the Energy to Lead

FINAL REPORT

Validation of Direct Natural Gas Use to Reduce CO_2 Emissions

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1.0 Executive Summary

This study analyzes the benefits of increased "direct use" of natural gas as a cost-effective mechanism to assist the nation in achieving two key goals: (1) increase the nation's full fuel cycle energy efficiency; and (2) reduce national greenhouse gas (GHG) emissions. Objectives of this study were to:

- Assess end use efficiency, national CO_2 emission reductions, primary energy savings, and consumer cost savings through encouraging direct use of natural gas to displace less efficient practices by creating economic incentives for equipment and educating consumers to gain immediate benefits, and providing new technologies through R&D investments for sustainable long term benefits.
- Compare the merits of increased direct gas use relative to other options to meet national energy efficiency and CO_2 emission reduction goals. In particular, compare the relative merits of providing a comparable level of subsidies to direct use of natural gas for space and water heating versus electric end-use resistance heating and water heating technologies.

The analysis used the National Energy Modeling System (NEMS), the model used by the Energy Information Administration (EIA) to provide national energy forecasts in the Annual Energy Outlook (AEO) and to analyze energy and environmental legislation upon request by Congress. The term "NEMS-DGU" (Direct Gas Use) is used in this report to distinguish use of the model in this project from uses by EIA. The NEMS-DGU analysis included three complementary and additive scenarios (PR1, PR2, and PR3) that encouraged direct use of natural gas as a part of a national energy and CO_2 emission reduction strategy, and a fourth scenario (AE50) that investigated the impact of an aggressive (50%) subsidy of electric end use technologies. The NEMS-DGU model calculated energy, cost, and CO_2 emission changes from 2010 through 2030 under these scenarios compared to the EIA AEO 2008 Reference Case.

Conclusions from this study include:

- The increased direct use of natural gas will reduce primary energy consumption, consumer energy costs, and national CO_2 emissions compared to the *AEO2008* Reference Case ("business-as-usual")
- Subsidies provided to increase the direct use of natural gas will provide greater benefits than comparable subsidies to electric end-use technologies with respect to reducing primary energy consumption, consumer energy costs and national CO_2 emissions.
- Subsidies provided to increase the direct use of natural gas, together with increased efforts in consumer education and R&D funding, in comparison to the *AEO2008 Reference Case*, will provide the following benefits by 2030:
  - 1.9 Quads energy savings per year
  - 96 million metric tons CO_2 emission reduction per year
  - $213 billion cumulative consumer savings
  - 200,000 GWh electricity savings per year
  - 50 GW cumulative power generation capacity additions avoided, with avoided capital expenditures of $110 billion at $2,200/kW.
- By 2030, the benefits derived from subsidies to increase the direct use of natural gas significantly exceed those with respect to comparable subsidies to electric end-use technologies

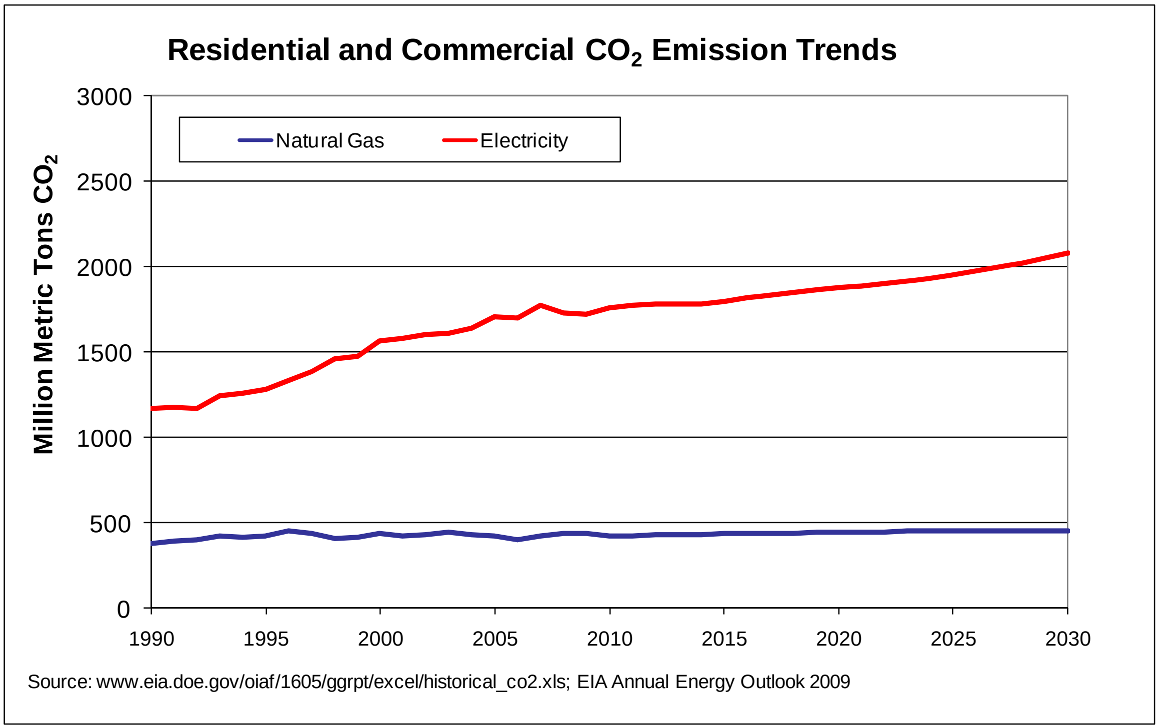
in four out of the five categories above (all except for cumulative consumer savings, due to the assumption of the conversion from oil and distillate fuel to electricity in that scenario).

- The natural gas subsidy scenario PR3 shows a 3.7% increase in residential gas prices and little increase in commercial gas prices compared to the Reference Case by 2030. Natural gas prices fall in the electric subsidy scenario while electric prices are unchanged compared to the Reference Case.
- A direct natural gas use subsidy has significantly lower gross cost to reduce a metric ton (tonne) of CO_2 than an electric end use equipment subsidy or a building insulation retrofit subsidy. Avoided cost of new power plant construction as well as consumer savings from efficient natural gas direct use can result in a substantial net societal savings from direct gas use, especially in new construction markets.
- Retrofit markets pose unique challenges for direct gas use CO_2 emission or primary energy reduction strategies. The high installed cost of retrofit of gas technologies (especially for electric homes and multifamily dwellings) compared to new construction as well as variability of retrofit costs complicates economics and incentive strategies. It will be critical to focus on the most attractive regions and market segments to minimize the net cost per tonne in retrofit markets.
- The natural gas end use equipment subsidy will increase the amount of natural gas used in the commercial and residential end use market, but it will result in reduced fossil fuel production and a net reduction in CO_2 emissions. This is because of the better full cycle efficiency of natural gas end use equipment coupled with the resultant power generation fuel mix.
- While the three natural gas end use equipment subsidy scenarios will result in a moderate increase in natural gas consumption reporting by Local Distribution Companies (LDCs), the per capita consumption declines. The reduction in natural gas usage per residential customer ranges from 3 to 12% by 2020.

2.0 Background

2.1 Energy and Emissions Trends

Buildings consume nearly 40 percent of the primary energy resources and 74 percent of the electricity generated each year in the United States[1]. Homes and commercial businesses have been growing contributors to CO_2 emissions for the last 15 years – a trend that is projected to continue for the next two decades. As shown in Figure 1and Figure 2, the increasing CO_2 emissions from residential and commercial buildings are being driven by growing consumption of electricity, including generation losses. Much of the increased CO_2 emissions from residential and commercial electricity use comes from power plants and the relatively inefficient "full fuel cycle" of extraction, processing, transportation, production, and delivery of electricity to the buildings. In contrast, CO_2 emissions per residential natural gas customer have fallen by 40% since 1970, and total CO_2 emissions have been flat in spite of an increase from 38 million customers in 1970 to 65 million customers in 2007. Aggregate CO_2 emissions from natural gas consumption in U.S. buildings are currently at 1990 levels. Due to continued efficiency improvements, they are projected to remain nearly flat through 2030 despite continuing growth in the number of gas customers.



Source: www.eia.doe.gov/oiaf/1605/ggrpt/excel/historical_co2.xls; EIA Annual Energy Outlook 2009

Figure 1 Gas and Electric CO_2 Emission Trends in Residential and Commercial Buildings

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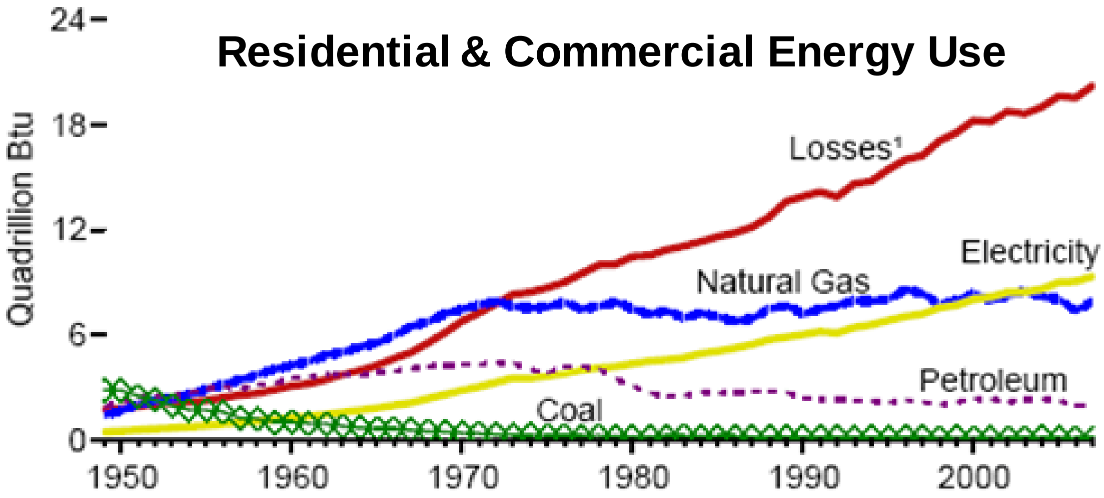
[1] DOE. 2008. Annual Energy Review 2007, (DOE/EIA-0384(2007)). Washington, D.C. Energy Information Administration, U.S. Department of Energy.



(1) Energy lost during generation, transmission, and distribution of electricity

Figure 2 Energy Use Trends 1950 – 2007 in Residential and Commercial Buildings[2]

2.2 Why is Full Fuel Cycle Analysis Needed?

Traditionally, residential and commercial energy use discussions have been focused on end use equipment efficiency. With the advent of the discussions of Global Climate Change and more sophisticated modeling that identifies full cycle energy use, there has been an awareness that the simple end use efficiency metric that has been in place for over 30 years is insufficient as a tool to measure and predict outcomes that society is facing. It is important to define and differentiate alternative metrics that describe energy use and emissions.

The terminology for energy efficiency and emissions metrics used in this report reflect the language used in current legislative initiatives and industry analysis. Those terms are summarized below and presented in more detail in Appendix A.1.

- *CO_2 emission reduction* is used to describe the reduction of airborne CO_2 produced. It differs from the term *carbon output*, which includes any other direct emissions of greenhouse gases during normal use such as CH_4, HFC's, PFC's, and SF_6. CO_2 represents approximately 85% of total greenhouse gas emissions.
- *Full fuel cycle (or source) energy efficiency* accounts for the cumulative impact of extraction, processing, transportation, generation, transmission, and distribution losses on overall energy usage. Unlike *site energy efficiency*, full fuel cycle is useful for hybrid and multi-fuel consumption calculations. Full fuel cycle means that for every Btu of primary energy usage in the coal mine, only 26%-38% of the energy value gets delivered to the customer. In contrast for every Btu of natural gas in the well, 91% of the energy value gets delivered to the customer. Full fuel cycle energy efficiency shows the impact of a scenario on the nations primary energy consumption. *Primary energy consumption* is defined by the EIA as the total consumption of petroleum, cola, natural gas, biomass, hydro, and nuclear power. *Source energy efficiency* is considered the same as full fuel cycle energy efficiency since both metrics consider extraction, processing, and transportation energy requirements. These metrics show that the direct use of

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[2] DOE. 2008. Annual Energy Review 2007, (DOE/EIA-0384(2007)). Washington, D.C. Energy Information Administration, U.S. Department of Energy.

natural gas by residential, commercial, and industrial users is far more energy efficient than the traditional use of coal or natural gas to produce electricity, which then must be delivered for use by homes, businesses, and industries. Full fuel cycle efficiency metrics do have the drawback that they are difficult to measure in the laboratory and are thus difficult to standardize.

- *Site energy efficiency* metrics, such as AFUE[3], are useful for comparing equipment of the same fuel type in an efficiency rating system. These metrics, however, give incomplete information by omitting energy needed to produce and transport the appliance energy to the site. They do not allow direct comparison of appliances using different fuels (e.g., gas versus electric water heaters). *Appliance efficiency* and *end-use efficiency* metrics are also commonly used and have the same drawbacks.
- *Energy cost or site energy cost* is based on site energy consumption by fuel type as well as peak energy demand for electricity in many buildings. *Energy cost* is sometimes used as a proxy for energy efficiency in hybrid and multi-fuel appliance consumption calculations.
- *Energy security* is a term in common use that describes the national security derived from domestic production of energy with domestic fuel sources such as coal and natural gas to the exclusion of imported fuels from U.S. trading partners. Energy security considerations drive decision-making outside the realm of economics and infrastructure issues and into the political arena. For this analysis, energy security impacts were not considered.

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[3] Annual Fuel Utilization Efficiency

3.0 Project Overview

3.1 Objectives

This study analyzes the benefits of increased “direct use” of natural gas as a cost-effective mechanism to assist the nation in achieving two key goals: (1) increase the nation’s full fuel cycle energy efficiency; and (2) reduce national greenhouse gas (GHG) emissions. Objectives of this study were to:

- Assess end use efficiency, national CO_2 emission reductions, primary energy savings, and consumer cost savings through encouraging direct use of natural gas to displace less efficient practices by creating economic incentives for equipment and educating consumers to gain immediate benefits, and providing new technologies through R&D investments for sustainable long term benefits.
- Compare the merits of increased direct gas use relative to other options to meet national energy efficiency and CO_2 emission reduction goals. In particular, compare the relative merits of providing a comparable level of subsidies to direct use of natural gas for space and water heating versus electric end-use resistance heating and water heating technologies.

3.2 Scope of Work

The scope of this project was to use the NEMS-DGU model to determine the impact of three investment options that support the direct use of natural gas to reduce production of CO_2 chiefly produced by electric power generation and consumption. The project provides the core modeling and other analyses needed to provide a firm analytical underpinning for the benefits of increased direct use of natural gas described above, and form the basis for use of the information for educational purposes intended to provide scientific data for the development of local, state, or U.S. climate change policy and associated incentives. This analysis can also expand the base of support for this proposition to others beyond the natural gas industry.

3.3 Approach

3.3.1 Project Team and Modeling Approach

GTI teamed with Science Applications International Corporation (SAIC) for this project. SAIC executed all NEMS-DGU model runs, performed analysis of results, and contributed key input to meetings and reports.[4] GTI provided input on scenarios, modeling assumptions, and analysis, prepared presentations and reports, and provided overall program management. The steering team provided guidance on program needs, external stakeholder involvement, and publication.

Figure 3 shows the NEMS model. NEMS is a national, economy-wide, integrated energy model that analyzes energy supply, conversion, and demand. EIA uses NEMS to provide U.S. energy market forecasts through 2030 in the EIA Annual Energy Outlook. The residential and commercial modules

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[4] SAIC is a FORTUNE 500® scientific, engineering and technology applications company that uses its deep domain knowledge to solve problems of vital importance to the nation and the world, in national security, energy and the environment, critical infrastructure, and health.

SAIC is a policy-neutral organization. SAIC executed the NEMS model in this project using input assumptions provided by the project sponsor organizations and companies. Analysis provided in this report is based on the output from the NEMS model as a result of the project sponsors’ input assumptions. The input assumptions, opinions and recommendations in this report are those of the project sponsors, and do not necessarily represent the views of SAIC.

were the focus of this study and inputs were modified as necessary to meet the objectives of each scenario. The other 10 modules used Reference Case values for all scenarios. Impact to the environment, consumers, and the natural gas industry was considered and is provided in the tables below and in Appendix A.5 of this report.

3.3.2 Scenario Descriptions

The project base case is the AEO2008 Reference Case with modifications to the residential and commercial data input files depending on the scenario to be examined. Table 1 shows the three scenarios that subsidize natural gas direct use and an alternate scenario that subsidizes electric equipment. Each scenario builds on the prior scenario, encompassing the assumptions of its predecessor. The following discussion provides more details on each scenario.

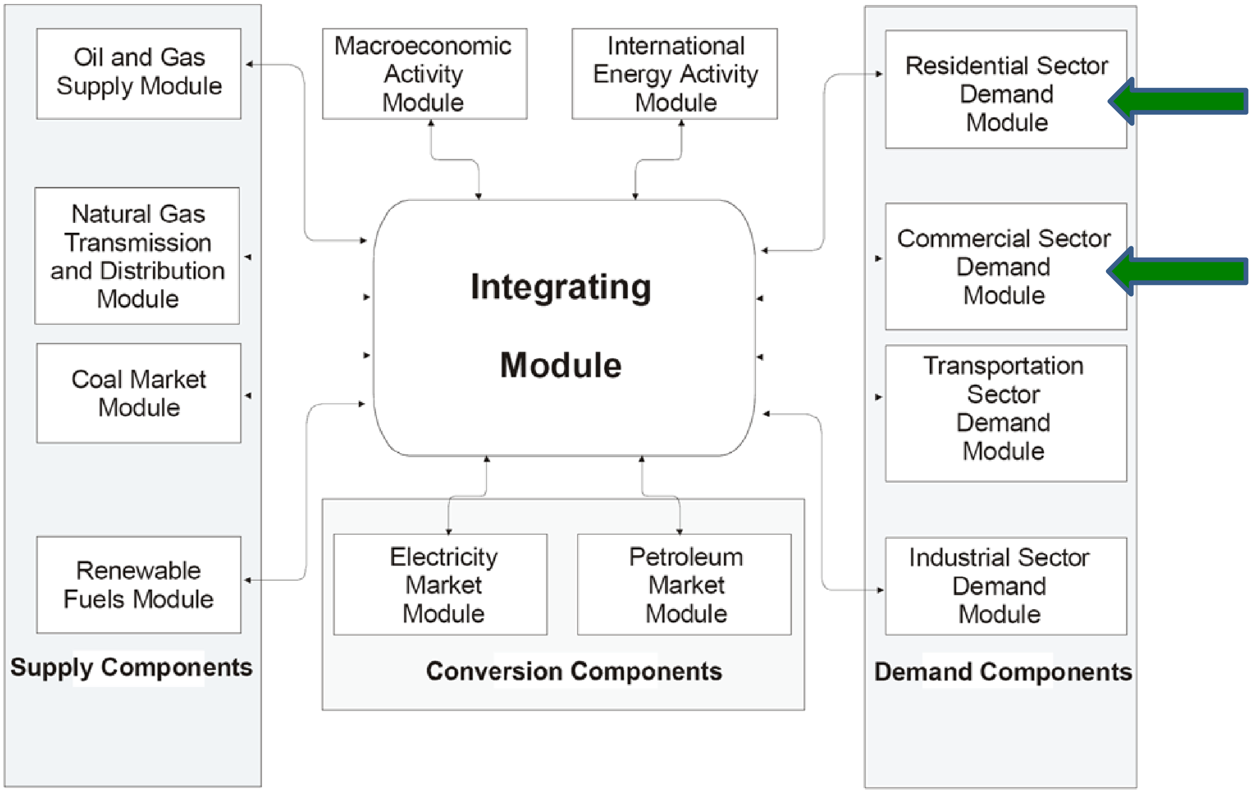

Figure 3 NEMS Model

Table 1 NEMS-DGU Model Scenario Descriptions

Scenario	Description
PR1	**40% Natural Gas Subsidy**
PR2	**Natural Gas Education**
PR3	**Natural Gas R&D**
AE50	**50% Electric Equipment Subsidy**

PR1: 40% Natural Gas Subsidy

This scenario encourages the acquisition and use of natural gas appliances and discourages purchase of their electric counterparts. The methodology specifically imposed in the modeling was to:

- Reduce capital costs of the most-efficient NG appliances & equipment by 40% through a societal subsidy such as a rebate or tax credit;
- Eliminate incremental costs of fuel switching (e.g. the cost of connecting to natural gas); and,
- Impose an economic disincentive as a reflection of a policy decision to discourage the use of electric resistance space & water heating systems.

PR2: Natural Gas Education

This scenario, which includes the changes made in PR1, attempts to reflect the impact of education and promotion programs intended to improve the perception of natural gas. This is more difficult to quantify than the changes made in the other scenarios in that there is no cost/impact lever in NEMS that would motivate such a change. However, there are behavioral parameters in the model that can be changed to reflect behavior modification efforts. Accordingly, changes to the behavioral input files are made with the understanding that consumer response may be both unpredictable and transitory.

- Increases percentage of new and existing residential and commercial facilities capable of using or switching to NG
- Modifies bias parameters related to users' favorable perception of natural gas

PR3: Natural Gas R&D

This scenario, which includes scenarios PR1 and PR2, adds the estimated impact of future cost reduction and increased efficiency through R&D on natural gas heat pumps and combined heat and power (CHP) systems. Increased R&D reduces the cost and increases the efficiency of the specified systems.

- Reduced cost, increased efficiencies and tax incentives for CHP systems (commercial users only)
- Reduced cost and increased efficiencies for natural gas heat pumps

AE50: 50% Electric Equipment Subsidy

For the purpose of comparison, this study also included a scenario with the aggressive promotion of electricity at the expense of other fuels, particularly natural gas. This scenario was designed to mirror for electricity, to the extent possible, the conditions in the PR1 and PR2 natural gas scenarios.

- Reduces capital cost of electric appliances and equipment by 50%

- Encourages electricity in the fuel-choice decision for all appliances
- Other electric incentives that mirror PR1 and PR2 natural gas incentives

4.0 Results and Discussion

Key findings by topic area are provided below. More detailed charts and comparisons are provided in Appendix A.

4.1 Impact on Building Energy Consumption

Figure 4 shows that direct use causes an increase in natural gas residential and commercial consumption. The impact on the residential sector is triple the impact on the commercial sector because residential has greater flexibility in fuel choice. Reduction in electric consumption is less as a percentage because of the higher baseline usage. While the three natural gas end use equipment subsidy scenarios will result in increased natural gas consumption reporting by LDCs, the per capita natural gas usage will go down. Figure 5 shows that the per capita reduction from residential customers ranges from 3 to 12% by 2020 for the gas subsidy scenarios.

