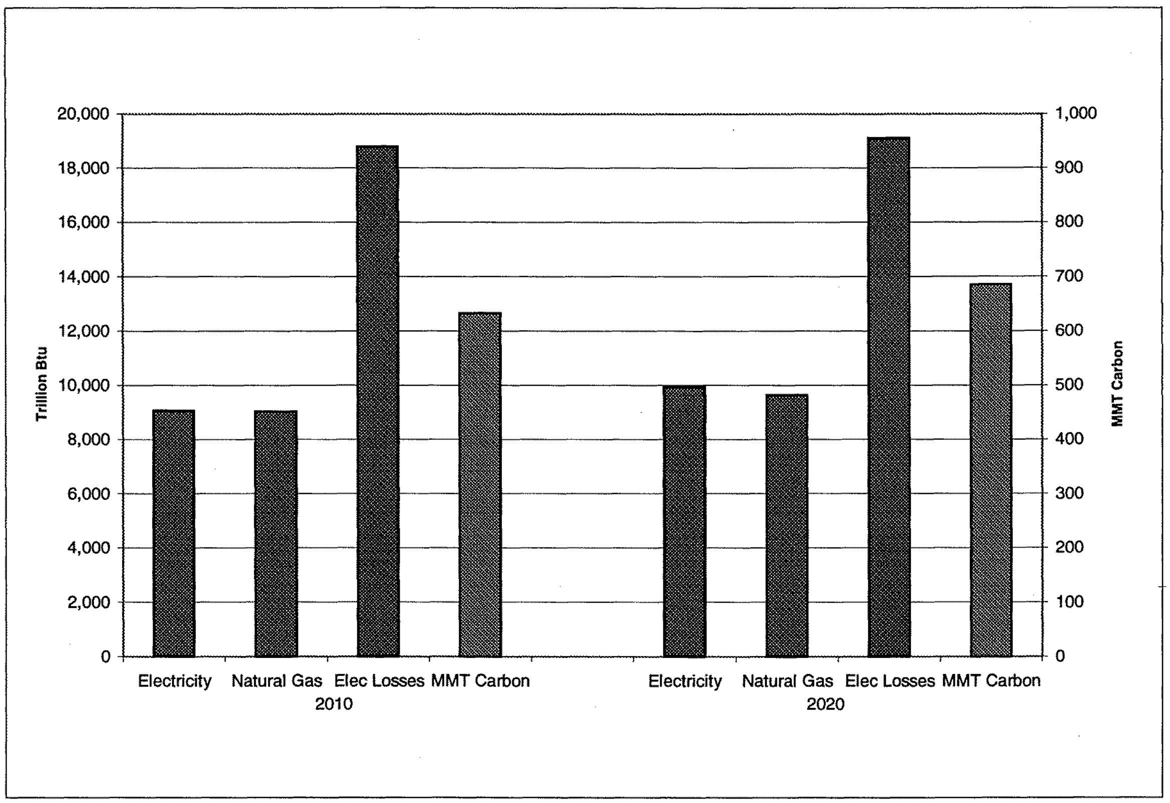

Figure 2. Buildings Sector Energy Consumption and Carbon Emissions in the AEO2000 Reference Case, 2010 and 2020

Accelerated Technology Improvement Scenario

The accelerated technology improvement scenario assumes that the installed cost of distributed generation technologies will improve, relative to the AEO 2000 reference case, over the projection period. In this scenario, energy prices, policies, and consumer behavior are as projected in the AEO reference case, thus isolating the effect of optimism for technology improvement. In this scenario, fuel cell prices decline 20 percent from the AEO 2000 reference case level by 2010, and 25 percent by 2020. Similarly, PV prices decline 6 and 28 percent in 2010 and 2020, respectively, relative to the AEO 2000 reference case as shown in Table 1.[6]

Table 1. Installed Cost for Photovoltaics and Fuel Cells by Year of Introduction (1998 Dollars per kW)[7]

	2000	2005	2010	2015
Reference Case				
PV	$5529	$4158	$3178	$2426
Fuel Cells	$4125	$3000	$2425	$1725
Accelerated Technology Improvement Case				
PV	$5529	$3840	$3000	$1750
Fuel Cells	$4125	$2400	$1940	$1293