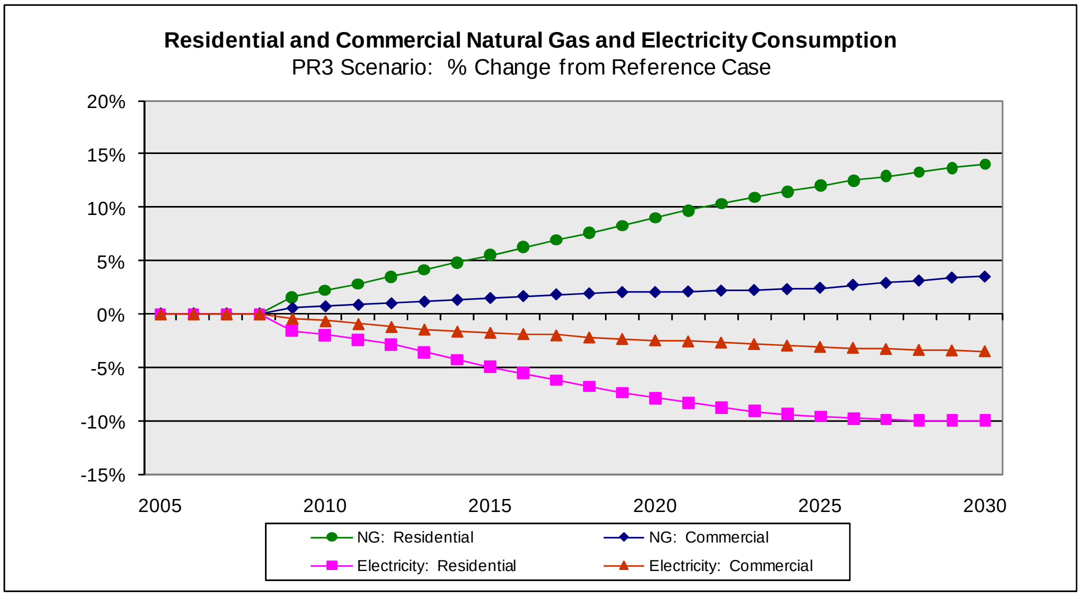

Figure 4 Residential and Commercial Consumption - PR3 Change from Reference Case

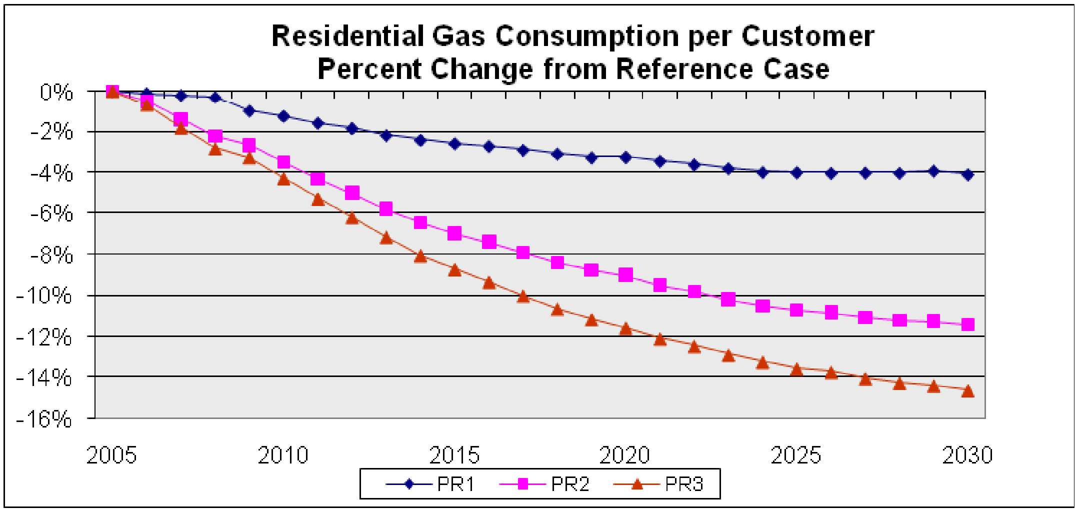

Figure 5 Residential Gas Use per Customer – Gas Subsidy Scenarios Change from Reference Case

4.2 *Impact on National Energy Consumption*

Figure 6 shows that expanded direct gas use decreases total primary energy demand by up to 1.9 Quadrillion Btu's by 2030 due to reduction in electricity consumption with lower full fuel cycle efficiency. All natural gas scenarios decrease demand more than the electric subsidy scenario, AE50, due to the differences in full fuel cycle efficiency between gas and electric resistance space heating and water heating.

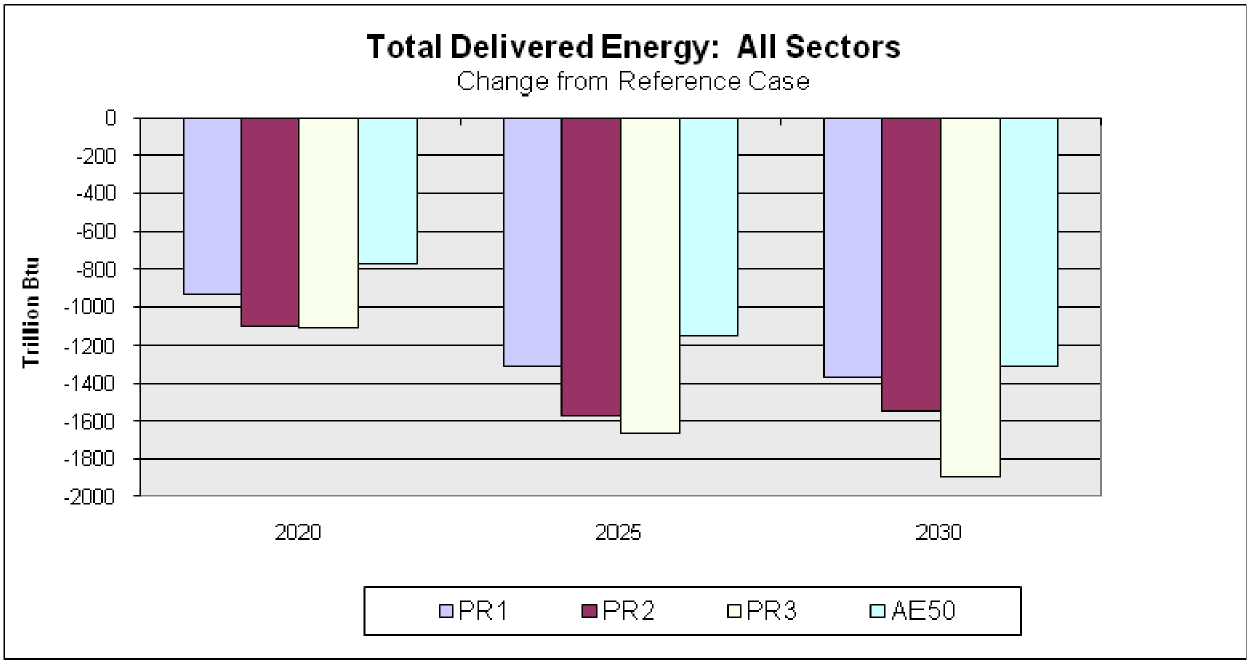

Figure 6 Total Delivered Energy: All Sectors

4.3 Impact on CO_2 Emissions

Figure 7 shows a key result of this study: National CO_2 emissions are reduced significantly by implementing a strategy of rational fuel switching to natural gas end use in buildings. The net CO_2 emission reduction is due to lower electricity consumption in the buildings sector and associated full fuel cycle emission reductions. Emissions are reduced for each of the three scenarios in this model, with the largest reduction provided by PR3 – the cumulative effect of gas incentives, consumer education, and R&D investments. The aggregate effect of the incentives is a reduction of 96 million metric tons (MMT) of CO_2 per year in 2030, which represents a 3.3% emission reduction from the buildings sector. The net annual benefit of the incentives grows with time, from 53 MMT per year in 2015 to 96 MMT in 2030, as national demand for energy increases.

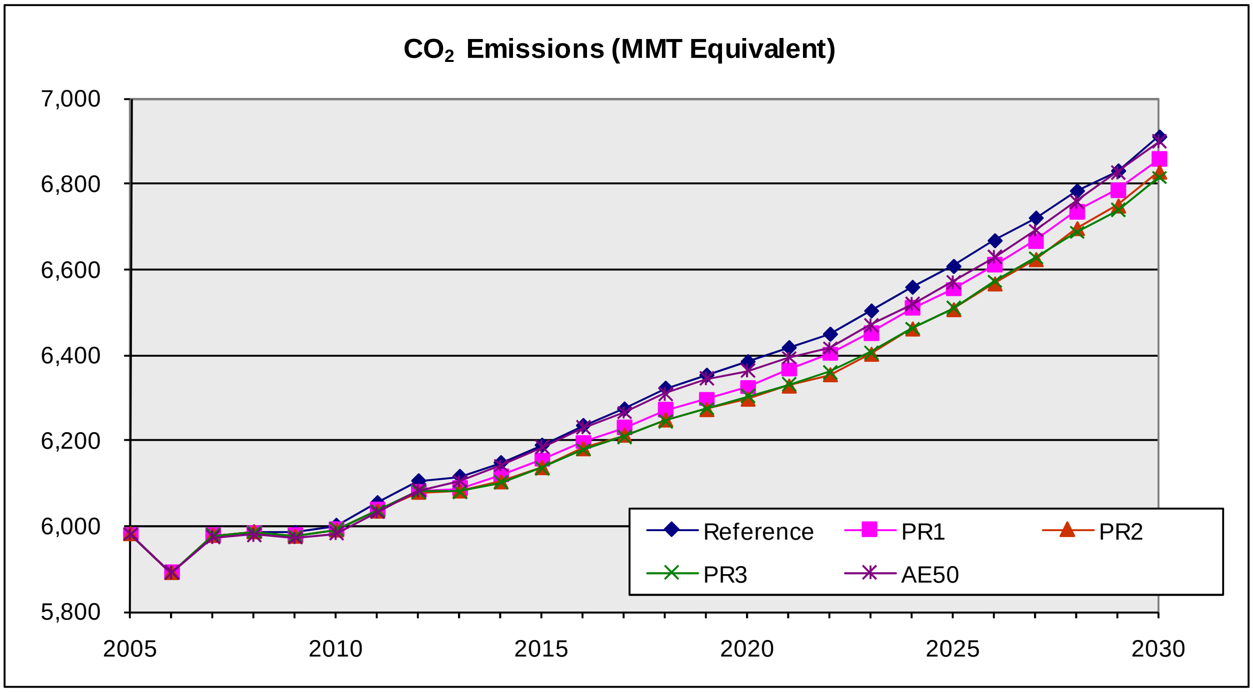

Figure 7 CO_2 Emissions for all Scenarios

4.4 Cumulative Consumer Savings

Figure 8 and Figure 9 show cumulative consumer savings compared to the Reference Case through 2030. Direct natural gas use provides residential and commercial consumers \$120 - \$150 billion cumulative savings, \$30 - \$60 billion more savings than the electric subsidy scenario, while total national energy expenditures show a more significant reduction for all scenarios, with the electric subsidy scenario having more national energy savings than the natural gas subsidy scenarios due to the conversion of 78% of the “Distillate Fuel Oil and LP Gases” consumption to electricity in the residential sector in this scenario. .

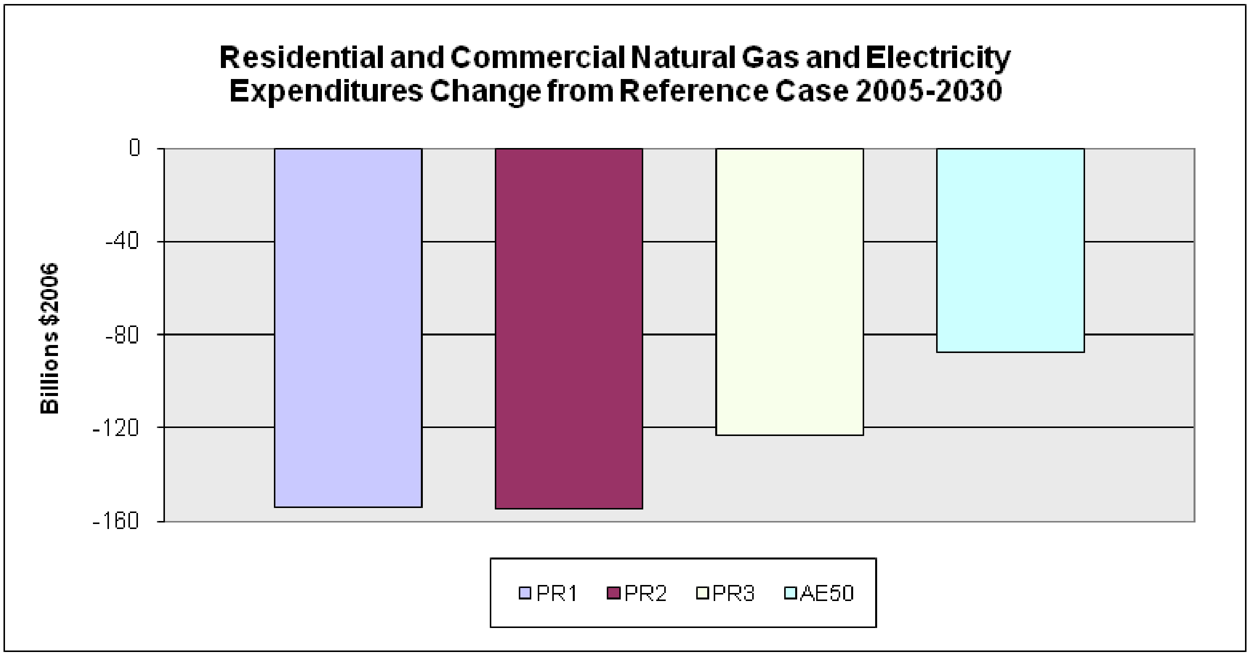

Figure 8 Residential and Commercial Energy Expenditures Change from Reference Case

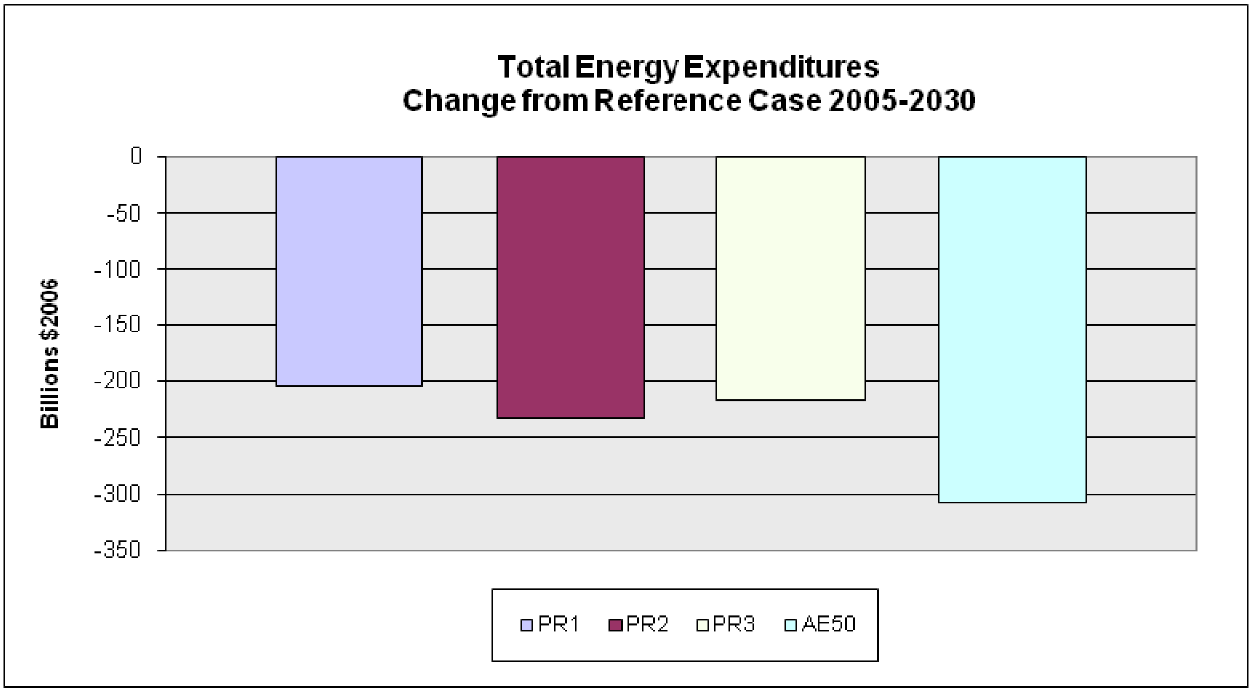

Figure 9 Energy Expenditures Change from Reference

4.5 Cost per Tonne of CO_2 Emission Reduction

Figure 10 shows the CO_2 emission reductions for each scenario relative to the Reference Case. As expected, the greatest incremental impact of the three natural gas subsidy scenarios is produced by Scenario PR1 (incentives). In 2030, more than 50% of the net benefit is provided by that scenario – a reduction of approximately 50 MMT per year. Scenario PR2 (incentives and education) provides the rest of the net benefit until 2025 when the incremental impact of education is reduced and Scenario PR3 (incentives, education, and advanced technology due to R&D) has a higher net benefit. The impact of the three scenarios grows steadily until 2025 and then stays slightly below 100 MMT per year through 2030.

Scenario AE50, the electric incentives and education equivalent to PR2, provides initial CO_2 emission reduction as less efficient electric appliances are replaced with more efficient electric technologies, but the net benefit is reduced to near zero in 2030 for reasons that cannot be explained by the aggregate value provided by the NEMS model. Possible factors include fuel mix changes for electricity generation, or replacement of oil and LP equipment by electric equipment. Policies that include natural gas incentives and education are much more effective in providing sustainable CO_2 emissions reductions than similar electric incentives and education – a difference of approximately 65 MMT per year in 2030.

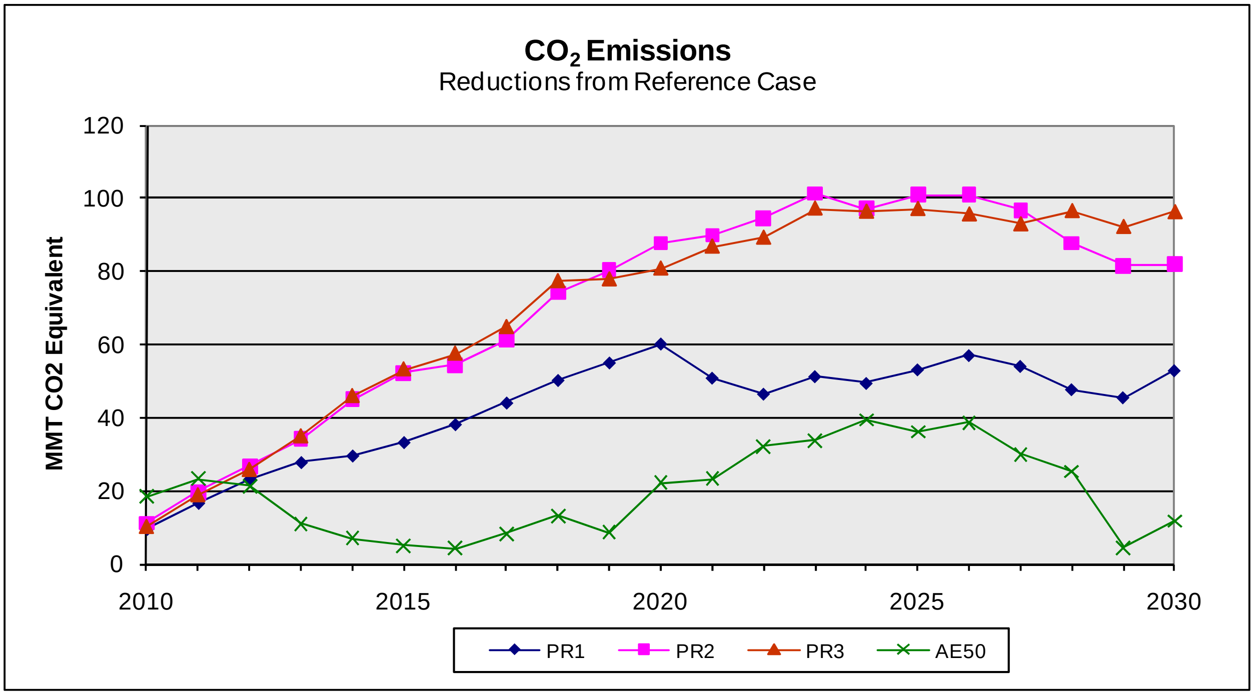

Figure 10 CO_2 Emission Reduction Relative to the Reference Case

Figure 11 compares the gross subsidy cost per tonne of CO_2 emission reduction over time of the three gas subsidy scenarios and the electric subsidy scenario. The gross cost per tonne of the electric subsidy scenario for the five years ending in 2030 is more than an order of magnitude higher than the cost of any of the three gas subsidy scenarios. Figure 11 also shows that the gross gas subsidy cost per tonne of CO_2 emission reduction declines over time as the impact of behavior, incentives, and technology development spreads in the marketplace. The gross cost per tonne of the AE50 scenario falls for a period of time as efficient electric technology market penetration increases, but rises as the generation fuel mix changes and market saturation reduces the incremental reduction opportunities. These costs do not represent the total societal cost or savings of the scenarios, but do provide a relative indicator of which options are likely to be more cost-effective when other societal savings, such as avoided power plant construction, are included in the analysis.

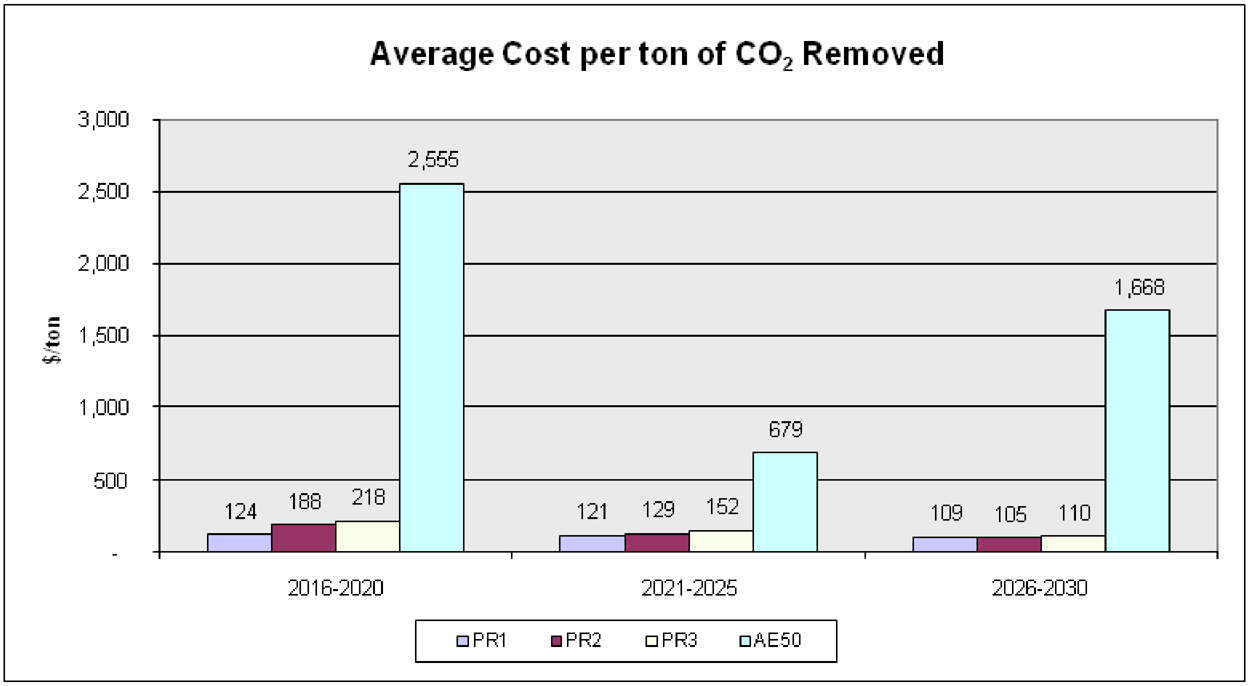

Figure 11 Cost per Tonne of CO_2 Reduction

Societal benefits of direct gas use in scenario PR3 include eliminated or deferred cost of electricity generation that would have been needed otherwise. As summarized in Table 2, approximately 50 GW of electric power generation is eliminated in scenario PR3, for a total cumulative capital cost savings of $111 billion (an average cost of $2,200/kW). The 1,496 MMT cumulative CO_2 emission reduction compared to the Reference Case results in a societal savings of approximately $74/tonne of CO_2. This societal savings offsets the gross societal cost of the subsidy to obtain the benefits of direct gas use.

Cumulative consumer energy cost savings through 2030 associated with the PR3 scenario are $213 billion. This represents an additional societal savings of $142/tonne of CO_2. Inclusion of these societal savings more than offsets the gross cumulative subsidy cost per tonne of the PR3 scenario, creating a significant net societal benefit.