Figure 3 depicts the forecasted energy and carbon emissions savings in the building sector when the projected cost of distributed generation technologies improve, relative to the AEO 2000 reference case. Given the projection of relatively stable energy prices through 2020 in this scenario, energy and carbon savings are modest, resulting from little increased penetration of distributed generation technologies. An increase in the use of fuel cells can be seen by the shift from primary energy use in the utility sector (elec. losses in Figure 3) to an increase in the use of natural gas in the buildings sector. By 2020, carbon emissions are projected to be 1 million metric tons less than the AEO2000 reference case level.

[6] Costs for the PV and fuel cells in the accelerated technology improvement scenario are based on the assumptions for the residential and commercial high technology cases presented in the *Annual Energy Outlook 2000*. For more details, see Energy Information Administration, *Assumptions to the Annual Energy Outlook 2000 with Projections to 2020*, DOE/EIA-0554(2000), Washington, DC, January 2000.

[7] Fuel cell costs for residential installations are assigned relatively higher values in the 2000 vintage to prevent the model from forecasting any penetration for this technology since only prototypes are currently available.

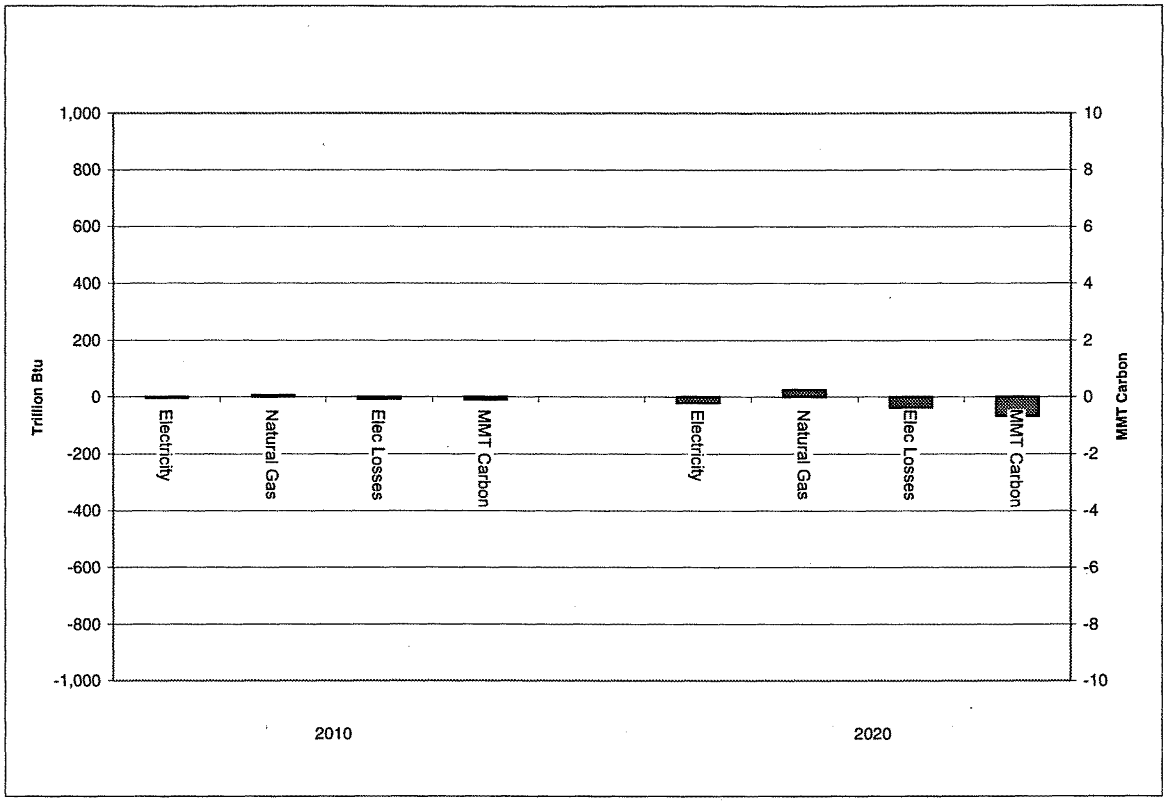

Figure 3. Changes in Buildings Sector Energy Consumption and Carbon Emissions in the Accelerated Technology Improvement Scenario Relative to the AEO 2000 Reference Case, 2010 and 2020

Accelerated Technology Improvement with Tax Credits Scenario

Tax credits have been used in the past to spur 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 similar tax credit on energy consumption and carbon emissions, a 40 percent tax credit was applied to the purchase of fuel cells and PV for this scenario. As described above, the tax credit is recovered in the year following the initial investment.

Figure 4 details the effects that tax credits, combined with accelerated technology improvement, are forecasted to have on energy consumption and carbon emissions, relative to the AEO 2000 reference case. The figure clearly shows that adding tax credits to the accelerated technology improvement scenario is forecasted to have a larger impact on the penetration of distributed generation technologies than accelerated technology improvement characteristics alone (Figure 3). The 40 percent tax credit allows for a faster positive cash flow for the investment, which in turn spurs a greater penetration for fuel cells and PV in the buildings sector. Almost 380 trillion Btu of electricity is projected to be avoided in the buildings sector in 2020, which represents 18 percent of the total projected increase in buildings sector electricity use by 2020 in the AEO 2000 reference case. With the adoption of fuel cells, natural gas consumption is transferred from the utility sector (shown in the reduction of elec. losses in Figure 4) to the buildings sector. The energy savings resulting from this transfer involve transmission and distribution savings as well as a slight efficiency gain from the use of fuel cells with recovery of the waste heat in place of efficient gas combined-cycle generators. For these reasons, the amount of carbon saved annually is projected to be relatively modest, with about 10 million metric tons saved by 2020. Cumulatively, over 85 million metric tons of carbon emissions are projected to be avoided from 2001-2020.

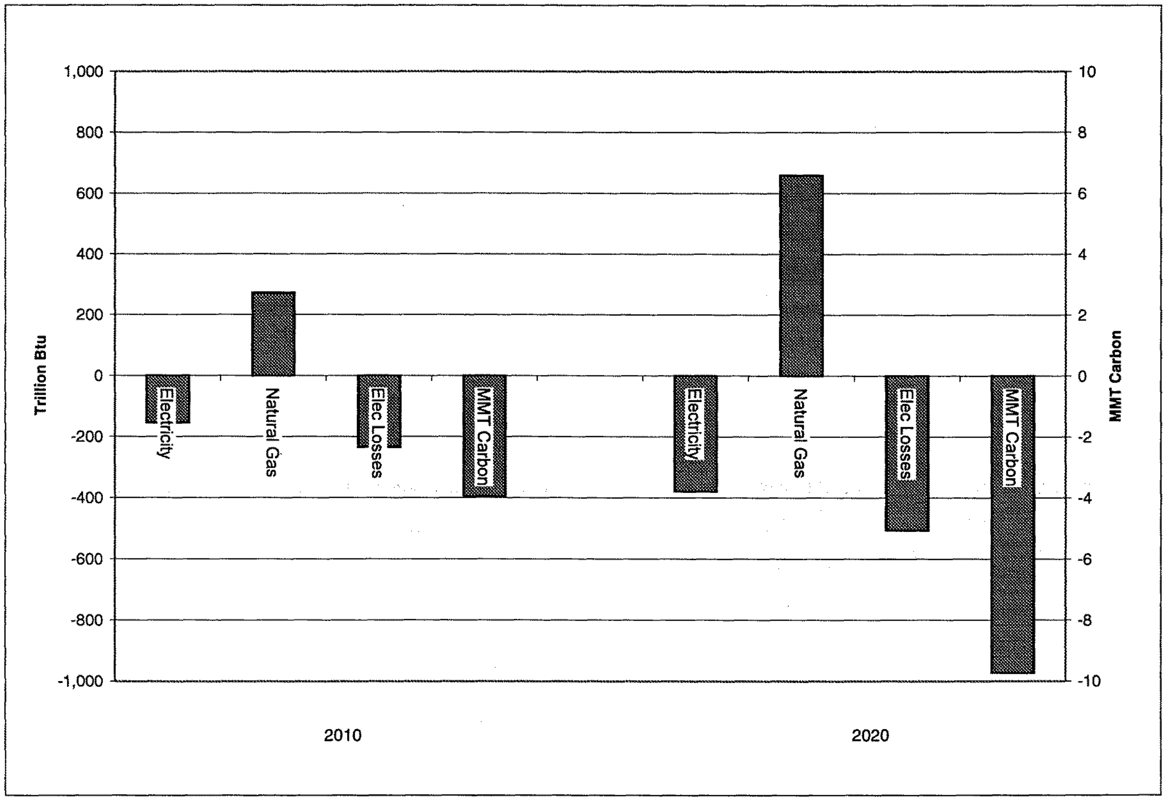

Figure 4. Changes in Buildings Sector Energy Consumption and Carbon Emissions in the Accelerated Technology Improvement and Tax Credits Scenario Relative to AEO 2000 Reference Case, 2010 and 2020

High Energy Prices, Accelerated Technology Improvement, and Tax Credits Scenario