Table 2 Power Plant Capital Cost Savings from Reduction in GW

Power Plant Description	Fuel Source	Cumulative Reduction in GW Built (2030)	Capital Cost ($/kW)	Total Capital Costs Avoided ($ M)	Cumulative CO_2 Reduced, PR3 Case (MMT)	$/Tonne CO_2 Savings
Steam Turbine	Coal	11.0	700	7,700		
Steam Turbine	Natural Gas	6.5	500	3,250		
Combined Cycle Turbines	Natural Gas	2.7	650	1,755		
Combustion Turbines	Diesel	10.9	1,500	16,350		
Nuclear Power Plants	Nuclear	11.0	3,500	38,500		
Renewables Central Station	Renewables	3.5	10,000	35,000		
Distributed Generation	Natural gas	4.3	2,000	8,600		
Totals		**49.9**	N/A	**111,155**	**1,496**	**74**

Another option available in the residential market to reduce CO_2 emissions is improved performance of the thermal envelope. The NEMS-DGU model was not suitable for evaluating installed costs for this option. An alternative simulation analysis was conducted using GTI's Residential Energy Efficiency Wizard, an hourly simulation tool that evaluates the installed cost and energy savings of energy efficiency improvement options. The analysis compared installed cost and energy savings for envelope improvements and substituting gas for electric water heater in representative cities in each of the nine U.S. census regions. The incremental cost of envelope upgrades in new construction was compared to the incremental cost of installing a gas water heater rather than an electric water heater to determine which option is likely to be more cost-effective.

Table 3 provides a snapshot of the cost per tonne of CO_2 emission reduction for a water heater upgrade from electric to natural gas and an insulation upgrade for the attic and wall in a major city in each census region. On a national average basis, the incremental cost of a gas water heater over electric water heating as an upgrade in new construction produces a gross cost per tonne of CO_2 emission reduction of $84. Upgrading insulation as a new construction choice produces a gross cost per tonne of CO_2 emission reduction over $1,200 on a national average basis. This suggests that rational fuel switching to natural gas water heating in new construction would likely be an order of magnitude more cost-effective than an envelope upgrade as a national CO_2 emission reduction strategy.

For a retrofit of gas appliances or insulation into an existing building there are many possible scenarios to be considered that likely would increase installed cost significantly. Appendix A.3 provides further information on the retrofit costs of gas furnaces and water heaters as well as insulation. This analysis shows the importance of making good decisions on fuel choice and level of insulation when the home is first built.

Table 3 Water Heater Fuel Switching and Thermal Envelope Upgrade Options for New Homes

City	Census Region	Water Heater Upgrade Cost/Tonne of CO_2 Reduced ($)	Thermal Envelope Upgrade Cost/Tonne of CO_2 Reduced ($)
Boston	New England	57	1,124
New York	Mid Atlantic	98	1,256
Indianapolis	E. N. Central	29	1,061
Omaha	W. N. Central	38	987
Atlanta	S. Atlantic	46	1,610
Nashville	E. S. Central	51	1,354
Dallas	W. S. Central	48	1,642
Denver	Mountain	32	1,132
Seattle	Pacific	----	1,304

4.6 Impact on Natural Gas Production

Figure 12 shows the impact of each scenario on natural gas production compared to the Reference Case. When direct use of natural gas is encouraged through subsidies, natural gas production increases by up to 0.2 Quadrillion Btu's. This is a relatively small change of about 1% in total natural gas production. The electric subsidy scenario, however, reduces natural gas production 1.1 Quadrillion Btu's, about 5% of total natural gas production.

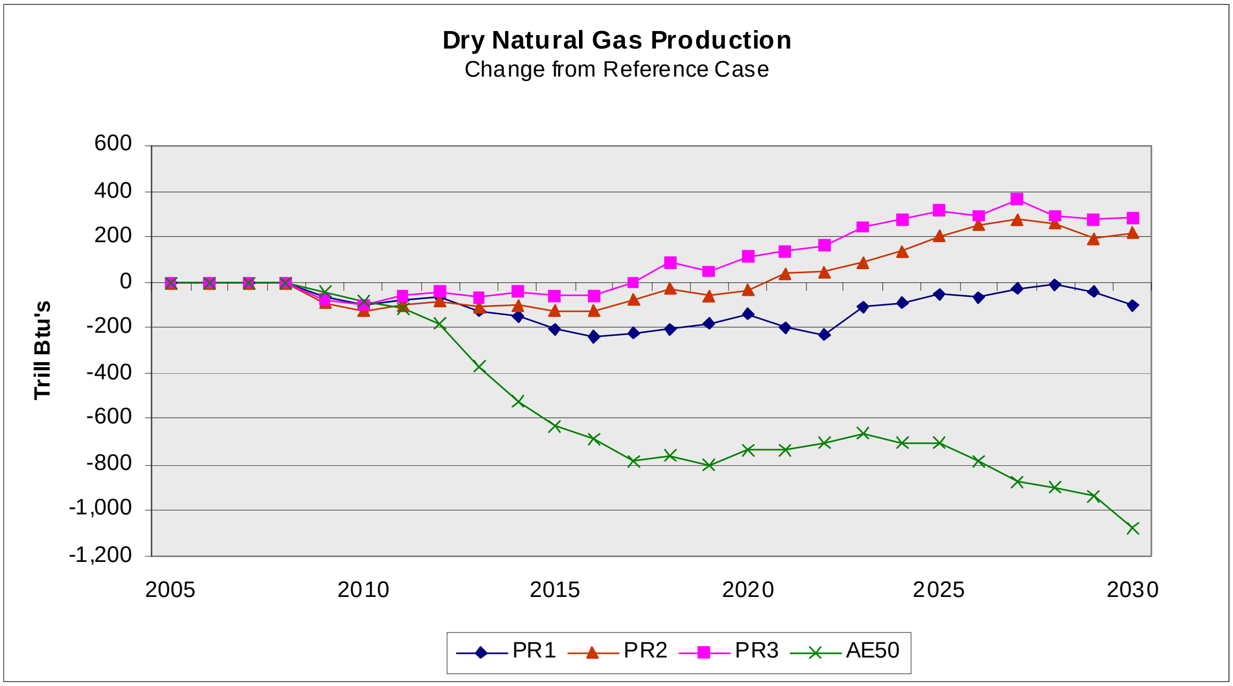

Figure 12 Dry Natural Gas Production

4.7 Impact on Natural Gas Prices

Figure 13 and Figure 14 show the impact of each scenario on natural gas prices. Residential customers will see a slight price increase of 3.7% for the PR3 scenario relative to the Reference Case by 2030 as a result of increased gas demand, while commercial customers will see essentially no price increase.

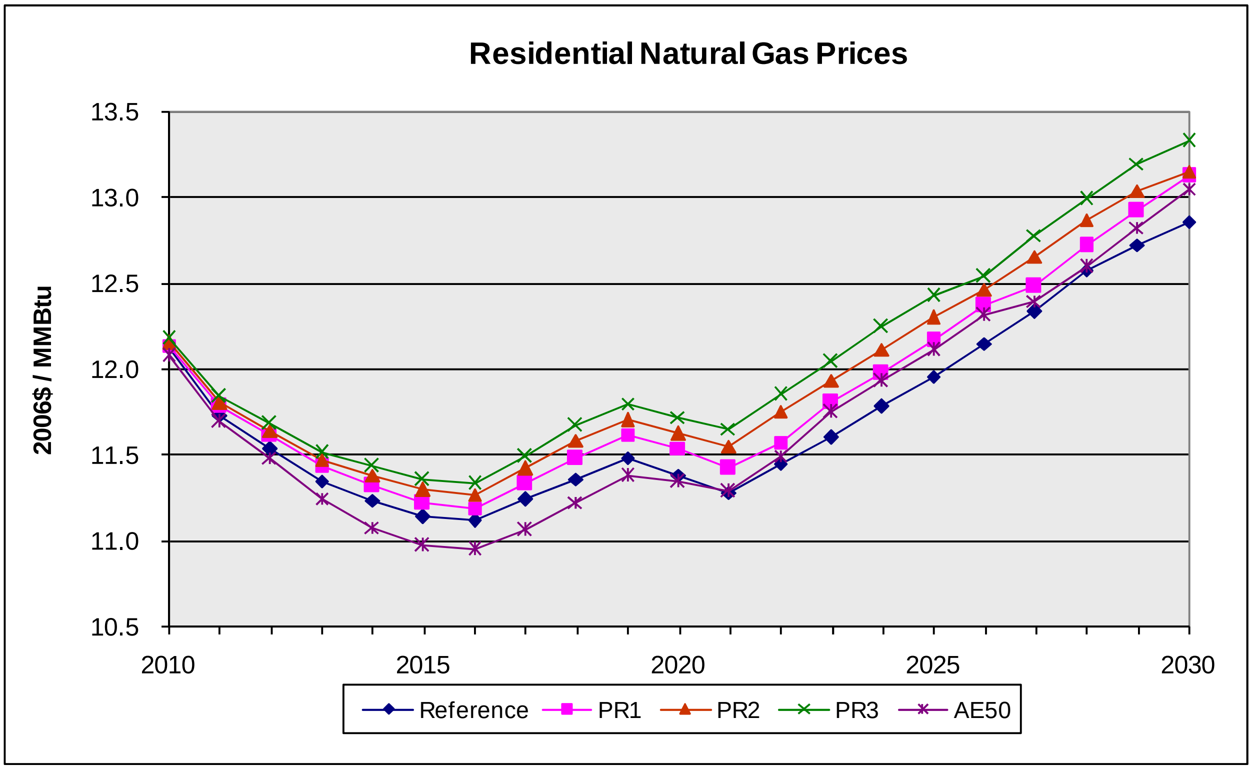

Figure 13 Residential Natural Gas Prices

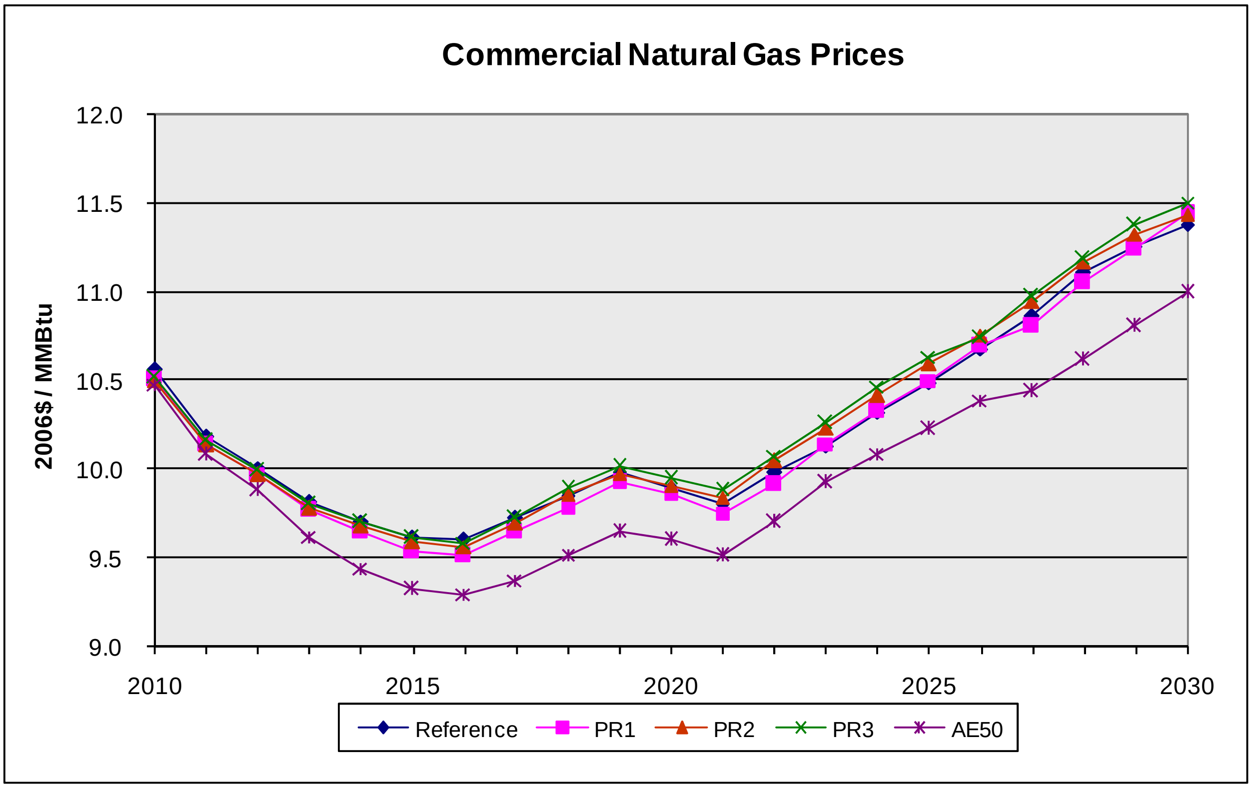

Figure 14 Commercial Natural Gas Prices

4.8 Impact on Electric Generation

Figure 15 shows generating capacity impacts from the Reference Case for all 4 scenarios in 2030. PR1 through PR3 show reductions across all fuels whereas AE50 shows increases in required generation capacity for all fuels with the combustion turbine/diesel category increasing most – all of which is due to increased gas turbine generation. For generation impacts across generating sources for each scenario, see Appendix A.5.6.

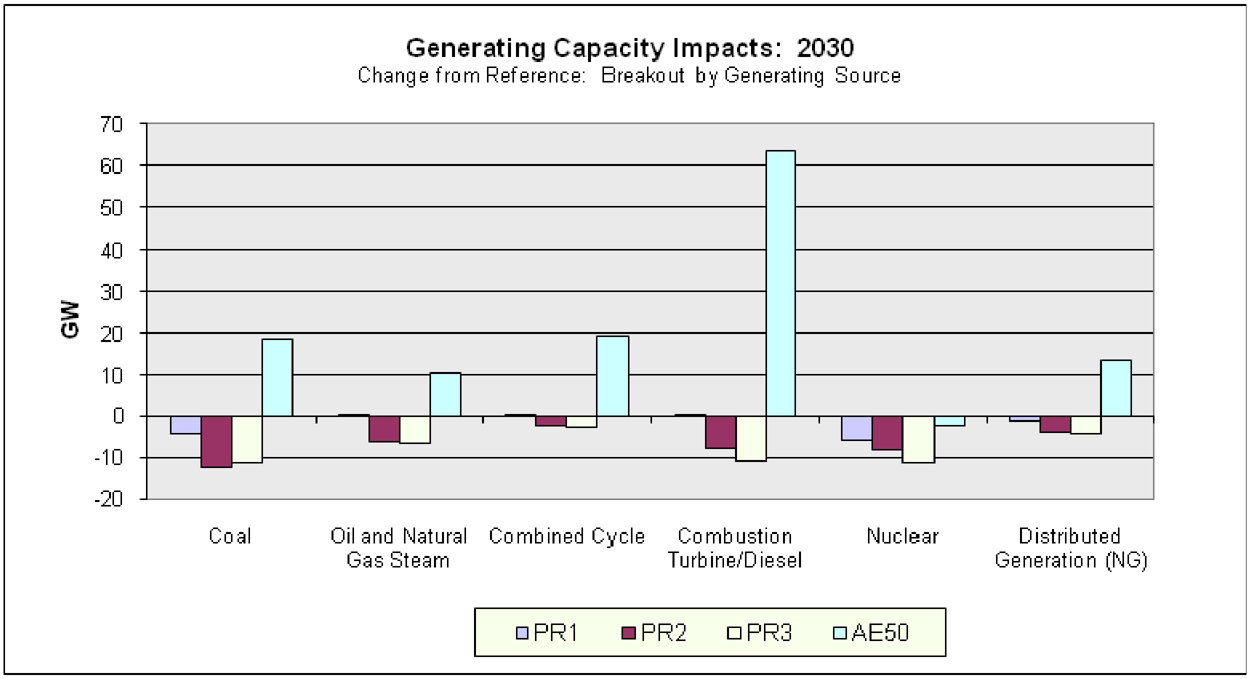

Figure 15 Generation Capacity Impacts

5.0 Conclusions and Recommendations

The NEMS-DGU analysis supports prior CO_2 emission reduction study results showing the benefit of policies that encourage efficient direct natural gas use in certain residential and commercial market applications. Strategies are ready for immediate implementation, and have low or negative net societal cost per tonne.

As the cornerstone principle of any U.S. policy to reduce CO_2 emissions, the country should first ensure that it uses its existing energy sources in the most efficient way possible. Optimizing the use of the nation's current energy sources will increase energy efficiency by converting 26-38% full fuel cycle efficiency for converting coal in the mine to electricity vs. 91% full fuel cycle efficiency for natural gas from the wellhead to the appliance. Optimizing the use of the nation's current energy sources will also reduce primary energy demand by up to 1.9 Quadrillion Btu's by 2030, avoid the need for over 40 GW of electric generating capacity, and help to reduce the potential high cost of implementing legislation to reduce GHG emissions.

GHG legislative initiatives will need to include appropriate stakeholder incentives for overall emission reduction strategies that selectively reduce electricity consumption while increasing natural gas use.

Further research is needed into cost-effective gas options with optimal CO_2 reduction targeted to building performance improvements, combined heat and power at the micro or macro level, and appliance usage by market segment and region of the country. This information will provide further evidence of the benefits of gas options to reduce national CO_2 emissions.

Appendix A

A.1 Metrics for Energy Use and Emissions

There are a number of alternative metrics to account for energy consumption, efficiency, and emissions related to building operation. Examples include:

- Site energy use (therms, kWh, gallons, Btu)
- Full fuel cycle energy use (Btu)
- Energy use index (kBtu/ft^2/Year)
    - Usually site energy based irrespective of fuel type
    - Sometimes includes partial or full fuel cycle energy

Depending on the goal of the energy analysis, one or more of these metrics will be required. Irrespective on the analysis, site energy consumption will always be required. Alternative metrics include cost, emissions, and ecological factors such as:

- Energy cost ($)
- Energy price ratio ($/therm, $/kWh, $/gallon, $/Btu)
- Energy cost index ($/$ft^2$/Year)
- Greenhouse gas emissions (CO_2, CH_4, N_2O, HFC’s, PFC’s, SF_6, CO_2e)
- Total environmental impact (energy, water, materials, air quality, society, ecosystem)

These metrics will always require supplemental information beyond site energy consumption and may be significantly more challenging to estimate.

Site energy and site energy use index are the only metrics that can be measured directly in a building. Other metrics are derived from site energy by considering other factors such as cost, upstream energy consumption, or emissions. The most significant issue with site energy is that not all energy forms are equivalent, making comparisons either difficult or impossible when considering more than one fuel in a building as well as the impact of purchased fuels on local, regional, or national energy consumption and efficiency. Oil, natural gas, propane, coal, and nuclear are the dominant primary energy sources in the U.S. Electricity and hydrogen are energy carriers derived from primary energy sources. Hydropower is currently the dominant renewable source, but future renewable energy growth will come from wind, solar, and biomass. None of these different energy sources can be directly compared using only site energy.

Site energy is a necessary but not sufficient metric for site and national energy inventories and efficiency improvements. Site energy-based efficiency metrics for multi-fuel appliances give incomplete energy information (e.g., AFUE). Site energy also does not allow direct energy comparisons of appliances consuming different fuels (e.g., gas versus electric water heaters) or multi-fuel appliances (e.g., powered combustion appliances, combined heat and power systems, hybrid renewables). Additional information is needed for aggregation and rational comparisons within buildings, macro-analysis of energy inventory and efficiency initiatives, and consideration of externalities such as national CO_2 emissions.

Full fuel cycle analysis enables a comprehensive analysis of total energy and environmental impact. Full fuel cycle energy efficiency shows the impact of a scenario on the nation’s primary energy consumption. As shown in Figure A-1[1], primary energy consumption is defined by the EIA as the total consumption of petroleum, cola, natural gas, biomass, hydro, and nuclear power. Full fuel cycle energy metrics are intended to account for the cumulative impact of extraction, processing, transportation, generation, transmission, and distribution losses on overall efficiency. Unlike site energy, full fuel cycle energy is useful for hybrid and multi-fuel appliance consumption calculations. Conversion efficiency is often used as a proxy for full fuel cycle efficiency, but it is only part of the full fuel cycle efficiency, most useful for evaluating net generation efficiency at power plants. Cumulative full fuel cycle efficiency is most appropriate for determining local, regional and national impact of building energy consumption, since it addresses multi-fuel, hybrid, and combined heat and power (CHP) systems, and includes all losses from extraction through distribution to the building.

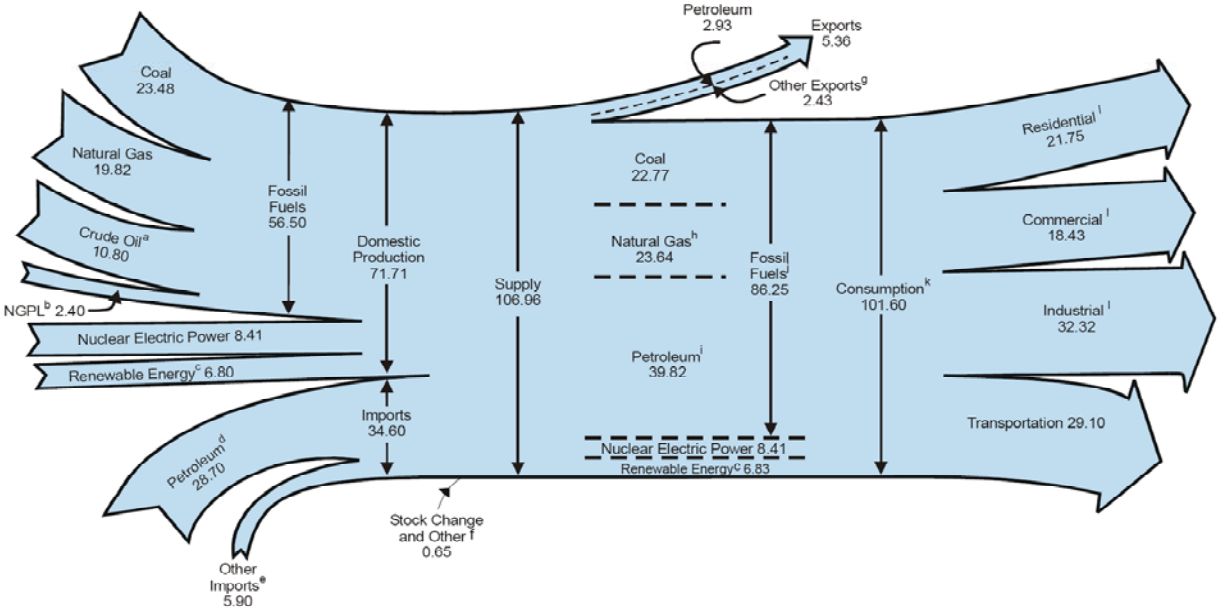

Figure A-1 Primary Energy Consumption

Full fuel cycle energy metrics also have limitations and challenges. They cannot be measured directly, but must be derived from site energy. Primary energies are not easily compared. Fossil and biomass fuels have different CO_2 emission factors, with coal having the highest emission factor and natural gas having the lowest emission factor. Nuclear, hydropower, solar, wind, and biomass each have different environmental impacts as well as resource availability. Also, source efficiencies may vary over time and location as technology improvements in power generation occur and as the relevant generation mix changes.

Full fuel cycle energy is a necessary but not sufficient metric for national greenhouse gas and total environmental impact assessments. It is required for whole building, regional, and national aggregations and comparisons. It is necessary as the basis of estimating national CO_2 and other greenhouse gas emissions due to appliances and buildings. However, additional CO_2 and environmental impact information is needed to complete those calculations to include the energy used for remediation.

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[1] EIA Annual Energy Review, 2007

Energy cost is based on energy consumption by fuel type as well as peak energy demand for electricity in many buildings. Cost is the bottom line consideration for consumers, and is the most easily understood metric. It is the basis of standards and certification requirements in certain minimum energy efficiency standards and green building programs. In these programs, life cycle cost impacts of options are evaluated only after appliance fuel type is chosen.

Site energy cost may be a useful proxy for energy in hybrid and multi-fuel appliance consumption calculations. It may also be useful for aggregations and comparisons of different energy source appliances, CHP, and multi-fuel appliances for whole buildings as well as regional and national evaluations, especially if life cycle cost (LCC) is used. However, price volatility makes LCC comparisons difficult. Subsidies can skew relative costs among fuels, and regulated utility price structures are often slow to change. These factors limit the usefulness of cost as a proxy for energy. In spite of these limitations, cost is expected to be a significant metric for GHG initiatives.

GHG metrics are an integral part of ongoing attempts to address global warming from anthropogenic sources. CO_2 is the key GHG, but CH_4, N_2O, and SF_6 are also considered significant enough to be of interest. CO_2 represents 85% of total GHG emissions, but the others have high global warming potential relative to CO_2, some with long atmospheric life. The discussion in this study focuses on CO_2 emissions, which are the key, but not only component of GHG emissions.

Recent legislation[2] has emphasized the improvement of efficiency of both natural gas and electric residential and commercial use and there are active legislative proposals to control GHG emissions. Significant subsidies are now available and are anticipated to be available in the future to achieve the goals. Based on the legislated goals, there can be difference in the performance of these initiatives and it is very important that end use efficiency, full fuel cycle efficiency and carbon footprint of these programs be assessed separately so there are no unintended consequences of the policy decisions.

Appliance End use Efficiency

The present consumer information on residential and commercial appliances implies that the performance of the electric end use appliances are better than the natural gas appliances because the conversion efficiency of the energy by the device itself. This misleading measurement does not take into account the overall efficiency of producing and transporting the energy to the marketplace, which in the case of electricity can lead to significant energy losses.

In response to this concern, the National Research Council recommended that "the U.S. Department of Energy should consider gradually changing its system of setting appliance energy-efficiency standards to a full-fuel-cycle measurement, which takes into account both the energy used to operate an appliance, as well as upstream energy costs -- energy consumed in producing and distributing fuels from coal, oil, and natural gas, and energy lost in generating and delivering electric power. This change would offer consumers more complete information on household energy consumption and its environmental impacts.[3]"

Full Fuel Cycle Efficiency

On a "full fuel cycle" basis, the direct use of natural gas by residential, commercial and industrial energy users is far more energy efficient than the traditional use of coal or natural gas to produce electricity, which then must be delivered for use in homes, businesses and industries. Full Fuel cycle means, for example, that for every Btu of primary energy in the coal mine, only 26% - 38% of the energy value gets delivered to the end-use customer after extraction, processing, transportation of the product to a

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[2] H.R. 2454 American Clean Energy and Security Act of 2009

[3] National Academy of Sciences. 2009. Review of Site (Point-Of-Use) and Full-Fuel-Cycle Measurement Approaches to Doe/Eere Building Appliance Energy-Efficiency Standards

power plant, and then the subsequent conversion and distribution of the electricity to the end users. In contrast, for every Btu of natural gas in the well, 91% of the energy value gets delivered to the end-use customer after extraction, processing, transmission, and distribution. The energy lost in delivered electricity from fossil fuels and nuclear energy is substantially greater than losses associated with natural gas delivery. A comparable analysis is the GREET model[4] that analyzes the fuel energy use from "wells to wheels."

Carbon Output

In the current debate in Congress regarding energy efficiency and GHG emission reductions, the House Energy and Commerce Committee has determined that "Carbon Output" is a better way to compare alternative technologies impact on the environment, as follows:

> "(i) national average energy use for the product including energy consumed a the point of end use based on test procedures developed under Section 323 of this part;
>
> (ii) national average energy consumed or lost in the production, generation, transportation, storage, and distribution of energy to the point of end use; and
>
> (iii) any direct emissions of greenhouse gases from the product during normal use."[5]

This and other legislative initiatives will need to include the most cost-effective alternative carbon output reduction strategies to maximize the impact on carbon output. Consideration of all options, including rational fuel switching, that reduce national carbon output will require justification in terms that legislators can understand and address.

Previous studies using a variety of analytic methods have identified increased direct natural gas use in place of less resource efficient technologies as an effective national CO_2 emission reduction strategy. It is important for the gas industry as it educates legislators and other stakeholders about the benefits of direct natural gas use to supplement and validate those studies using a methodology that is accepted by the federal government.

A.2 Project Description

The Congressional Budget Office (CBO) projects substantial revenues may be generated from selling greenhouse gas (GHG) emissions allowances under the leading Senate cap-and-trade legislation. These revenues could be available for incentives to enable consumers directly, or indirectly through utilities, to switch to higher efficiency appliances and equipment. Showing analytical support for the benefits resulting from the direct use of natural gas increases the potential for federal and state governments to adopt incentives for direct use applications. For example, additional incentives can be made available for consumers who achieve more than 80% efficiency on a "full fuel cycle" basis (e.g., 91% natural gas fuel cycle efficiency and 90% equipment efficiency) as compared to the low full fuel cycle efficiencies from electric resistance systems (e.g., 30% electric full fuel cycle efficiency and 91% to 99% equipment efficiency). Furthermore, once in place, these programs could reduce initiatives by the electric power industry to promote higher efficiency (on a site basis) electric appliances and equipment that do not provide full fuel cycle savings. Also, as some electric utilities begin to promote decoupling and energy efficiency, it is possible that promoting the conversion to more efficient gas appliances could be part of their Demand Side Management (DSM) programs.

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[4] ANL. 2009. Greenhouse gases, Regulated Emissions, and Energy use in Transportation GREET 1.8c.0., http://www.transportation.anl.gov/modeling_simulation/GREET/index.html. Argonne, IL. Argonne National Laboratory.

[5] H.R. 2454 American Clean Energy and Security Act of 2009, pp. 307, 308.

The natural gas industry has expressed concern that current provisions in proposed legislation to reduce GHG emissions could act to reduce residential, commercial and industrial demand for natural gas rather than recognize the positive contribution that natural gas can make as part of the GHG solution. Further, most analyses show that even demand for natural gas use for electric generation, while increasing in the near-term, will likely dramatically drop once zero-emission generation technologies (sequestration, renewables and nuclear) are viable - generally projected around 2030. There is also concern that the near-term increase in gas demand for power generation will substantially increase gas prices to natural gas core customers.

In the context of a GHG constrained market, this project offers a proposed path to: (1) optimize the nation's use of existing energy sources; (2) increase energy efficiencies; (3) reduce CO_2 emissions under a lower-cost, immediately available option; and (4) sustain/expand natural gas markets beyond 2030.

On a "full fuel cycle" basis, the direct use of natural gas by residential, commercial and industrial energy users is far more energy efficient than the use of coal or natural gas to produce electricity, which then must be delivered for use in homes, businesses and industries. For every Btu of energy of coal in the mine, only 26% - 38% of the energy value gets delivered to the end-use customer after extraction, processing, transportation to a power plant, and then conversion and distribution of the electricity. In contrast, for every Btu of natural gas in the well, 91% of the energy value gets delivered to the end-use customer after extraction, processing, transmission, and distribution.

This project directly supports the GTI white paper and the recent AGF direct gas use study by providing additional evidence of the benefits of direct gas use.

The objective of this project was to investigate the impact of near-term, aggressive deployment of increased-efficiency natural gas equipment in our nation's homes, offices, and industries to displace - - wherever feasible and effective - - similar electric applications. The project also explores how implementation of incentives for consumers to achieve high efficiency "full fuel cycle" targets can further the goal of reducing CO_2 emissions. The increased direct use of natural gas in residential, commercial, and industrial applications to replace existing electricity-based appliances and equipment technologies, which on a full fuel cycle are less efficient than the direct use of natural gas, will:

- Reduce electricity demand,
- Diminish the need for a commensurate amount of electric generating capacity,
- Lower CO_2 emissions that would be associated with such generation,
- Be less expensive in the near term than other proposed CO_2 emissions reductions technologies and plans (such as sequestration), and
- Establish a more permanent and diverse market for natural gas.

The project investigates the premise that the CO_2 emissions reductions that result from reduced electricity demand significantly exceed CO_2 emissions resulting from increased gas consumption. The project also examines the replacement of less-efficient gas-based technologies (e.g., water heaters, furnaces, and boilers) with higher efficiency gas technologies, which will result in further CO_2 emissions reductions. The use of advanced fuel cells as a modeling approach for residential combined heat and power applications is investigated as well. Efforts to improve gas equipment efficiencies further will be needed for gas appliances to remain competitive and to reduce incentives to switch back to electric appliances/equipment after zero-emission generation technologies are viable/operative, post-2030.

The project provides the core modeling and other analyses needed to provide a firm analytical underpinning for the benefits of increased direct use of natural gas described above, and form the basis for sponsors' use of the information for educational purposes intended to provide scientific data for the development of local, state, or U.S. climate change policy and associated incentives. This analysis can also expand the base of support for this proposition to others beyond the natural gas industry.

A.3 Detailed Scenario Descriptions

The three scenarios developed for in this project were developed by SAIC using the National Energy Modeling System Direct Gas Use (NEMS-DGU) model. The project base case is the AEO2008 Reference Case with modifications to the residential and commercial data input files depending on the scenario to be examined. Each scenario builds on the prior scenario, encompassing the assumptions of its predecessor. The three natural gas scenarios and one electric scenario comprising this model run can be described as follows:

PR1:	40% Natural Gas Equipment Subsidy
PR2:	Natural Gas Education
PR3:	Increased Natural Gas R&D
AE50:	50% Electric Equipment Subsidy

These are described in greater detail below.

A.3.1 PR1: 40% Natural Gas Equipment Subsidy

This scenario encourages the acquisition and use of natural gas appliances by: (1) subsidizing the purchase of higher-efficiency equipment; (2) reducing the assumed incremental costs of switching fuels to natural gas; and (3) imposing a significant surcharge on electric resistance water and space heating to make energy-efficient technologies more appealing.

(1) Subsidy: Based on tests of different levels of financial incentives, a 40 percent discount was applied to the capital costs of selected residential appliances and commercial equipment. Specifically, the following changes were made to the data input files (the AEO2008 Reference Case):

In the Residential model:

- Capital costs of the most efficient natural gas equipment were reduced by forty percent for the following end uses: space heating, water heating, and clothes drying.
- Costs of all models of natural gas cooking equipment were similarly reduced.
- The costs of natural gas heat pumps were not discounted.

In the Commercial model:

- Capital costs of all natural gas equipment designated as “high” efficiency were reduced by forty percent.
- Equipment without a “high” efficiency option were all uniformly discounted (this included natural gas cooking equipment and gas chillers). Natural gas heat pumps were not discounted.
- All other data inputs were left unchanged.

(2) Fuel Switching: This component reflects assumptions about the costs and feasibility of switching from electricity to natural gas in the residential sector. Specifically, in the residential model, the incremental costs of switching from electricity to natural gas appliances were reduced to zero. These reductions were applied to the end-uses of space heating, hot water, cooking, and clothes drying.

(3) Electric Surcharge: Finally, an adjustment was made to capital cost data to approximate the impact of a legislative ban on electric resistance water and space heating. The structure of the model precludes removing this technology as an option, so the impact was modeled by raising the capital cost of

electric resistance equipment in the residential and commercial sectors by 10 to 20 times the original cost, rendering them uncompetitive with other systems.

In addition, these scenarios incorporate one specific and important modification of the residential model's source code. One constant factor, BLDRWT, has been reset from a value of 6.0 to 1.0. This factor, the builder's weight, affects the choice of heating system installed in newly-constructed homes by discounting the contribution of expected operating costs when calculating the life cycle cost for the equipment. In other words, builders are assumed to be more concerned with initial capital costs than with the expected operating costs of equipment that will be installed in new homes—this has resulted in a weighting that has favored equipment with lower initial costs, typically electric resistance heating. By resetting the builder's weight factor to 1.0, the residential model evaluated equipment choice on an equivalent basis, that is equipment first cost and operating cost are equally weighted in the equipment buying decision.

A.3.2 PR2: Natural Gas Education

This scenario, which includes the changes made in PR1, attempts to reflect the impact of educational and promotional programs intended to improve the perception of natural gas. This is much less quantifiable than the changes made in the other scenarios in that there is no cost/impact lever that would motivate such a change. However, there are behavioral parameters in the model that can be changed to reflect actual behavior modification. Accordingly, changes to the behavioral input files are made with the understanding that consumer response may be both unpredictable and transitory.

In the Residential model:

For new home construction, bias parameters help determine the mix of heating technologies. These are unit-less indicators of a homeowner's predilection for a particular heating fuel & technology. These parameters vary by building type (single family, multifamily, mobile homes) and census division. In these scenarios, the natural gas bias parameters are reduced by 80 percent—the greater the reduction, the larger the resulting market share.

For existing homes, the bias parameter is used in the sharing function for replacement equipment. The bias parameter is also changed by 80 percent to increase the share of consumers favoring natural gas equipment.

The shell integrity of new housing is a function of capital and operating costs for several levels of total system efficiency. These include homes that meet the 2000 International Energy Conservation Code (IECC), Energy Star Homes, and homes that meet the goals of the Partnership for the Advancement of Technology in Housing (PATH) program. The choice of heating system within a given fuel type influences the resulting building shell efficiency. This scenario adjusts the parameter to increase the market share of higher-efficiency equipment.

The maximum fraction of single-family homes that can switch away from electric appliances when the time comes for replacement was adjusted, increasing the share from 20 percent to approximately 85 percent. This impact is limited to single-family homes. Multi-family and mobile homes (the other two building types) are assumed to be constrained to use the same fuel type when appliances are replaced.

In the Commercial model:

Commercial building owners' preference for a certain technology will be a function of the value of the increased capital costs versus the discounted fuel cost savings in the future. The time preferences regarding current versus future expenditures are assumed to be distributed among seven alternate time preference premiums. Adding the risk-adjusted time preference premiums to the 10-year Treasury Bill rate results in implicit discount rates, also known as hurdle rates, applicable to the assumed proportions of commercial floor space. The effect of the use of this distribution of discount rates is to prevent a single technology from dominating purchase decisions in the lifecycle cost comparisons.

The distribution used for the AEO2008 Reference Case assigns some floor space a very high discount or hurdle rate to simulate floor space which will never retrofit existing equipment and which will only purchase equipment with the lowest capital cost. Discount rates for the remaining six segments of the distribution get progressively lower, simulating increased sensitivity to the fuel costs of the equipment that is purchased. The lowest discount rate in the model is set at zero. This represents the estimate of the Federally owned commercial floor space that is subject to purchase decisions in a given year.[6]

In this scenario, the proportion of high-discount rate floor space (27 percent in the Reference Case) is decreased by 80 percent, and distributed proportionally to the other six segments. This is intended to simulate the effect of shifting attitudes in the commercial sector, encouraging the use of cash flow analysis in the purchase decision.

The purchase of new and replacement technology is governed by Behavior Rule Proportions. These rules, which can be based on the least cost (PLC), same fuel (PSF), or same technology (PST) objectives for commercial customers, determine how new, replacement, and retrofit decisions on equipment choice are made. New commercial floor space has the greatest flexibility in the choice of equipment, so this is where the data adjustments are focused.

In this scenario, the Behavioral Rule Proportions of new commercial floor space is altered so that, for the least-cost decision rule (PLC), the difference between the value used in the AEO2008 Reference Case and 100 percent (representing a total switch) is decreased by 80 percent. The same fuel (PSF) and same technology (PST) fractions are adjusted proportionally to ensure that the total is 100 percent.

A.3.3 PR3: Increased Natural Gas R&D

This final scenario, which includes scenarios PR1 and PR2, measures the estimated impact of increased R&D on the penetration of natural gas heat pumps and CHP systems. Increased R&D reduces the cost and increases the efficiency of the specified systems.

For natural gas heat pumps, the capital costs are decreased by 50 percent in stages over the course of the forecast, while heating and cooling COP’s are increased by 50 percent in a similar manner. In the residential sector, this is coupled with a 90 percent decrease in the incremental costs of fuel-switching, resulting in a significant market penetration for this equipment.

In addition, this scenario modifies the Reference Case assumptions affecting the penetration of CHP generating systems in the commercial and residential sectors. The cost (per kW) is lowered (linearly) across the forecast period to $1,000/kW in 2030; the heat rate is increased in a similar manner to 50 percent; and the percentage of waste heat available to offset water heating demand is increased to 90 percent. In addition, there is an assumed 30 percent tax credit applied to the purchase of this equipment, which serves to improve the discounted cash flow calculation, thus encouraging its use. Note: these changes had no material impact on residential purchases.

A.3.4 AE50: 50% Electric Equipment Subsidy

For the purpose of comparison, this study also included a scenario with the aggressive promotion of electricity at the expense of other fuels, particularly natural gas. The structure of this scenario was designed to mirror, to the extent possible, the conditions imposed in the PR1 and PR2 scenarios.

Accordingly, the capital cost of electric appliances and equipment in the residential and commercial sectors was subsidized at a 50 percent level. These subsidies were applied to equipment for which there is a viable natural gas alternative (i.e., refrigerators and freezers were excluded). This was coupled with adjustments to the data regarding fuel-switching capabilities: in the residential sector, the incremental

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[6] *Assumptions to the Annual Energy Outlook 2008*, Energy Information Administration, DOE/EIA-0554(2008)

cost of switching from non-electric fuels (including natural gas) to electricity was set to zero, and the maximum proportion of single-family homes capable of switching was increased to 100 percent (since it was assumed that all homes have access to electricity). In the commercial sector, the Behavioral Rule Proportions described in scenario PR2 were used, in order to relax the constraints on fuel choice for new and replacement equipment.

Commercial equipment types affected by these changes are electric heat, water heating, boilers, and ranges.

A.4 Cost of Retrofit for Gas Appliances and Insulation

There are several options available in the residential market to address CO_2 reduction through fuel switching and increasing the performance of the thermal envelope. Choosing gas over electric in new construction or adding insulation in new construction can be done at a small cost compared to the retrofit option where piping must be added and walls rebuilt. For a retrofit of gas appliances or insulation into an existing building there are many possible scenarios. In the case of gas appliances,

Is the gas piping in place in the home?
Is the vent system in place?
Is there an extension from the main?
Is the main in the street or does it require an extension?

Table A-1provides an estimate of the cost of performing some of these retrofits on a national average basis based on information obtained from gas company representatives.

Insulation retrofit costs also vary significantly. For some homes adding insulation to the attic is the best option, but there is a diminishing return for homes with insulated attics. Upgrading windows is the next option, and adding insulation to the walls is the next option. When retrofitting a home with insulation, some items to consider are:

Labor costs
Siding damage to be repaired
Build-out of doors and windows
Cost of re-siding or re-stucco
Moisture issues

Table A-1 Cost of Gas Retrofits

Scenario Number	Scenario Description	Equipment Installed Costs ($)	Interior Piping costs ($)	Vent system costs	Meter Set costs ($)	Gas service line installed costs ($)	Gas main Extension costs ($)	Total Costs of Gas Retrofit	National Average Estimate
1	Gas in house; they have pulled out the gas water heater and furnace and replaced with electric WH and EHP. Gas piping, vent systems in place We want to add back in gas water and space heating	$1,800	$1,000	$1,200	$225	$0	$0	$4,225	$ 3,200
2	Gas stub to house by builder; no gas appliances; need to put in meter set, interior piping, vent systems, appliances	$2,300	$2,500	$1,200	$225	$2,000	$0	$8,225	$ 6,200
3	Main in street, no gas to house. Need service line, meter set, interior piping, vent system, appliances	$2,300	$2,500	$1,200	$225	$3,600	$0	$9,825	$ 7,400
4	All electric neighborhood. Need all of above for scenario # 3 plus main extensions	$2,300	$5,500	$1,200	$225	$3,600	$7,000	$19,825	$ 14,900

Estimates provided by two California contractors indicate a factor of 3-5 times the cost of adding the insulation in new construction or a cost of up to $100,000, making insulation retrofits very difficult to justify for mass market applications. Targeted opportunities based on individual building characteristics may include roof radiant barriers, ceiling cavity insulation, and foam or cellulose injection in un-insulated wall cavities. These strategies may reduce energy consumption by up to 20 percent for poorly insulated homes. However, for under-insulated homes and businesses, the incremental benefits of adding insulation quickly diminish compared to the cost, and it is very challenging to identify acceptable insulating strategies that make economic sense.

A.5 Summary of Prior Study Results

As noted, this project directly supports the GTI white paper[7] and the recent American Gas Foundation (AGF) direct gas use study by providing additional evidence and credibility of the benefits of direct gas use. The white paper promotes direct gas, substitution of less-efficient gas appliances, methane leakage reduction, expansion of the NGV market, and biogas for pipeline gas. Projected CO_2 savings by 2030 are on the order of 369-554 million metric tons per year. The near-term direct gas use and less-efficient appliance substitution strategy alone results in a CO_2 savings of 233-350 million metric tons of CO_2 per year, and energy savings of about 3.9 quadrillion Btus per year.

The AGF direct gas use study[8] shows by 2030 emissions reductions for the reference direct gas use case of over 200 million metric tons of CO_2 per year, avoided new power plants of 63-80 GWe, and energy savings of 1.25-2.0 quads.

The 2009 McKinsey worldwide study[9] shows negative net costs for most residential and commercial space and water heating retrofits. For instance, residential water heating replacement is shown at -40 to -60 Euros per tonne of CO_2, (-$52 to -$78 per tonne).

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[7] Gas Technology Institute, “A Lower-Cost Option for Substantial Carbon Dioxide Emission Reductions in the U.S.”, April 2009, available from GTI at www.gastechnology.org.

[8] American Gas Foundation, “Direct Use of Natural Gas: Implications for Power Generation, Energy Efficiency, and Carbon Emissions, April 2008, Black & Veatch, available from A.G.A. at www.aga.org.

The 2007 McKinsey U.S. study[10] showed residential water heater net costs of -$20/tonne of CO_2. Combined Heat and Power potential of about 120 MM tonnes CO_2 per year was indicated for the residential and commercial markets.

A.6 Model Results

A.6.1 Shipments

Figure A-2 and Figure A-3show shipments of natural gas space heating appliances grow by one million units from the Reference Case for PR3 due to economic incentives, reduced bias, and increase in efficiency due to R&D. In the AE50 case, aggressive electric marketing due to economic incentives, disincentives and reduced bias toward electric equipment cause a reduction in gas space heating shipments by over 50%. Electric radiant space heating shipments show a complementary pattern.

Figure A-4 and Figure A-5 show that natural gas heat pump shipments are enabled by increased R&D investment in Scenario PR2 and PR3 and zero in all other cases. Electric heat pump shipments increase in PR1 due to economic disincentives toward electric resistance heating and are reduced for PR2 and PR3. Electric heat pump shipments increase in AE50 due to the shift in subsidy and bias towards electric equipment in that scenario.

Figure A-6 and Figure A-7 show that natural gas water heater shipments increase from 1 to 3 million units per year, growing more in the latter years of the simulation, for PR2 where there is a change in bias and an economic disincentive toward electric water heating. Natural gas water heater shipments decline a similar amount in AE50 due to the opposite bias and incentive. Electric water heaters follow a complementary pattern.