This scenario combines higher energy prices with accelerated technology improvement characteristics and tax credits for distributed generation equipment. In order to isolate the effects that these factors have on the penetration of distributed generation equipment, a new reference case with significantly higher energy prices was established.[8] In establishing a new reference case with much higher prices, care must be taken in interpreting the results. The demand for electricity in 2010 and 2020 in the new reference case is much lower than the AEO 2000 reference case, due to gains in the efficiency of end-use appliances

[8] The energy prices used for this scenario are based on the Energy Information Administration, *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity*, SR/OIAF/98-03, Washington, DC, October, 1998.

associated with the higher prices. Additionally, natural gas prices increase at a faster rate than electricity prices in this scenario, affecting the economic viability of fuel cells.

Figure 5 depicts the change in energy consumption and carbon emissions for the buildings sector in 2010 and 2020 due to increased penetration of distributed generation technologies in the high energy prices, accelerated technology improvement, and tax credits scenario. The results from this scenario are similar to the previous scenario with delivered energy prices being the only difference between the two scenarios. One might expect that higher delivered energy prices would bring about increased penetration of distributed generation equipment. Higher energy prices, however, are expected to dampen the penetration of this equipment for several reasons. In this scenario, the price of natural gas rises faster than the price of electricity, which lessens the attractiveness of fuel cells, since purchased electricity is replaced by the natural gas used to power the distributed generation equipment. Secondly, investments in energy efficiency are made in the new reference case with higher prices, crowding out the opportunity to invest in more expensive options, such as PV and fuel cells. Electricity savings and carbon emissions savings in this scenario are slightly less than the savings reported in the previous scenario with reference case energy prices.