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9 McKinsey & Company, “Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve”,

10 McKinsey & Company, “Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?”,Executive Report, December 2007

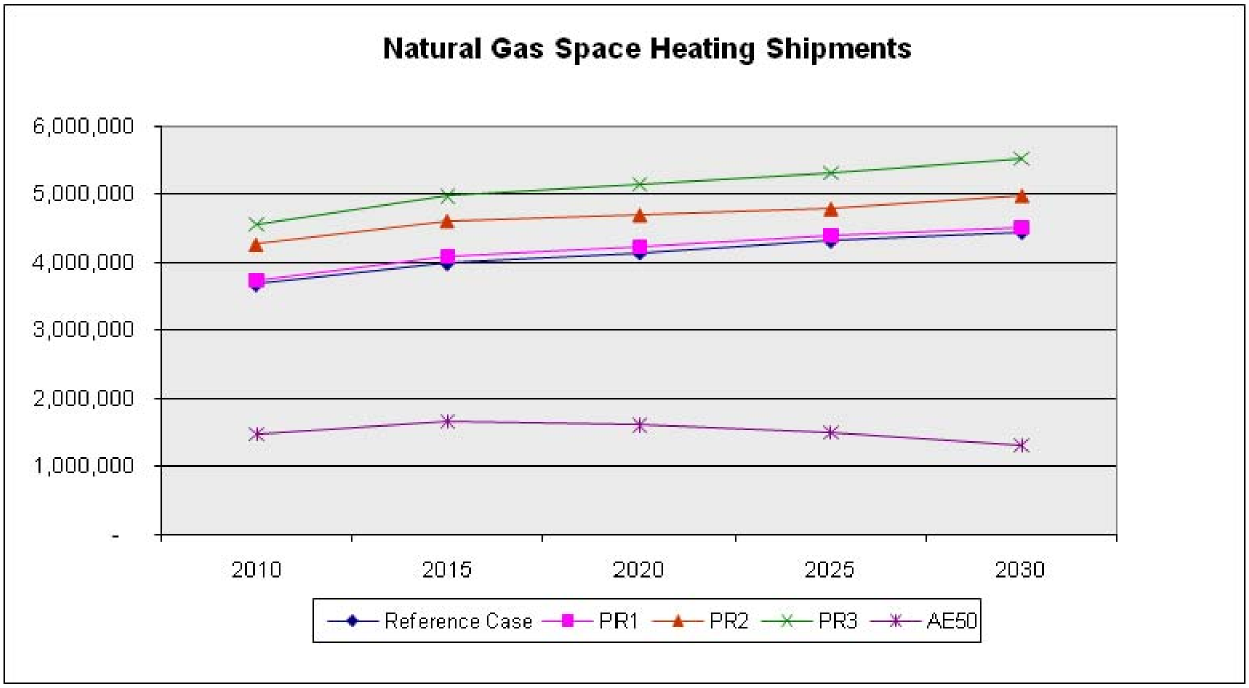

Figure A-2 Natural Gas Space Heating Shipments

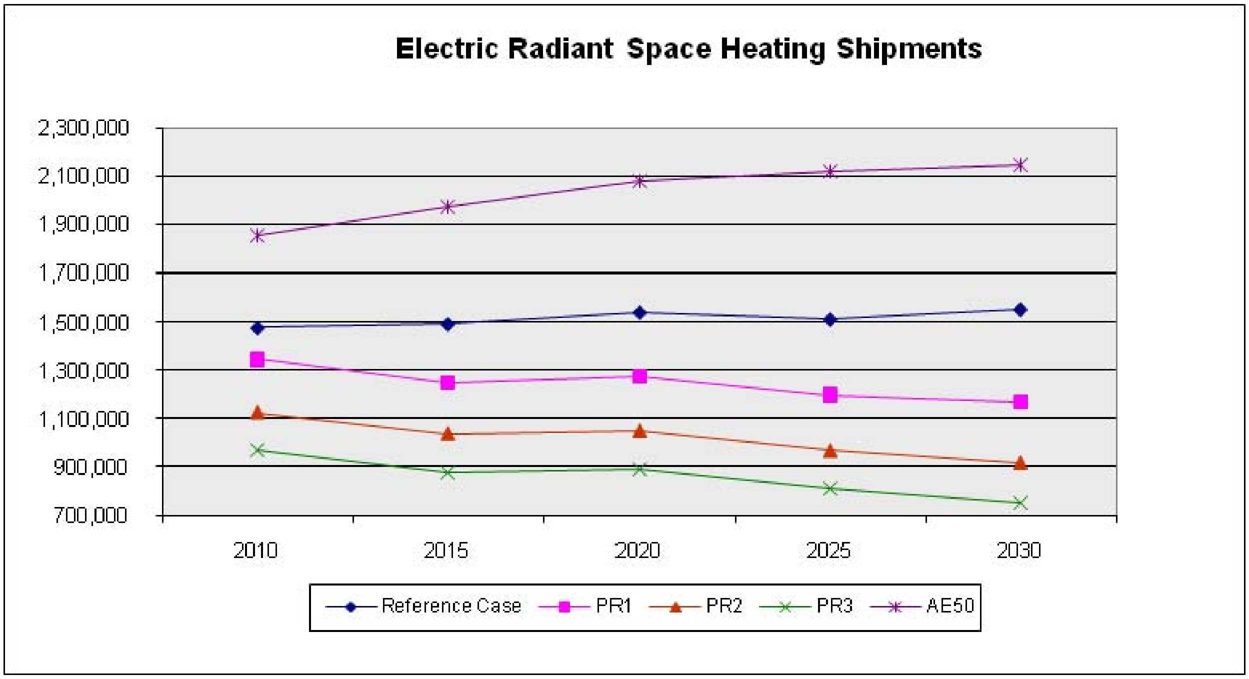

Figure A-3 Electric Radiant Space Heating Shipments

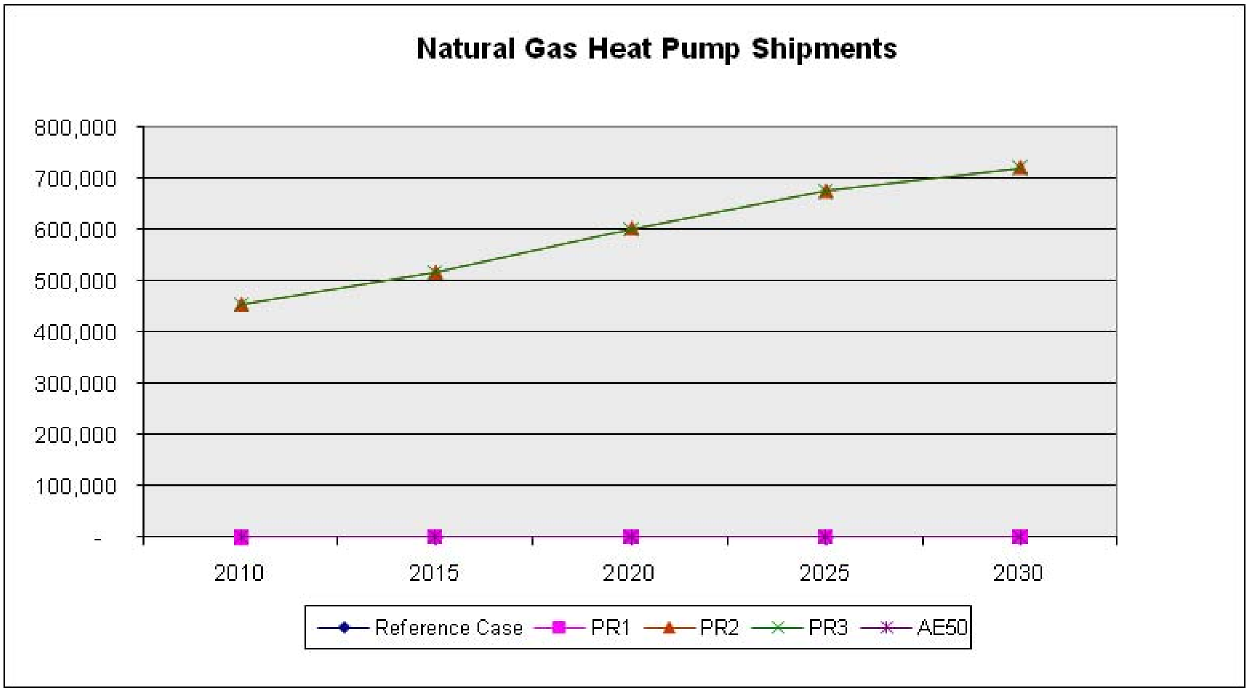

Figure A-4 Natural Gas Heat Pump Shipments

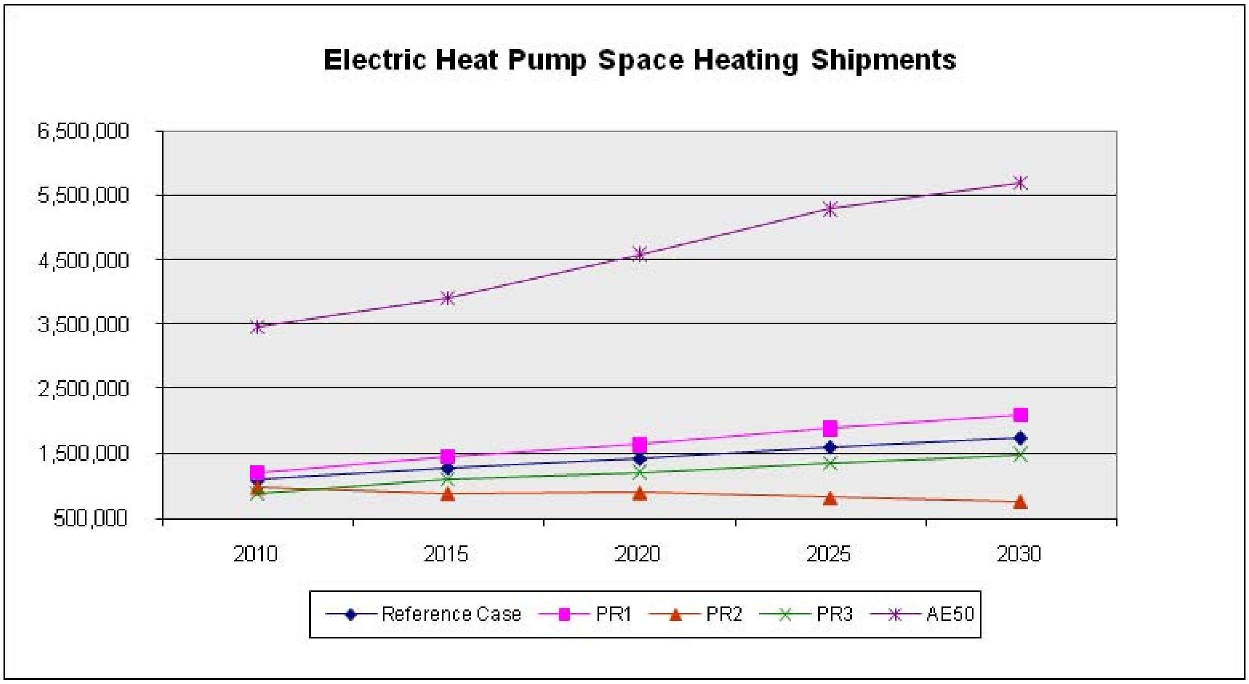

Figure A-5 Electric Heat Pump Space Heating Shipments

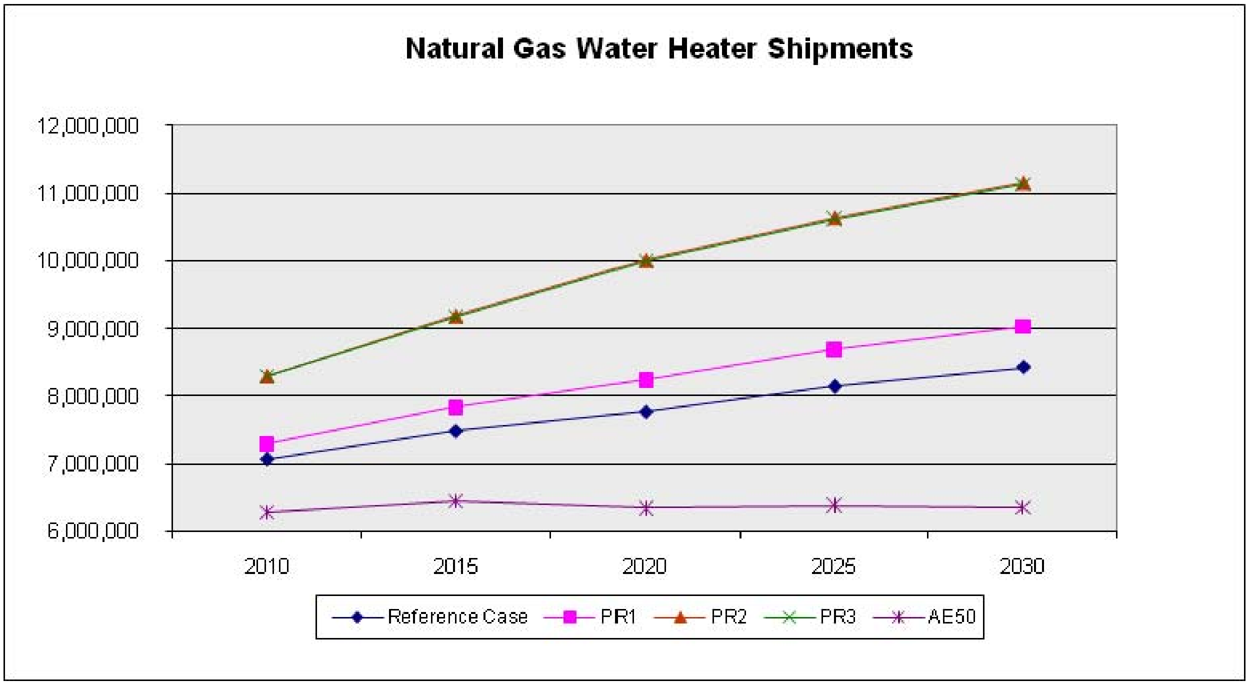

Figure A-6 Natural Gas Water Heater Shipments

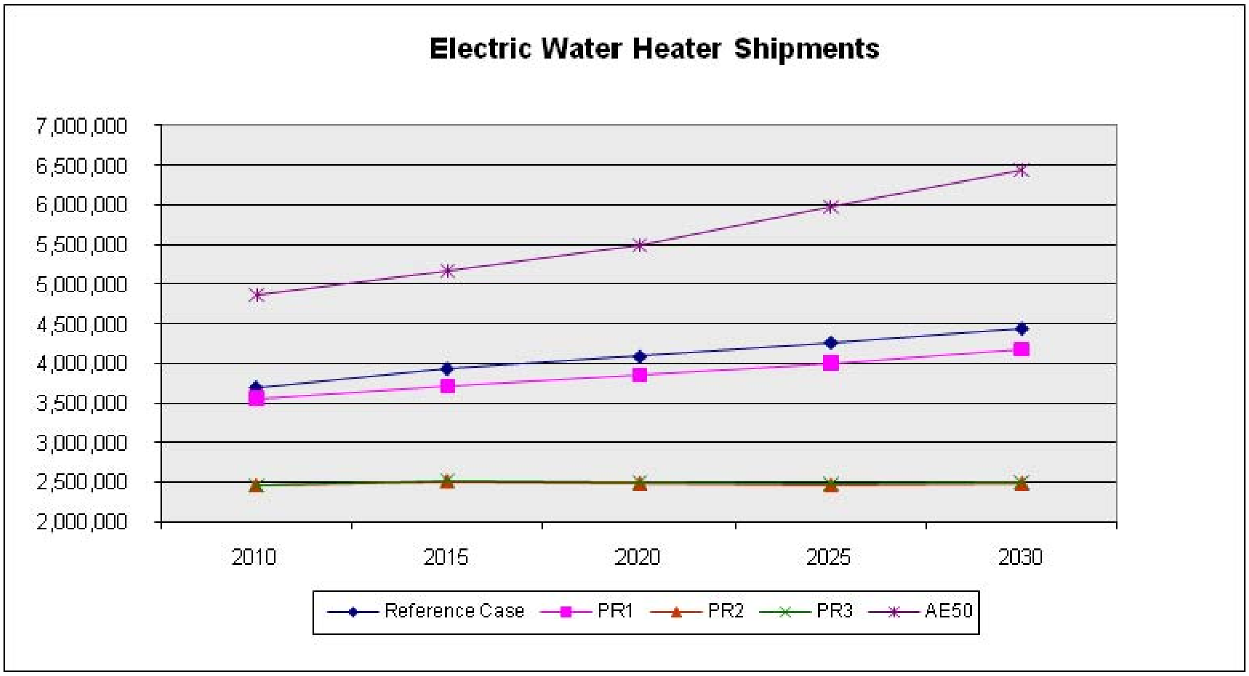

Figure A-7 Electric Water Heater Shipments

A.6.2 Installed Stock

Figure A-8 shows the cumulative impact of appliance shipments on installed stock follows from changes in space heating equipment shipments. Natural gas furnace stock grows by 0-12 million units above the Reference Case by 2030 for all scenarios except AE50. In the case of AE50, furnace stock would decline to approximately half of the current installed base in that time frame.

Figure A-9 and Figure A-10 show the impact of the scenarios on electric space heating equipment stock. Electric resistance space heating stock grows or declines by 10 million units, or about 40%, depending on the scenario. Electric heat pump stock grows under all scenarios, the larger growth under AE50 where significant incentives are applied.

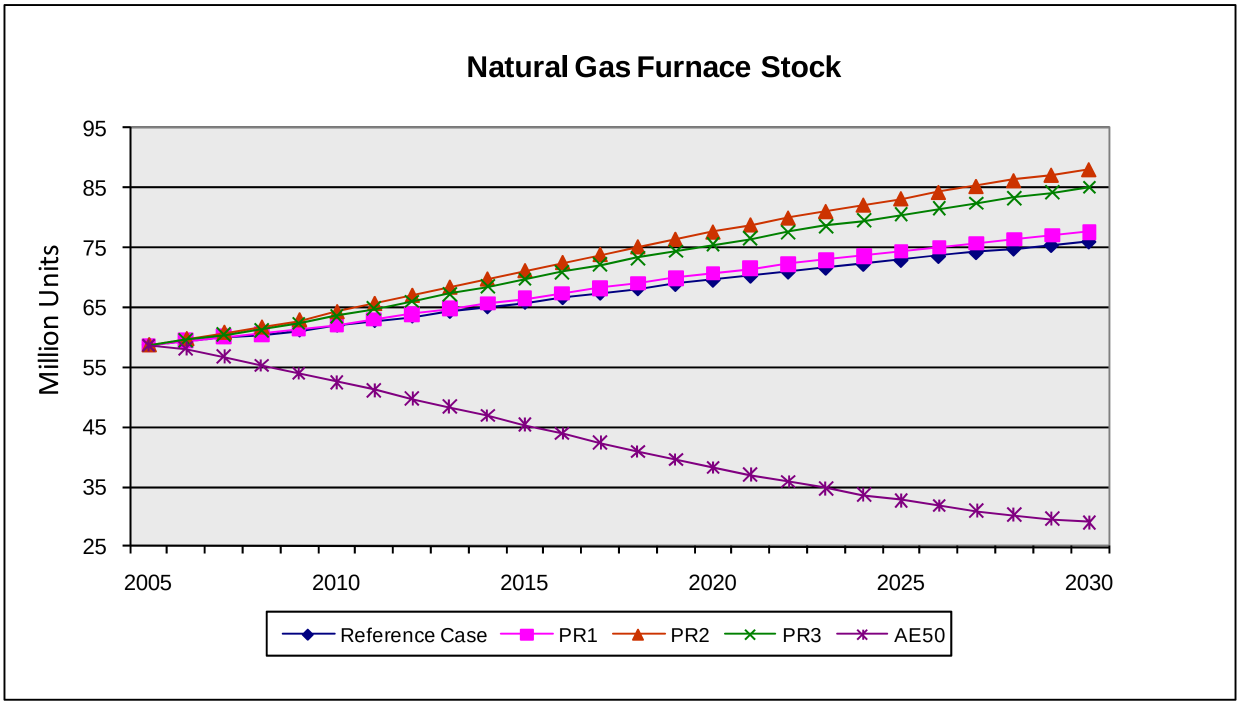

Figure A-8 Natural Gas Furnaces Stock

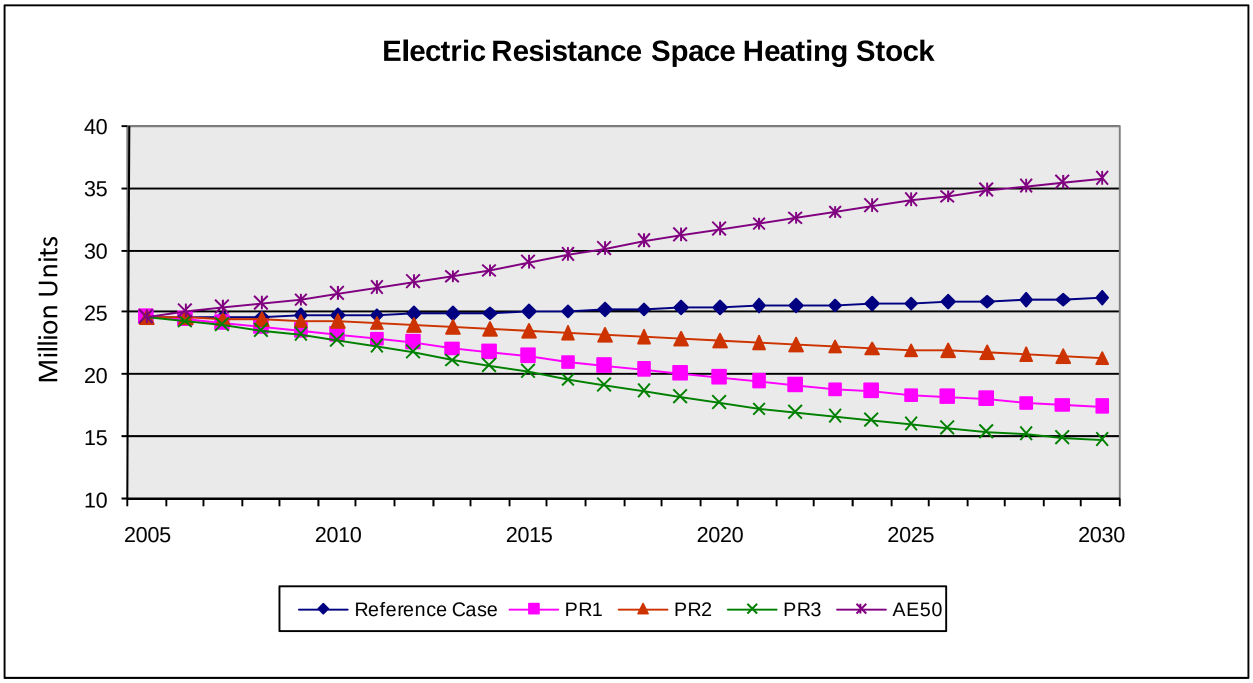

Figure A-9 Electric Resistance Space Heating Stock

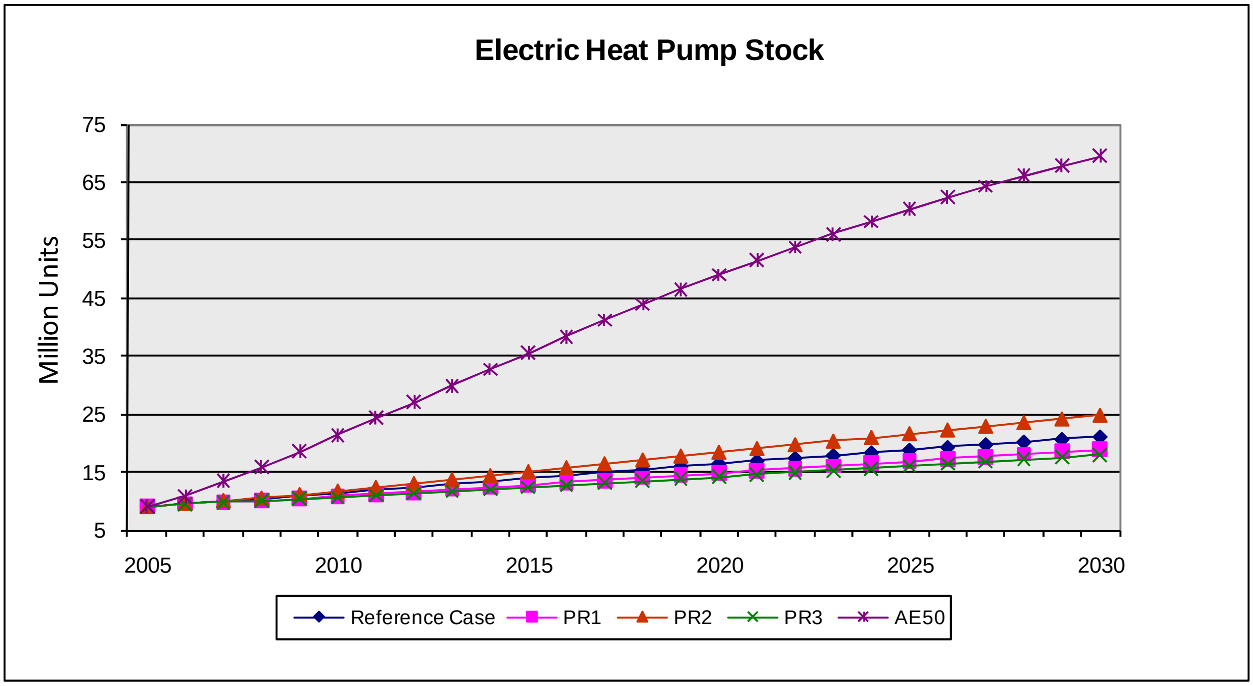

Figure A-10 Electric Heat Pump Stock

A.6.3 Market Share

Figure A-11 through Figure A-14 show the market share for major space heating technologies under all scenarios. The model shows that fuel choice for space heating favors natural gas for all gas scenarios PR1-PR3. The largest incremental impact is found with the PR2 scenario due to economic incentives and reduction in bias, that is a 10% increase in gas space heating share equates to a 9% drop in electric resistance space heating and a 3% increase in electric heat pump space heating.

Figure A-15 and Figure A-16 show significant differences in water heater market share by fuel type depending on the scenario. PR2 has the largest incremental impact due to the significant surcharge for electric resistance water heating to approximate the impact of a legislative ban on this equipment. AE50 shows the opposite effect- a market share increase of 15% favoring electric resistance water heaters.

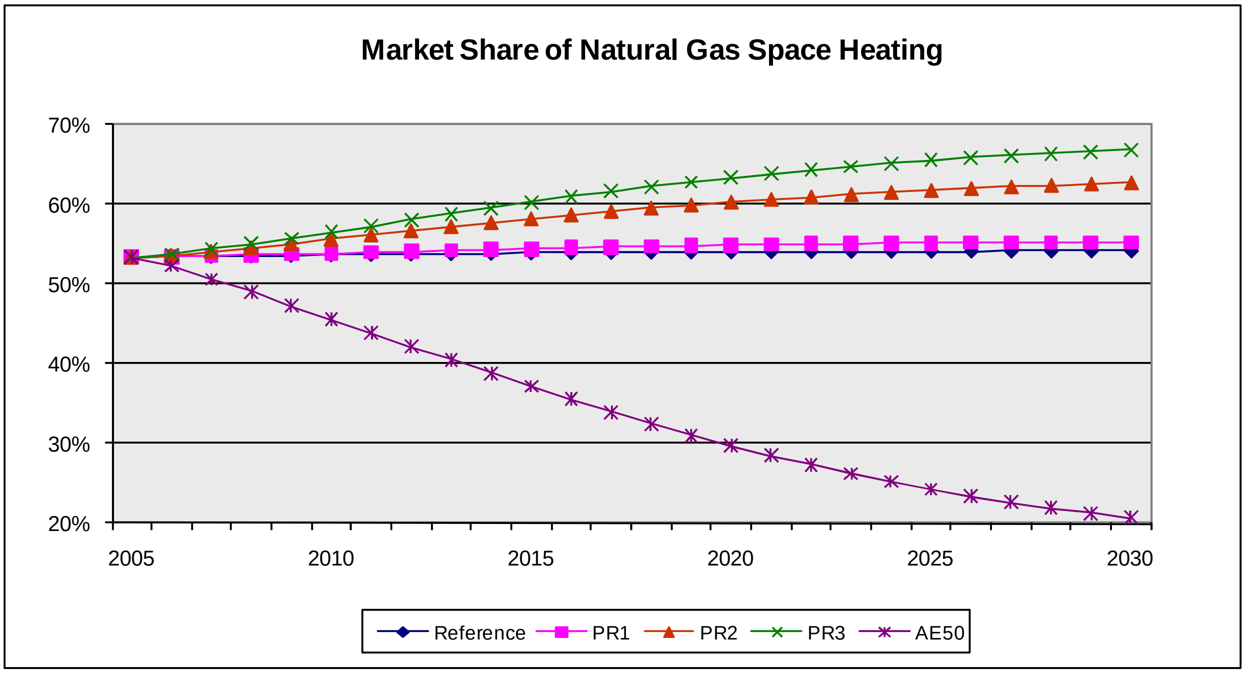

Figure A-11 Market Share of Natural Gas Space Heating

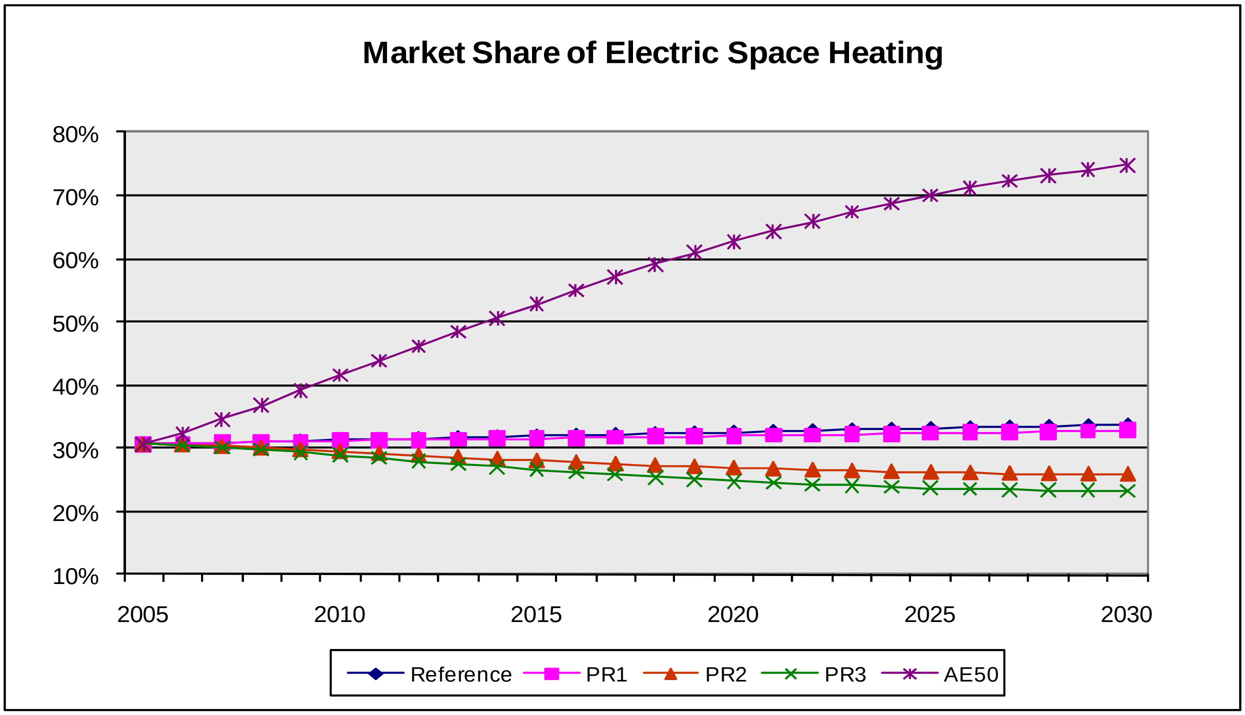

Figure A-12 Market Share of Electric Space Heating

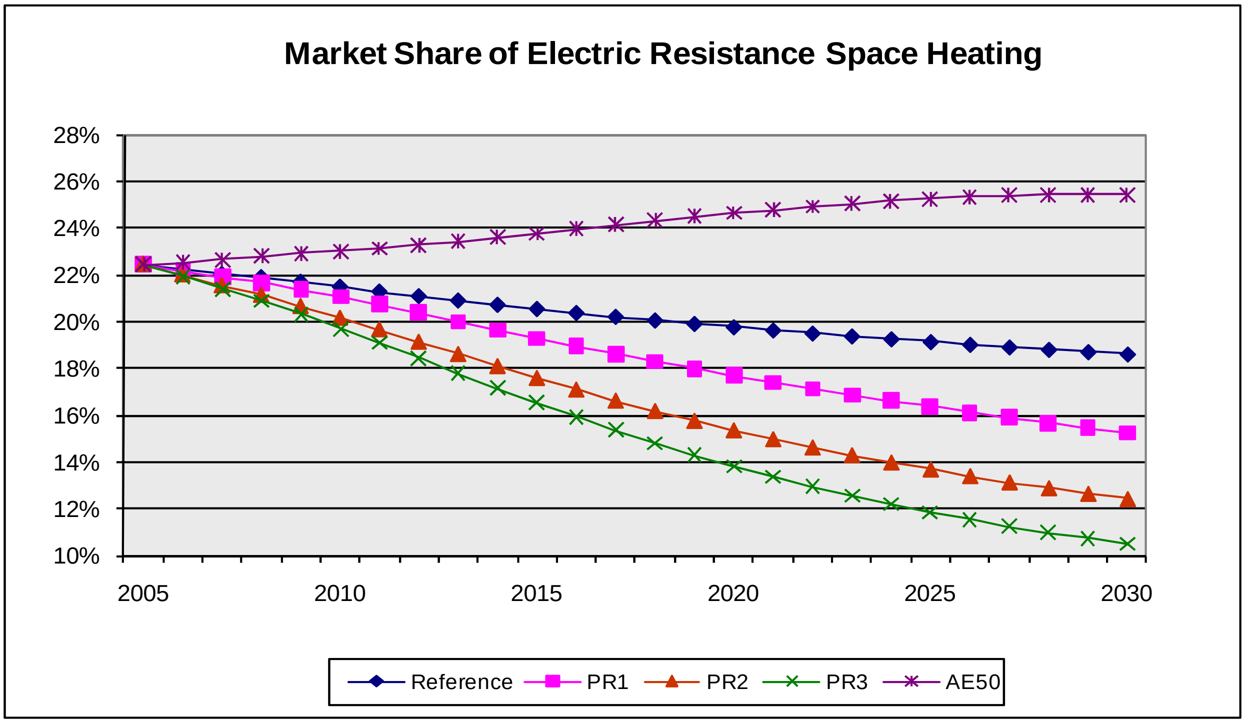

Figure A-13 Market Share of Electric Resistance Space Heating

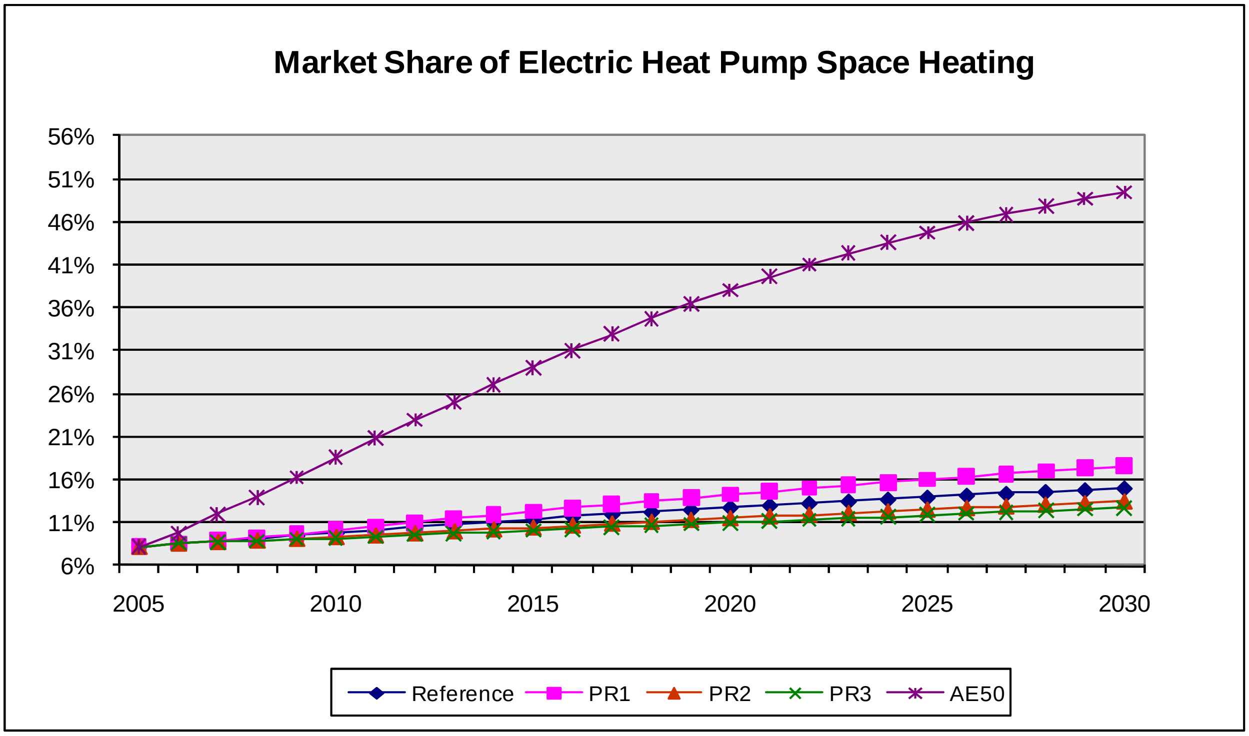

Figure A-14 Market Share of Electric Heat Pump Space Heating

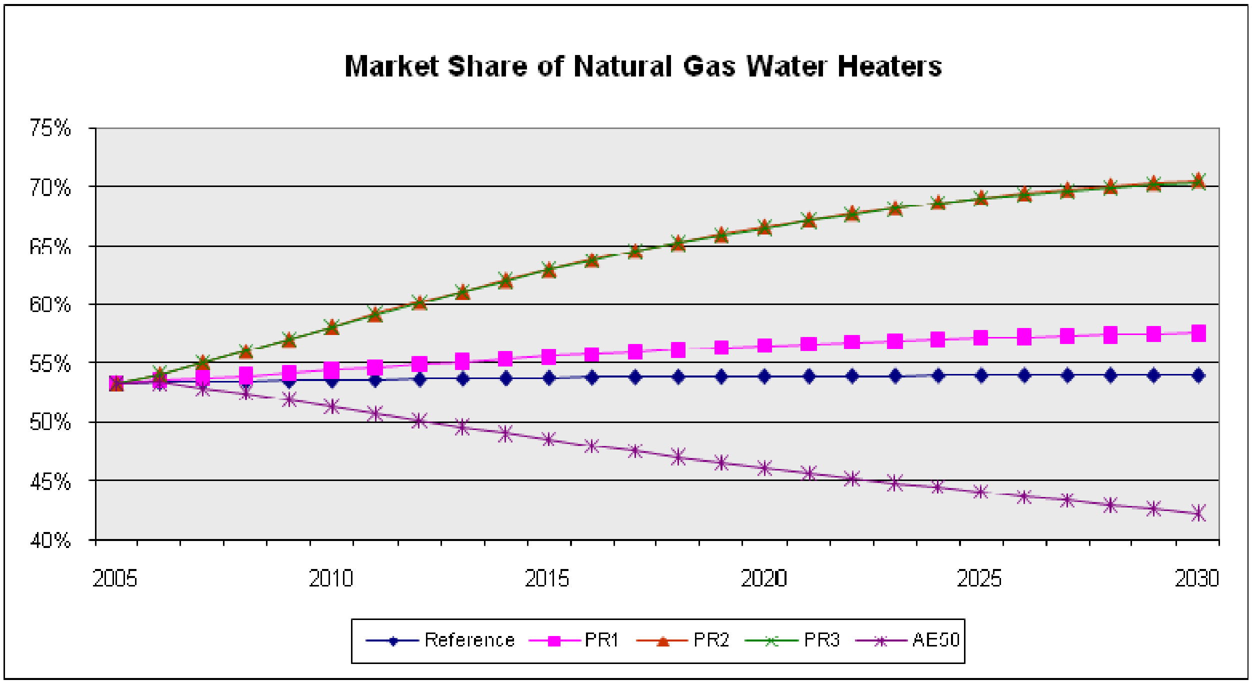

Figure A-15 Market Share of Natural Gas Water Heaters

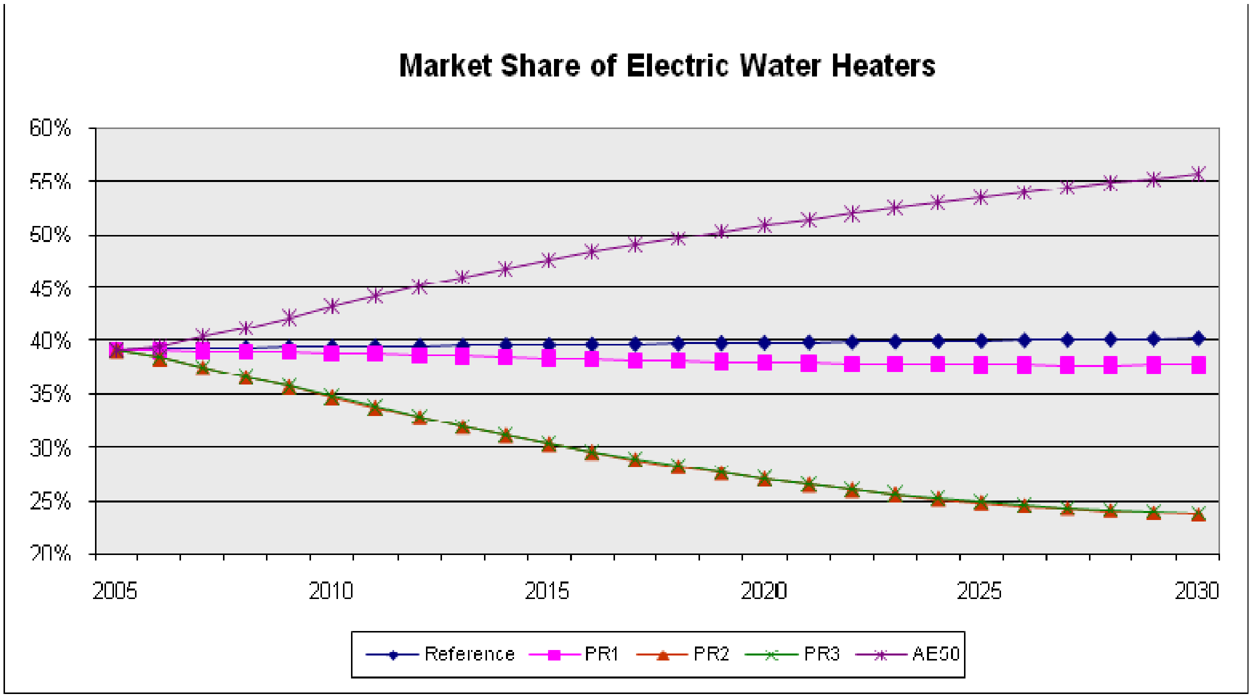

Figure A-16 Market Share of Electric Water Heaters

A.6.4 Energy Demand

Figure A-17 shows that the total demand for electricity declines at a rate of three times that of natural gas for the most aggressive scenario, PR3 due to the replacement of electric resistance heating and water heating with advanced gas technologies in these cases. In the PR1 case, residential natural gas demand is reduced due to the increase in the installed stock of higher-efficiency space and water heating equipment. Only in the AE50 case does electric demand increase and only then does the natural gas demand fall more than the change in the electric demand.

Figure A-18 and Figure A-19shows that in the residential markets, gas demand grows significantly in all cases where the bias is shifted toward gas or R&D further improves efficiency.

Figure A-20 and Figure A-21 show that in commercial markets, natural gas demand growth is positive at a lower installed base and electric demand falls under every scenario to reflect the bias toward life-cycle cost.