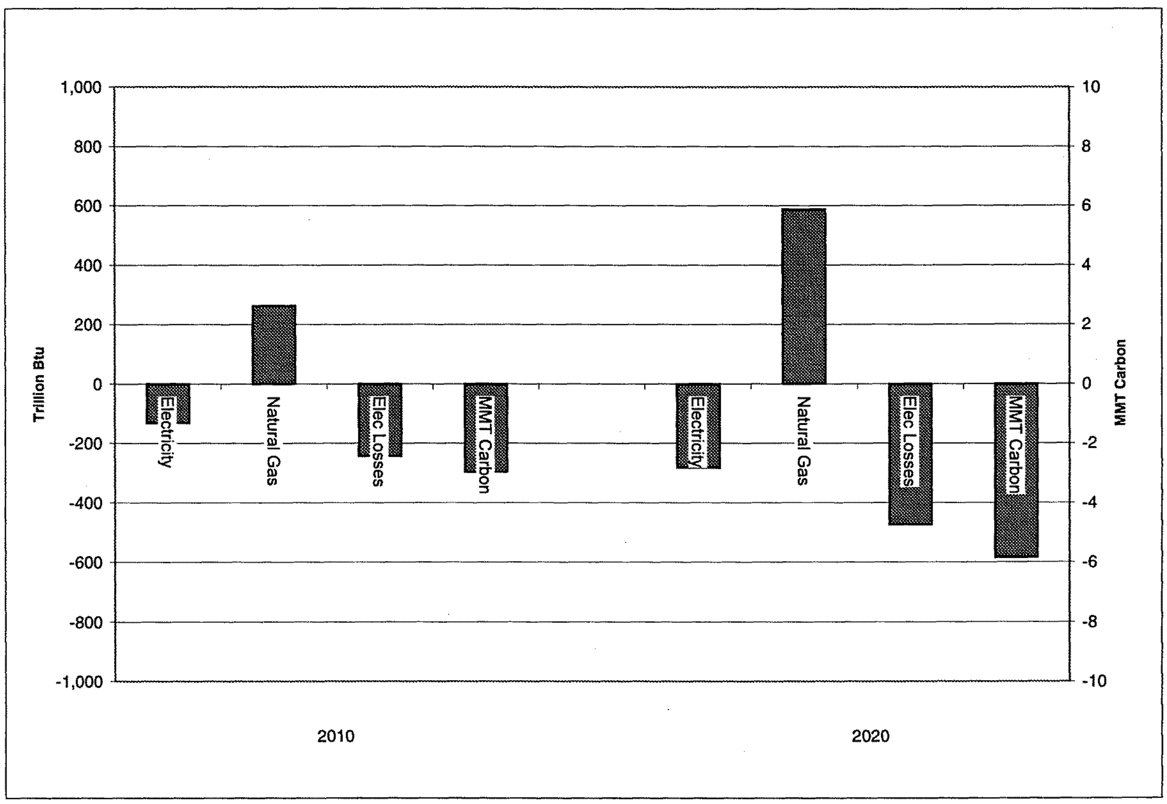

Figure 5. Changes in Buildings Sector Energy Consumption and Carbon Emissions in the High Energy Prices, Accelerated Technology Improvement, and Tax Credits Scenario Relative to High Energy Price Case, 2010 and 2020

Forced Penetration of Fuel Cells and PV

In order to gauge the effects of the "maximum potential" distributed generation penetration on buildings sector energy consumption and carbon emissions, two scenarios were developed whereby all future increases in buildings sector electricity use would be met by either all fuel cells or all PV. Although these cases are not realistic because the amount of investment in capital and infrastructure required to support the number of units purchased would be prohibitive, these cases serve to show how much carbon could be saved if fuel cells or PV become more commonplace.

Figure 6 shows the forecasted buildings sector energy and carbon savings from meeting all future additional electricity requirements (post 2000) with the installation of fuel cells in residences and commercial establishments. In this case, all of the increase in electricity use in the buildings sector (3.25 quadrillion Btu) is met by fuel cells, effectively shifting natural gas combined-cycle generation to the buildings sector. As mentioned earlier in this paper, the efficiency gains from on-site generation with fuel cells are modest when compared to natural gas combined-cycle units. Savings on transmission and distribution losses, and waste heat recovery, account for most of the projected 30 million metric ton savings in carbon emissions. This case reinforces the premise that the viability and marketability of fuel cells rests with power reliability and power grid issues, as opposed to energy savings alone.