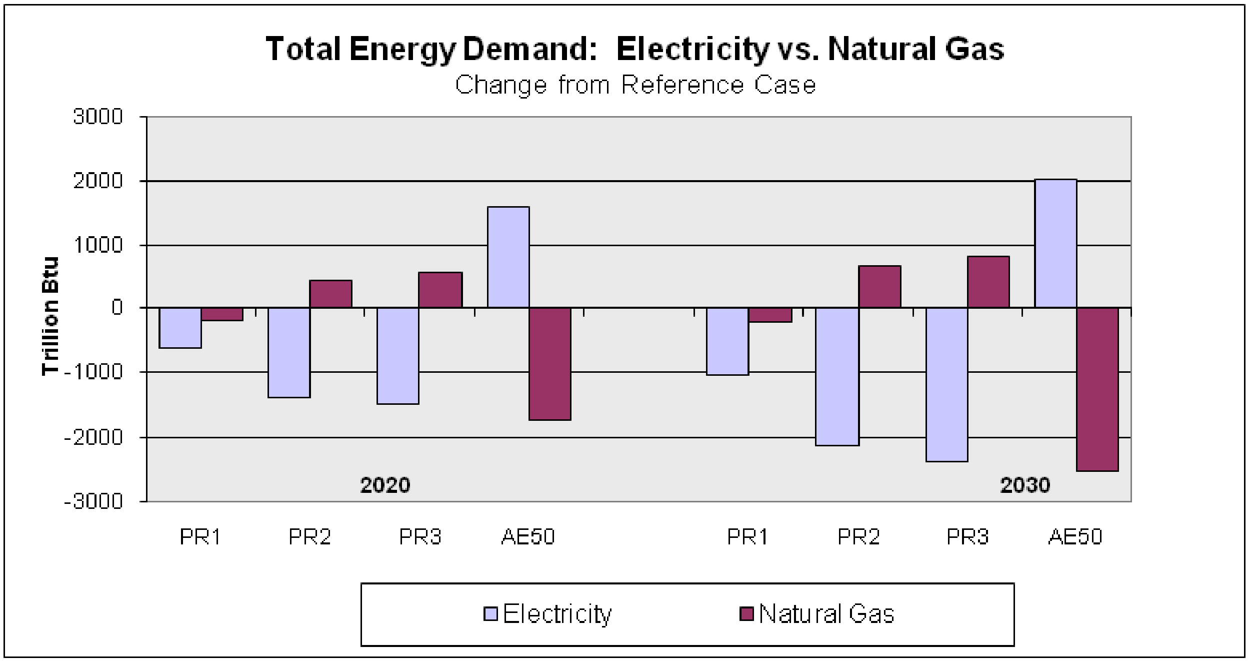

Figure A-17 Total Energy Demand: Electricity vs. Natural Gas

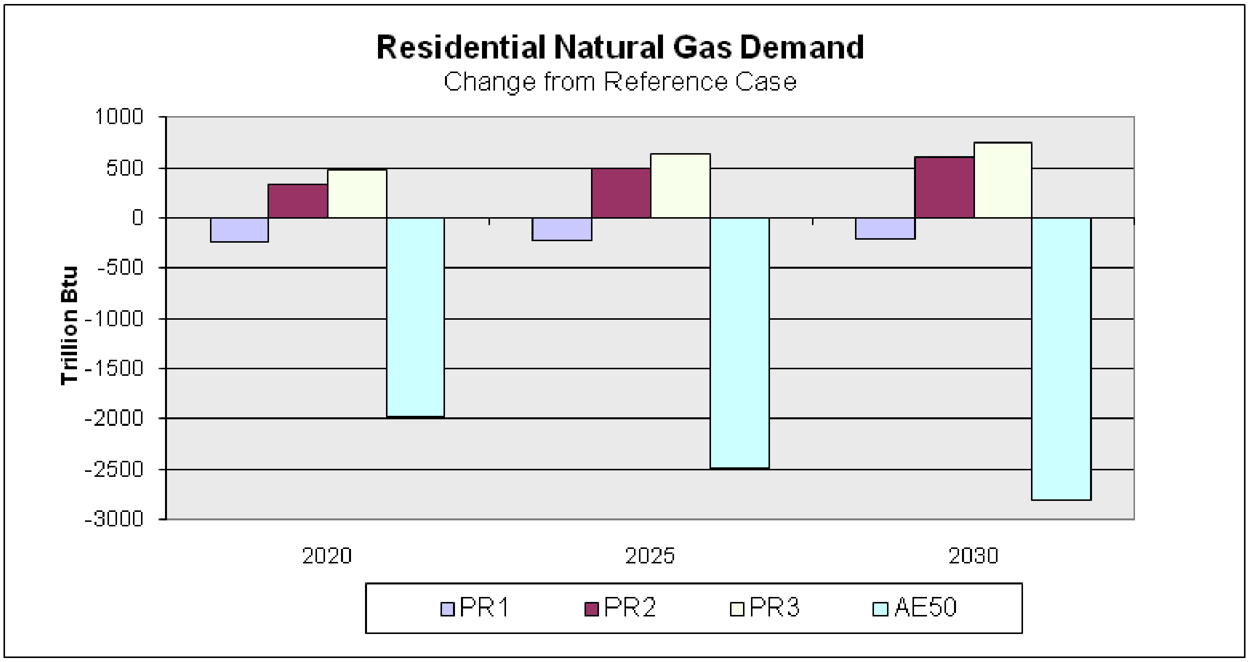

Figure A-18 Residential Natural Gas Demand

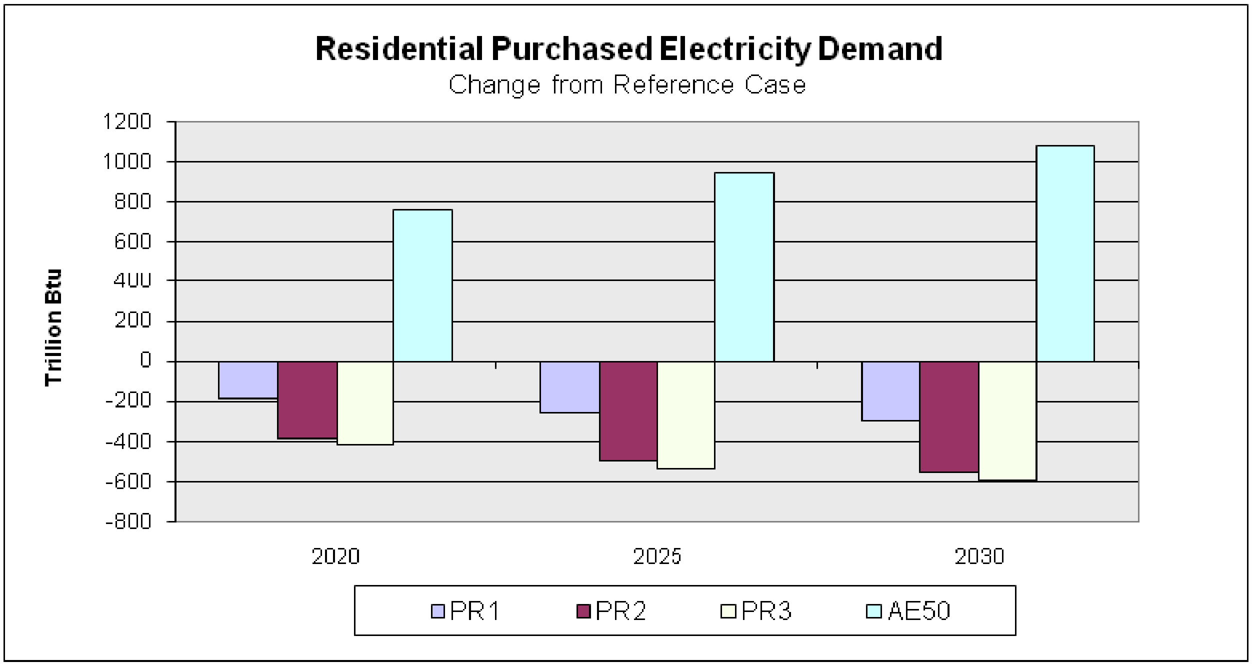

Figure A-19 Residential Purchased Electricity Demand

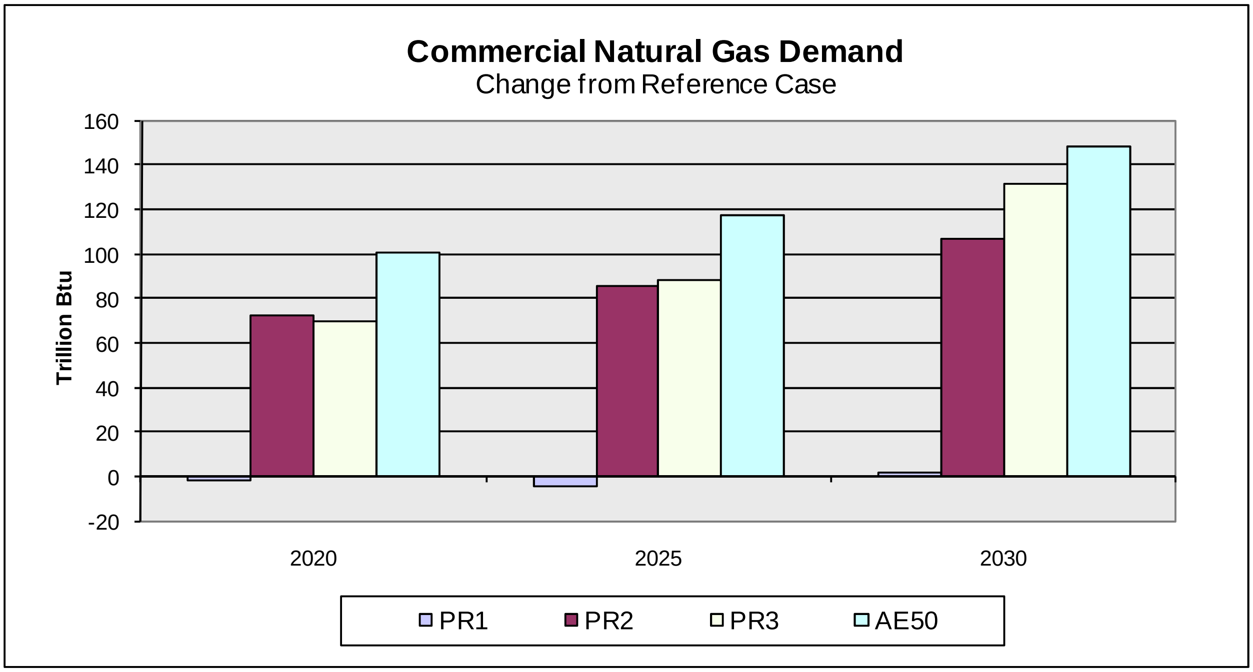

Figure A-20 Commercial Natural Gas Demand

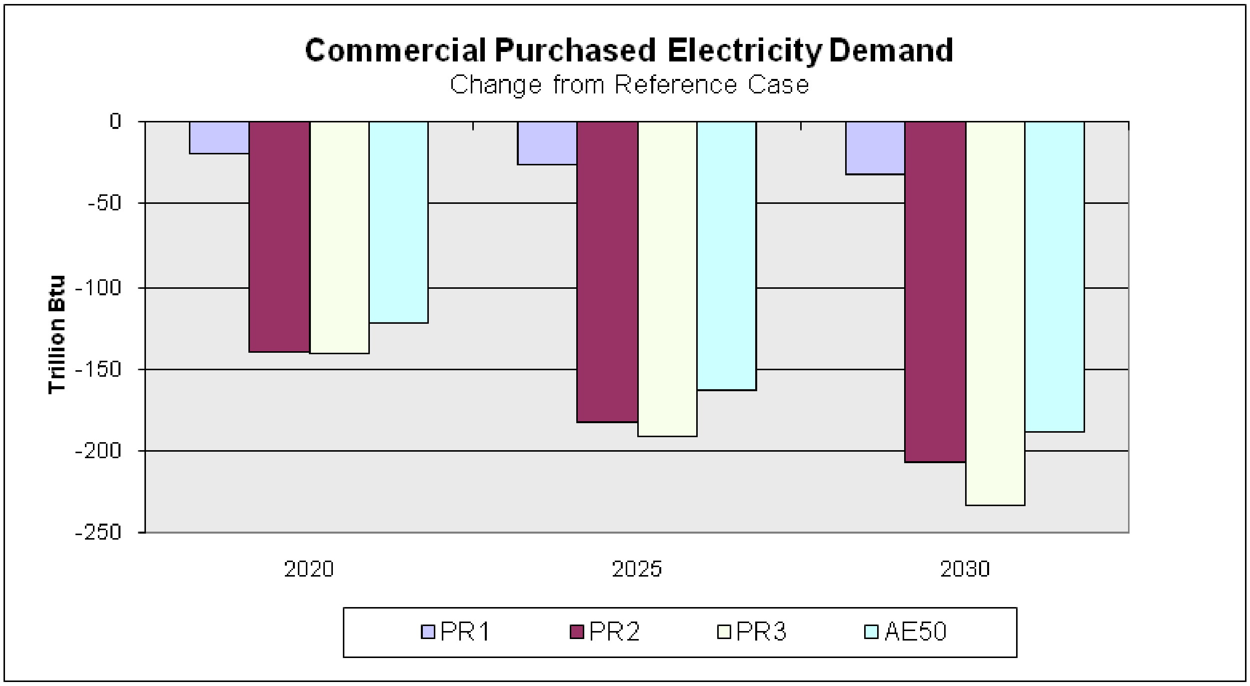

Figure A-21 Commercial Purchased Electricity Demand

A.6.5 Total Energy Expenditure

Figure A-22 and Figure A-23 show that in every scenario, total energy expenditures fall due to the financial incentives for higher efficiency equipment in Scenarios PR1 and AE50.

In the residential market, total energy expenditures in PR2 and PR3 cases decline less than PR1 as the improvements in thermal envelope performance and increases in appliance efficiency due to R&D offset energy expenditures by electricity in favor of lower-cost gas technologies.

In the commercial markets, PR2 includes a switch from first-cost to life-cycle cost analysis, favoring gas technologies. The AE50 change is largely driven by incentives in the opposite direction.

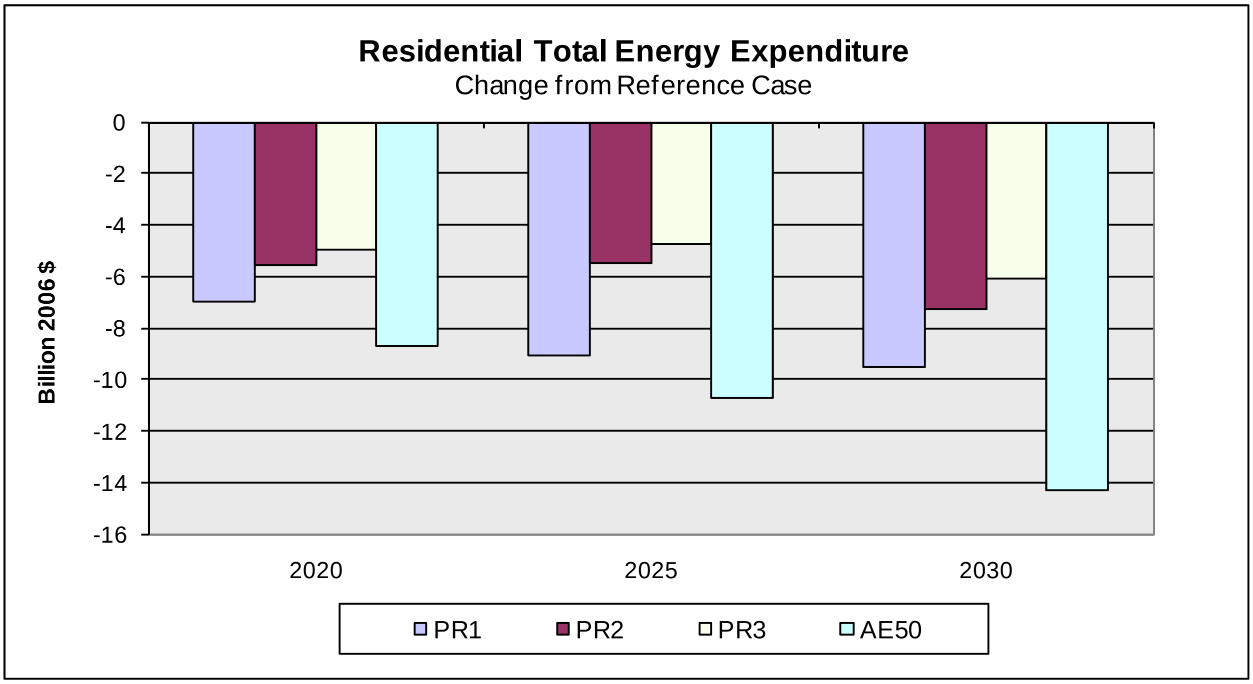

Figure A-22 Residential Total Energy Expenditure

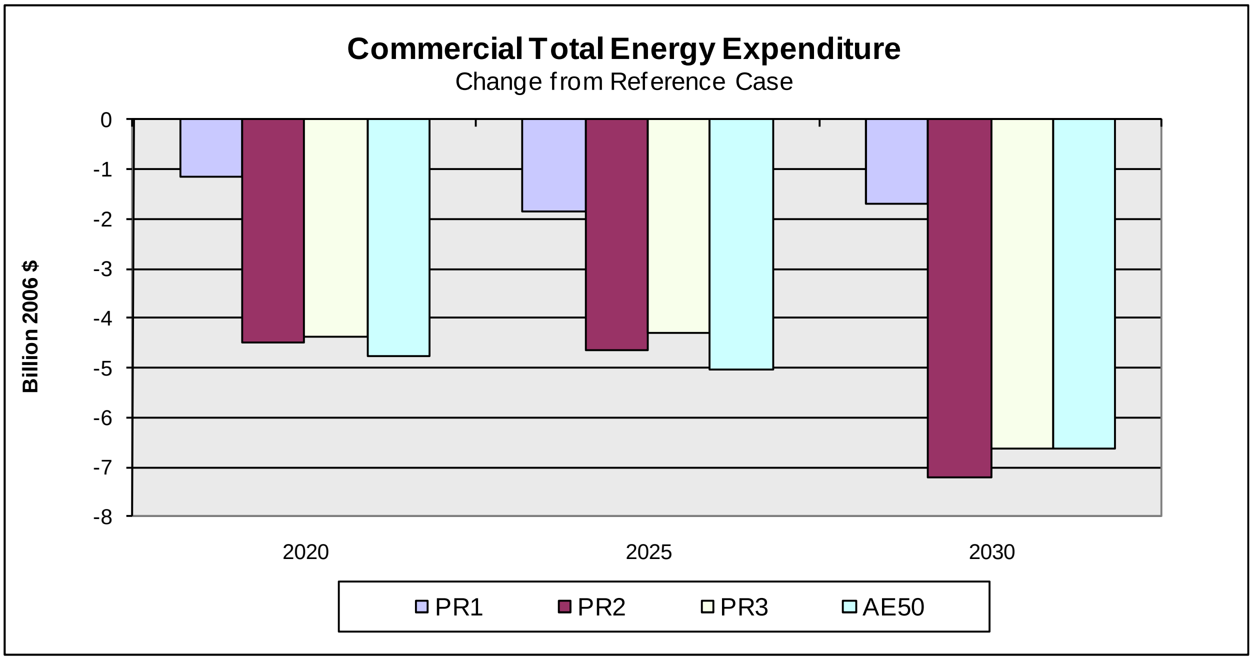

Figure A-23 Commercial Total Energy Expenditure

A.6.6 Generation Impacts

Figure A-24 through Figure A-26 show that early-stage generation reduction primarily impacts coal plants with later-stage reduction impacting nuclear power for all scenarios. For PR3, the net reduction in generation in 2030 is 200K GWh.

Figure A-27 shows that in the electric scenario, generation increases in all time horizons, reaching a maximum of 280 K GWh in 2030. The primary source is coal-fired power plants, then natural gas generation.

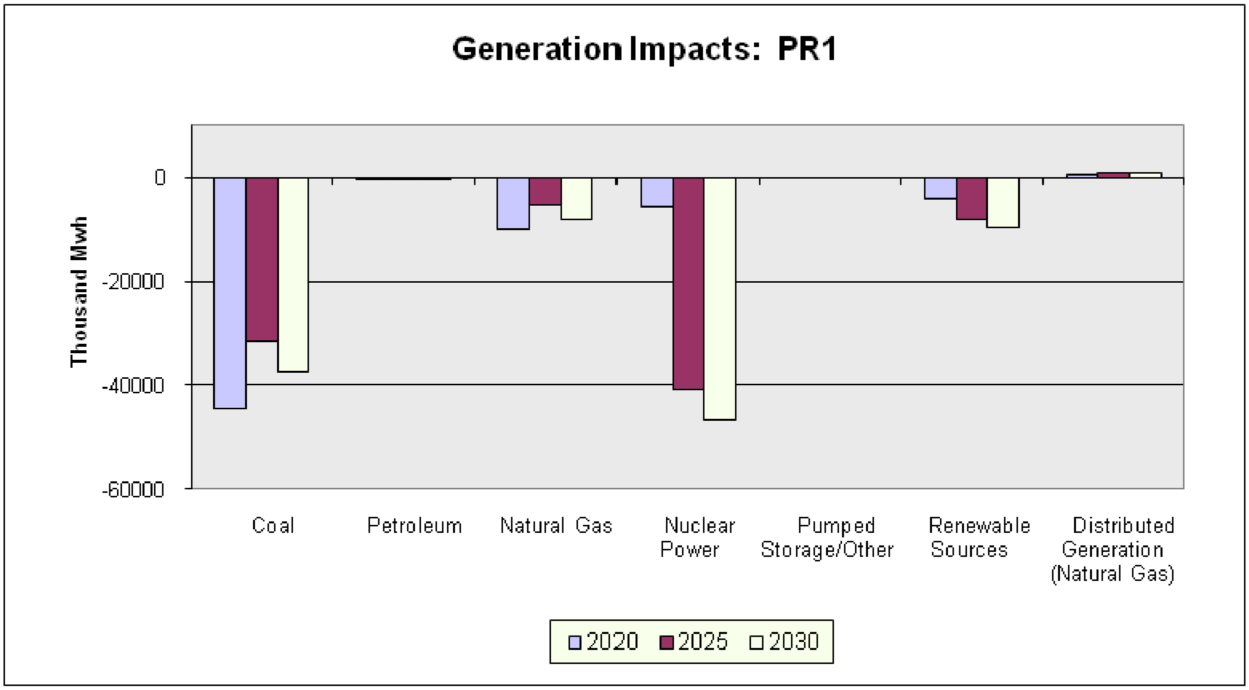

Figure A-24 Generation Impacts: PR1

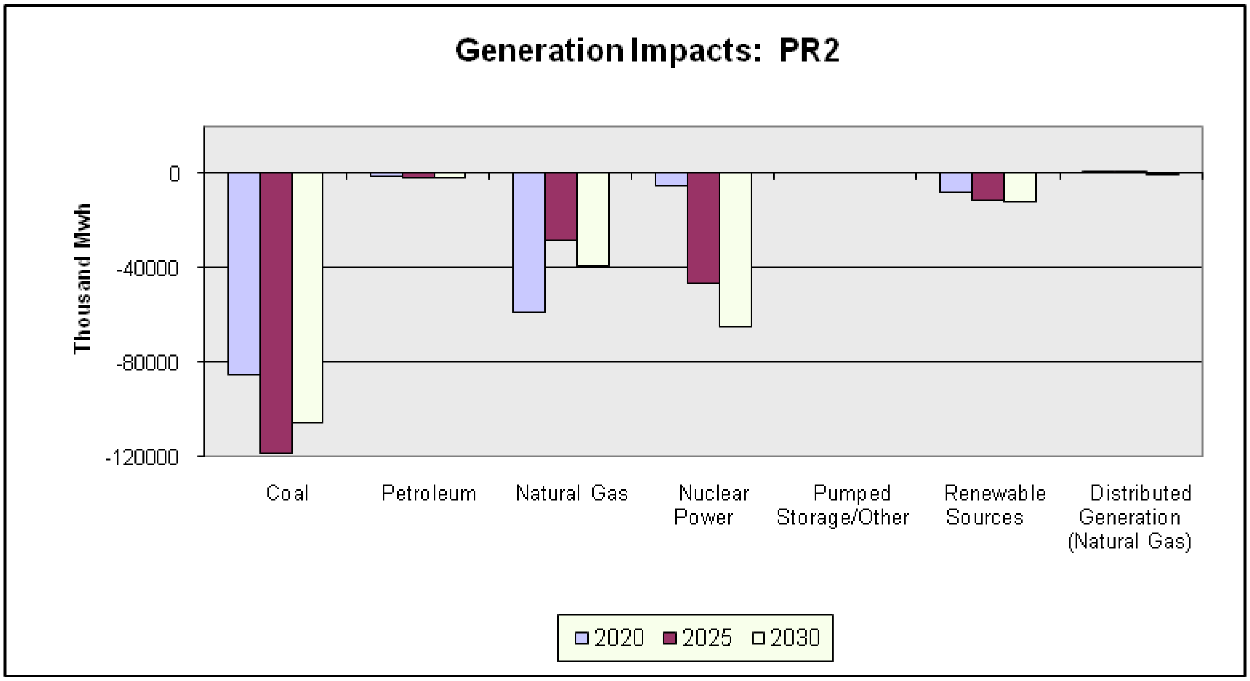

Figure A-25 Generation Impacts: PR2

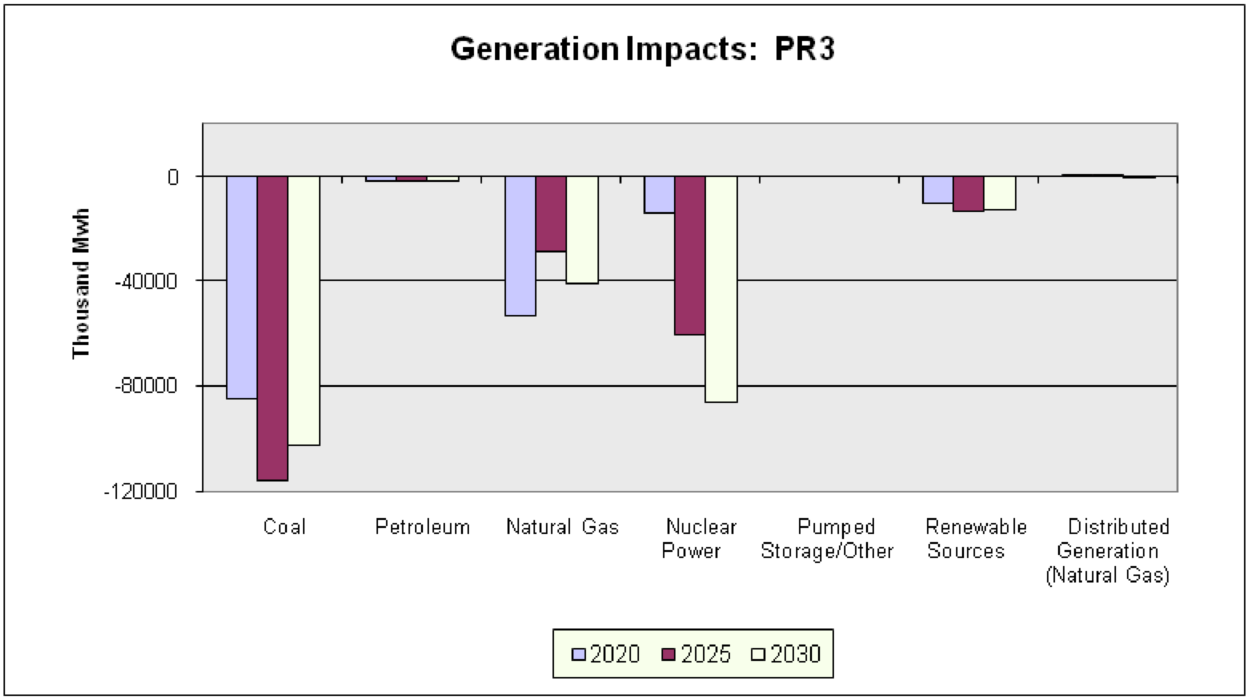

Figure A-26 Generation Impacts: PR3

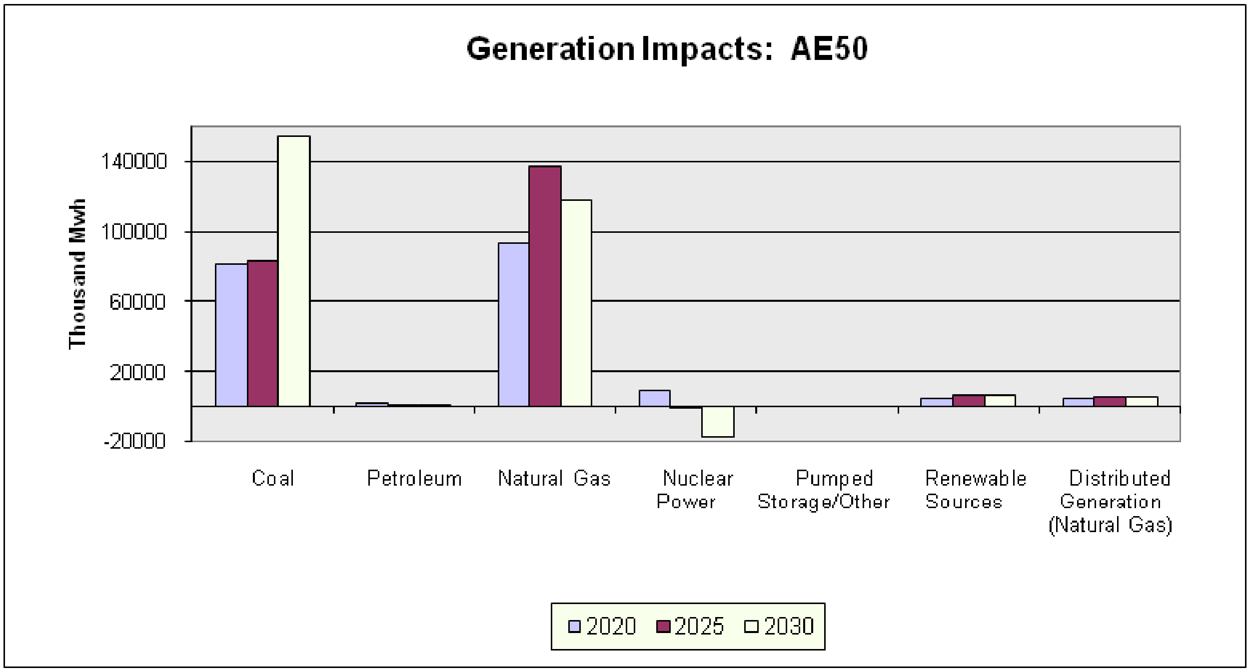

Figure A-27 Generation Impacts: AE50

A.6.7 Power Generation

Figure A-28 and Figure A-29 show that the natural gas options reduce generation and capacity needs from the baseline. The largest reduction comes from PR3 – incentives plus changes in bias and thermal envelope improvements plus R&D investments.