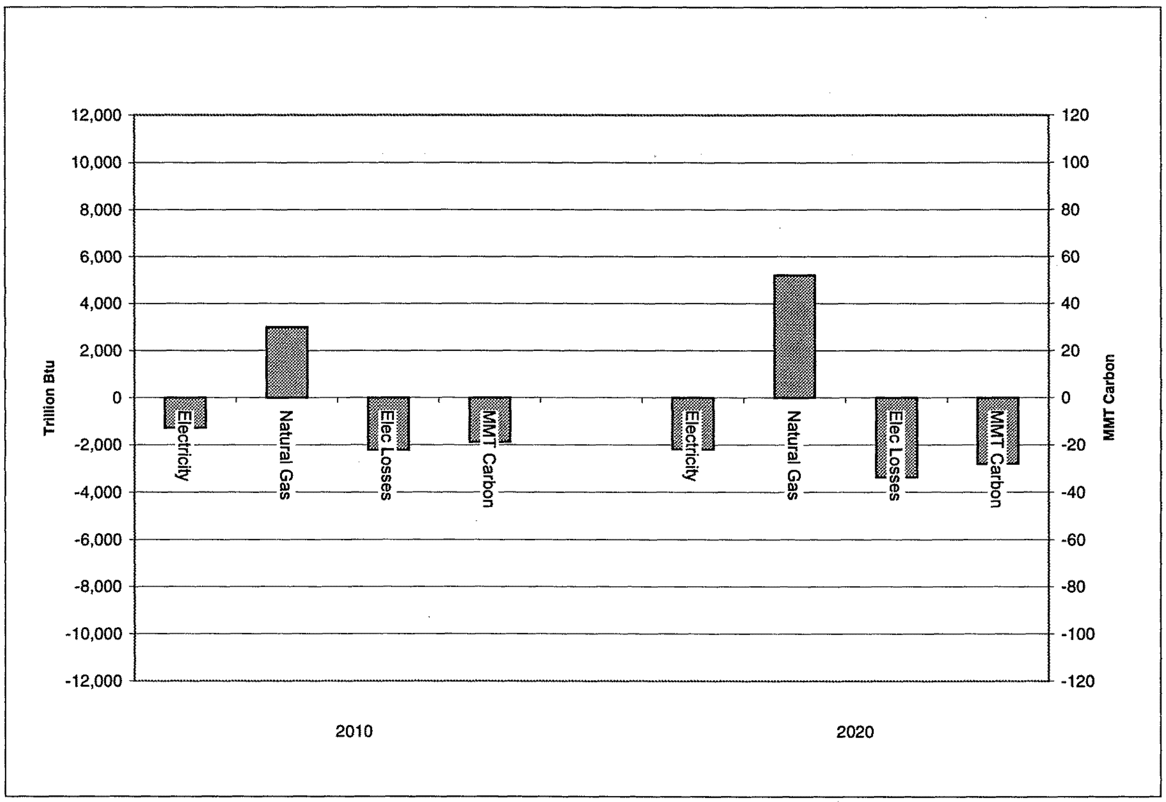

Figure 6. Changes in Buildings Sector Energy Consumption and Carbon Emissions in Meeting Future Electricity Demand with Fuel Cells Relative to AEO 2000, 2010 and 2020

Figure 7 shows the forecasted buildings sector energy and carbon savings from meeting all future additional electricity requirements (post 2000) with the installation of PV in residences and commercial establishments. PV, unlike fuel cells, requires no fossil fuel input to generate on-site electricity. In this case, carbon emissions savings are greatest, over 100 million metric tons by 2020. From this case, a "marginal" carbon per Btu of delivered electricity factor can be computed and compared to the current carbon factor to show the difference between average and marginal calculations when attributing carbon savings to electricity savings. Currently, 51 million metric tons of carbon are emitted per quadrillion Btu of electricity consumed. In the forced PV scenario, only 47 million metric tons of carbon are saved per quadrillion Btu of saved electricity, implying that the less carbon intensive forms of generation are avoided in this scenario. New, efficient generating units required for the projected increase in electricity demand in the AEO 2000 reference case would not be needed in these scenarios, resulting in a greater percentage of electricity demand being met by less efficient, more carbon-intensive units already in service.

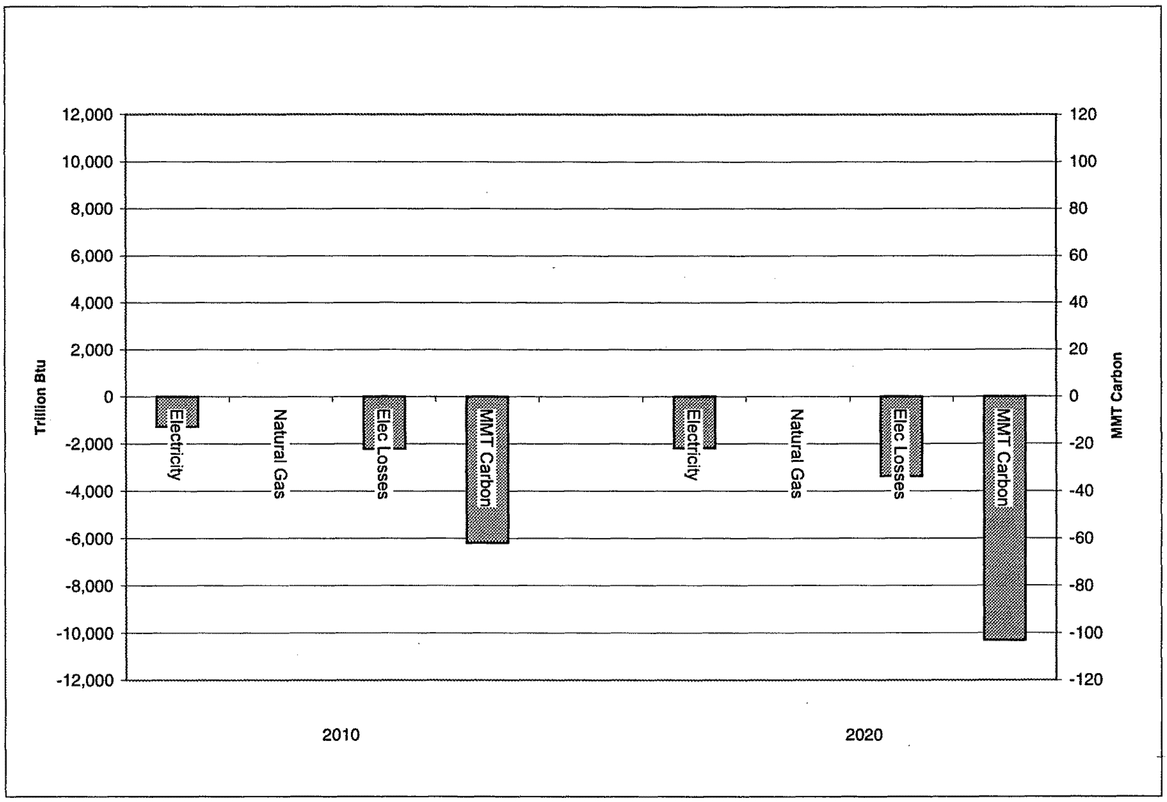

Figure 7. Changes in Buildings Sector Energy Consumption and Carbon Emissions in Meeting Future Electricity Demand with PV Relative to AEO 2000, 2010 and 2020

Summary

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 electric delivery reliability, and decrease costs with respect to extending the current electrical grid. This paper demonstrated the potential for distributed generation technologies to save both energy and carbon emissions from the buildings sector energy consumer's point of view. The scenarios explored here conclude that energy savings and carbon emissions reductions are likely to be relatively modest, given the costs of the technology and the efficiency of alternative methods of generating electricity in the form of new capacity. The success of distributed generation technologies will more likely lie within the realm of power reliability and concerns about the cost of extending the current electrical grid.

The application of accelerated technology improvements to AEO 2000 reference case assumptions provides a forecasted modicum of energy and emissions savings by 2020. The addition of tax incentives in the form of a substantial tax credit is projected to spur a significant increase in the adoption of distributed generation technologies in the buildings sector. Carbon emissions reductions are forecasted to remain modest since an increase in natural gas consumption will partially offset electricity savings, however, tax incentives will provide more than seven times the projected carbon savings of a scenario with accelerated technology improvements alone.

The assumptions for accelerated technology improvements and tax incentives were also applied to a scenario featuring high delivered energy prices. Energy and carbon savings, relative to a high energy price scenario with reference case technology and tax assumptions, were projected to be slightly lower than the savings exhibited in the technology and tax scenario with reference case energy prices. The introduction of assumed high energy prices dampened the projected penetration of distributed generation equipment for several reasons. In these assumptions, natural gas prices rose faster than electricity prices, lessening the attractiveness of distributed generation technologies fueled by natural gas. In addition, investments in energy-efficient end-use appliances were made in the reference case with high energy prices, providing less incentive to invest in more expensive options, such as PV and fuel cells.

In order to demonstrate a potential maximum impact of distributed generation technologies on buildings sector energy consumption and carbon emissions, two scenarios were developed whereby all future buildings sector electricity growth through 2020 would be met by increased penetration of either PV or fuel cells. While these scenarios are unlikely to come to fruition, they serve as important metrics for the projected impact that widespread acceptance of various distributed generation technologies can have on future energy consumption and carbon emissions attributable to the buildings sector in the United States.