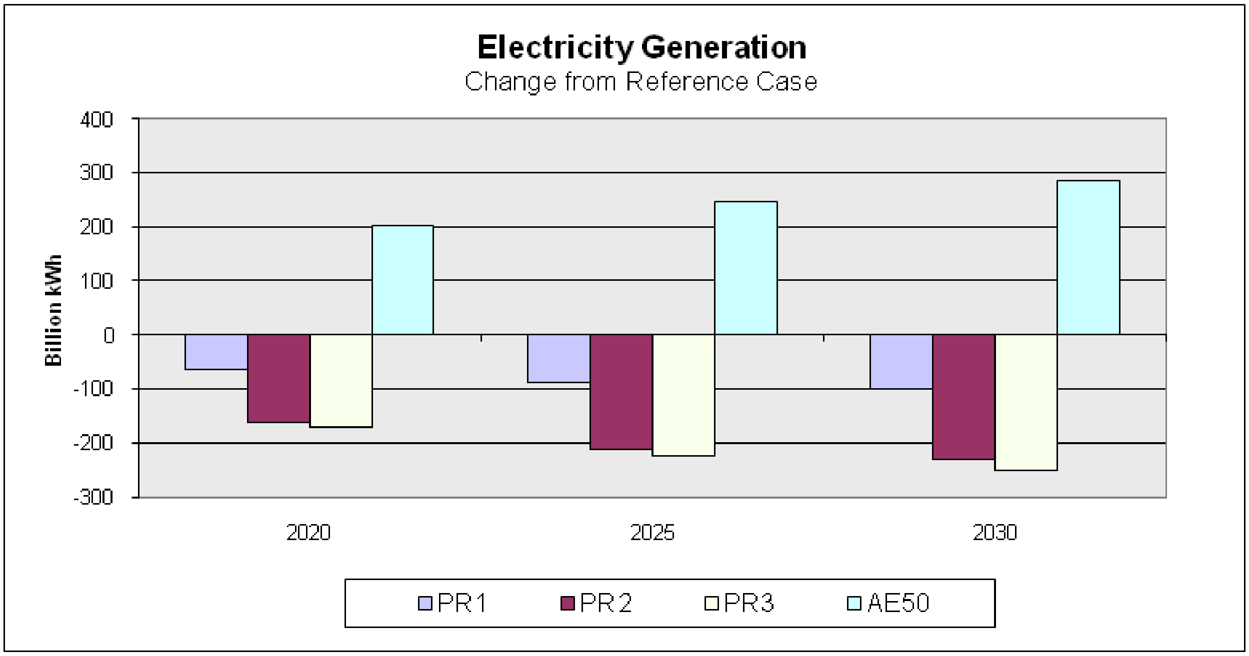

Figure A-28 Electricity Generation

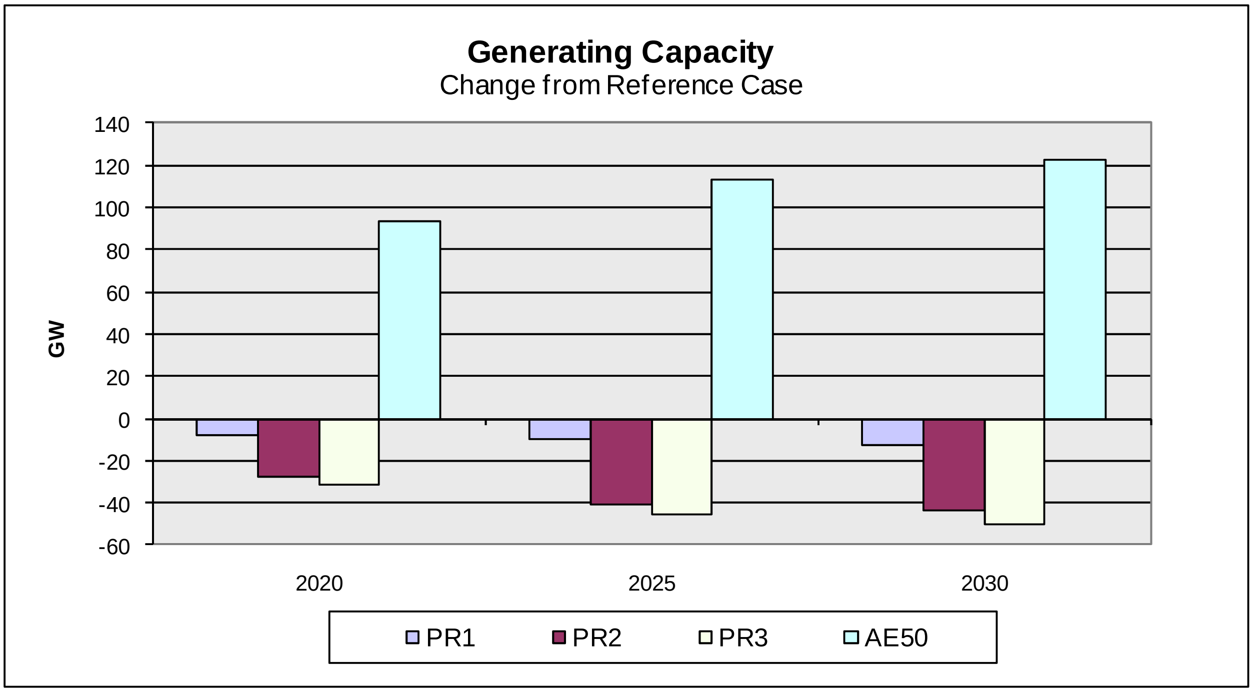

Figure A-29 Generating Capacity

A.6.8 Total Energy Production

Figure A-30 shows that total energy production follows the decline in consumption over time. Figure A-31 through Figure A-33 show that increases in production for scenario PR2 favor natural gas and biomass in the 2010-2020 timeframe. In the AE50 electric scenario, the fuel source for production favors coal at the expense of natural gas.

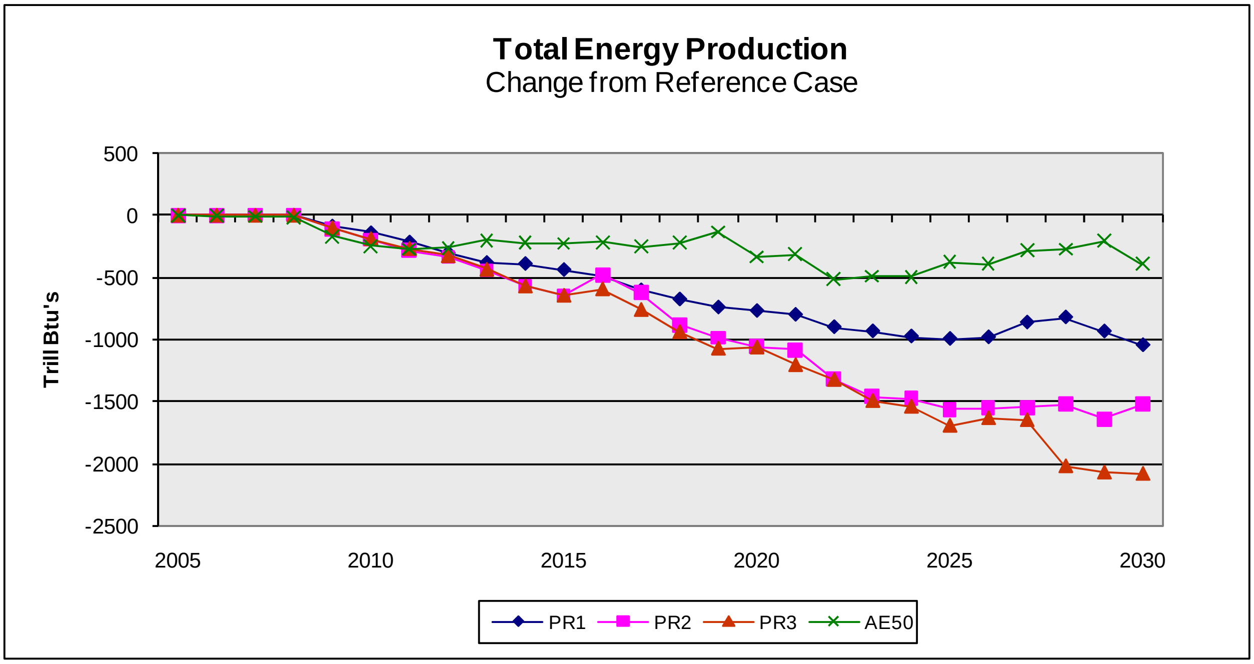

Figure A-30 Total Energy Production

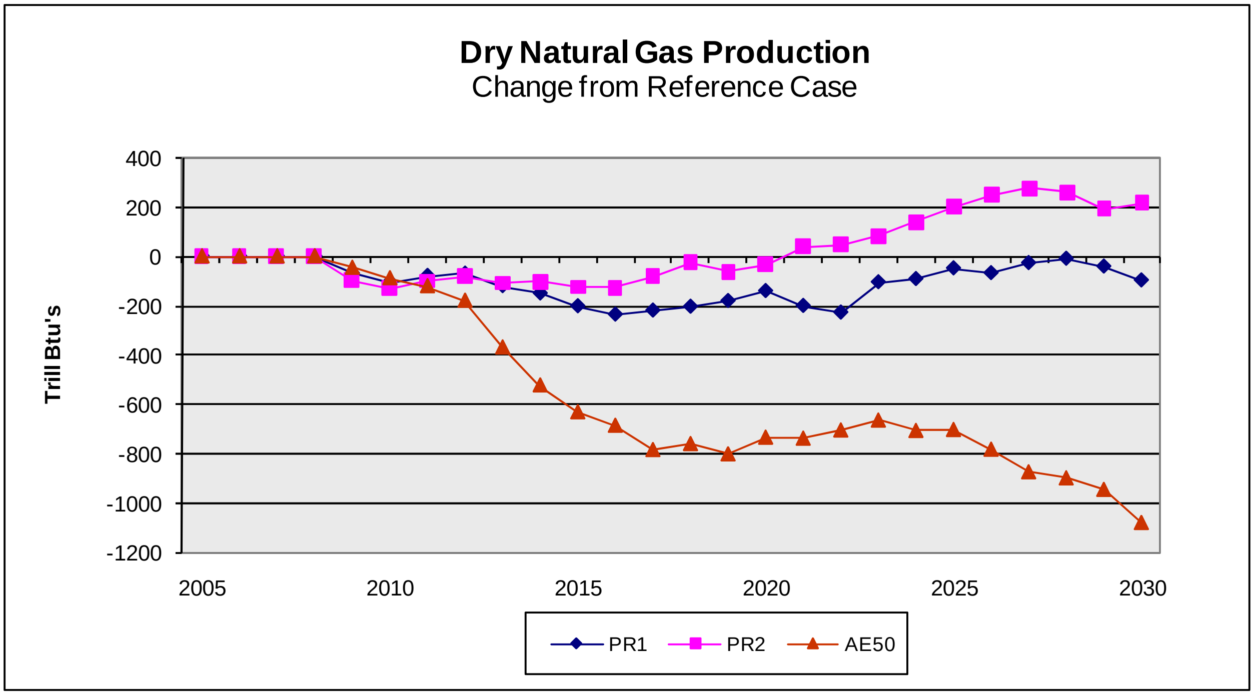

Figure A-31 Dry Natural Gas Production

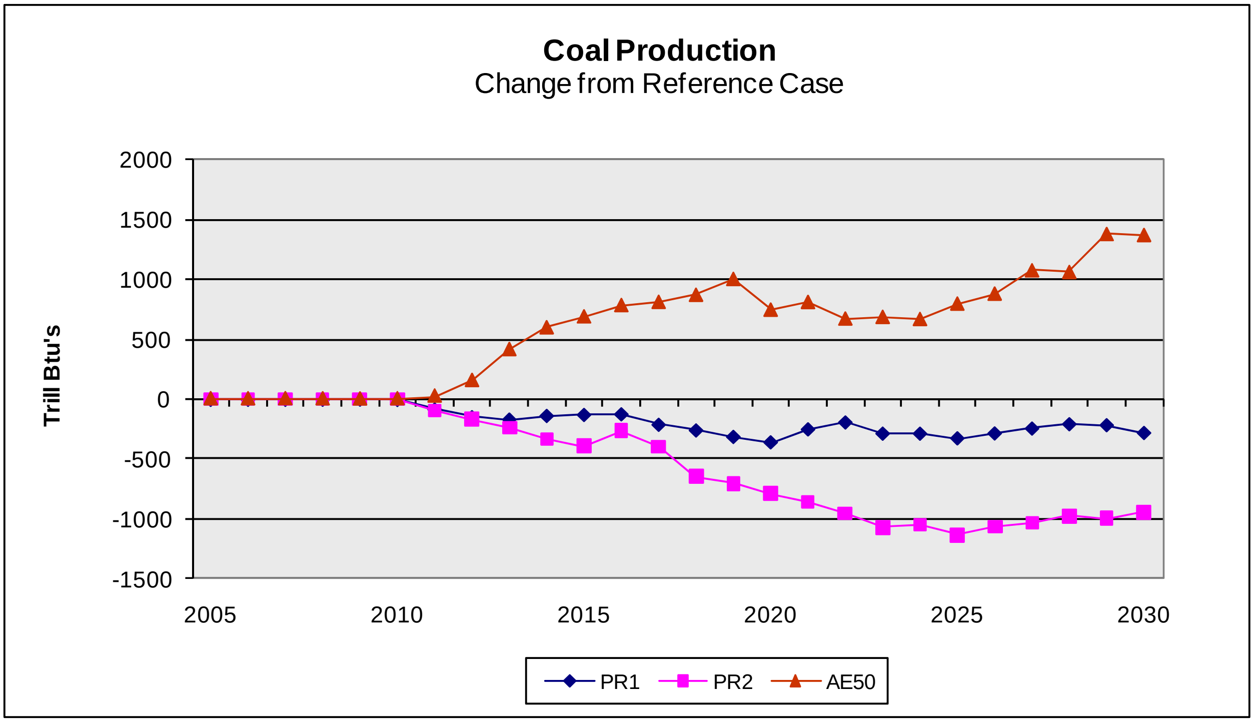

Figure A-32 Coal Production

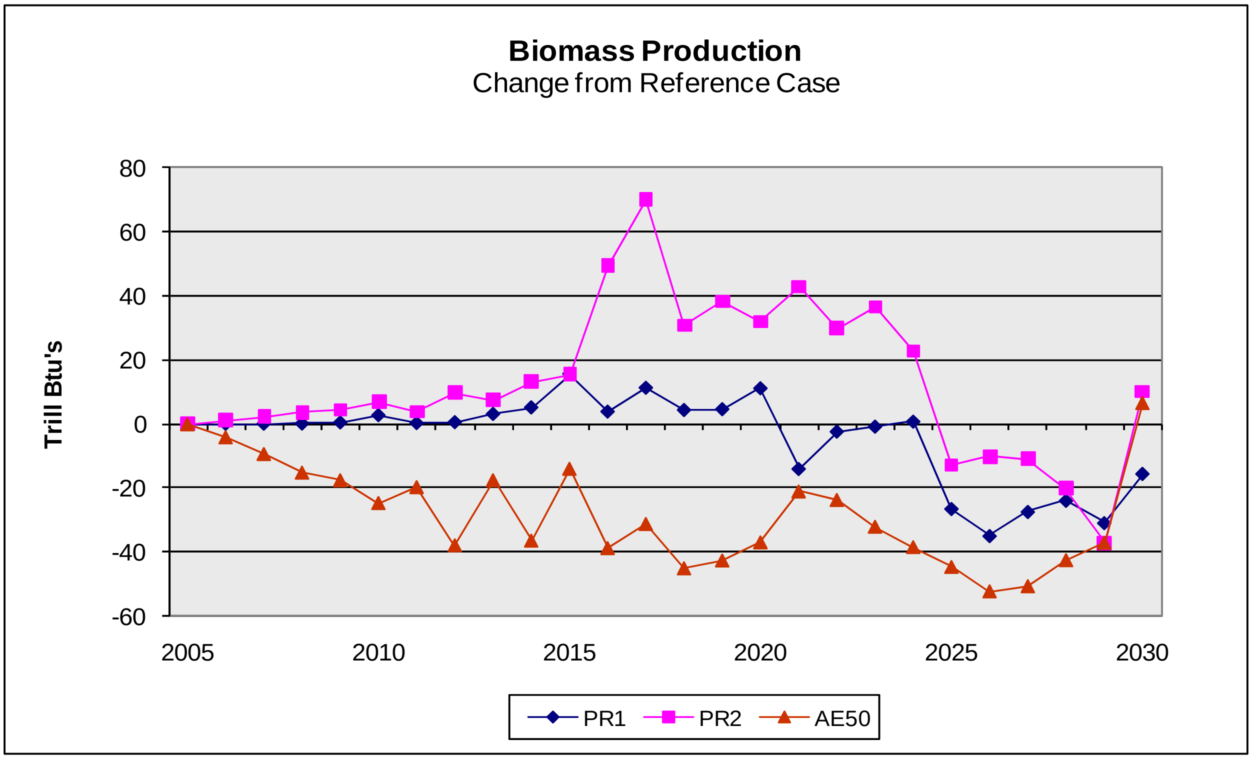

Figure A-33 Biomass Production

A.6.9 Energy Prices

Residential and commercial customers will incur only moderate increases in natural gas prices as a result of direct energy use under all scenarios.

Figure A-34 and Figure A-35 show that in the residential market, PR1-PR3 scenarios show slightly higher energy prices relative to baseline. Natural gas prices grow slightly by $0.50 per million Btu above the baseline, or about 3.7% higher than 2010 prices. Residential electric prices also show an increase of $0.50 per million Btu or about a 1.6% increase from 2010.

Figure A-36 and Figure A-37 show that in the commercial market, natural gas prices rise about 1% and electric prices decline about 2% relative to the Reference Case under PR1-PR3 scenarios. In the electric case, natural gas prices decline 5% due to lower demand, while electric prices are unchanged relative to the Reference Case.

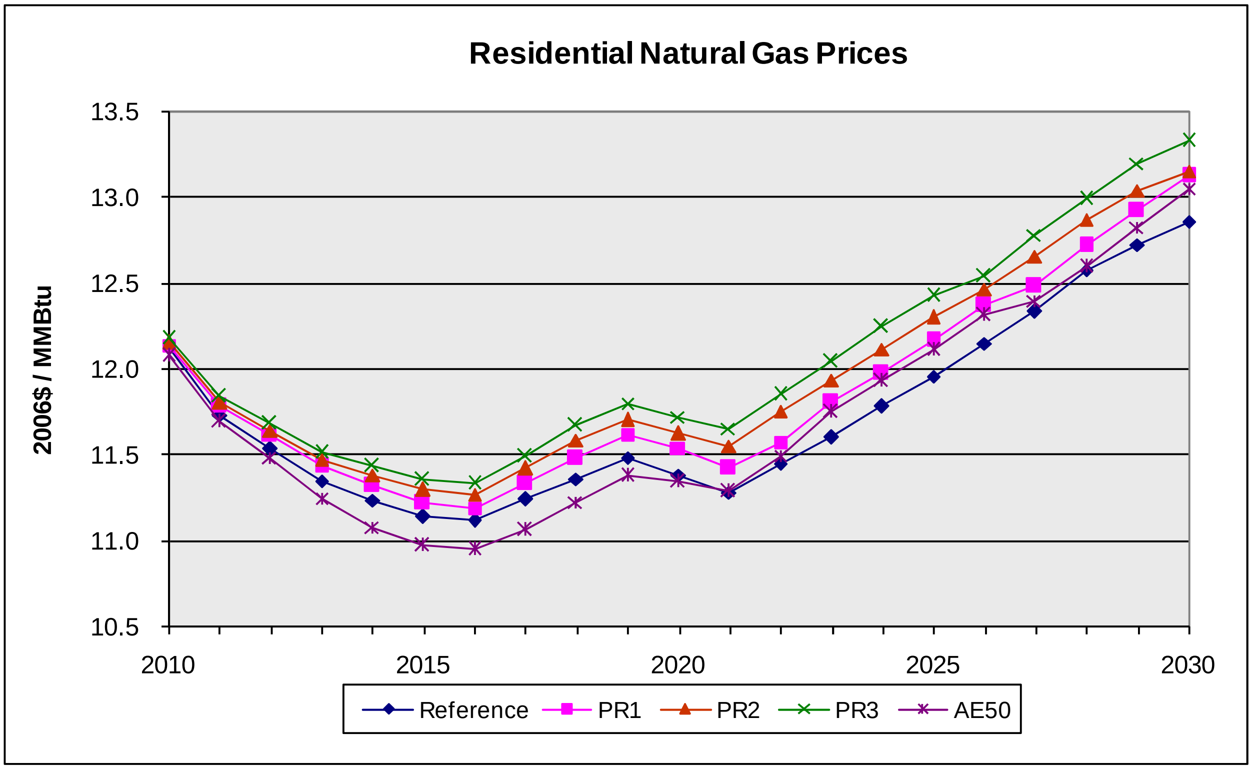

Figure A-34 Residential Natural Gas Prices

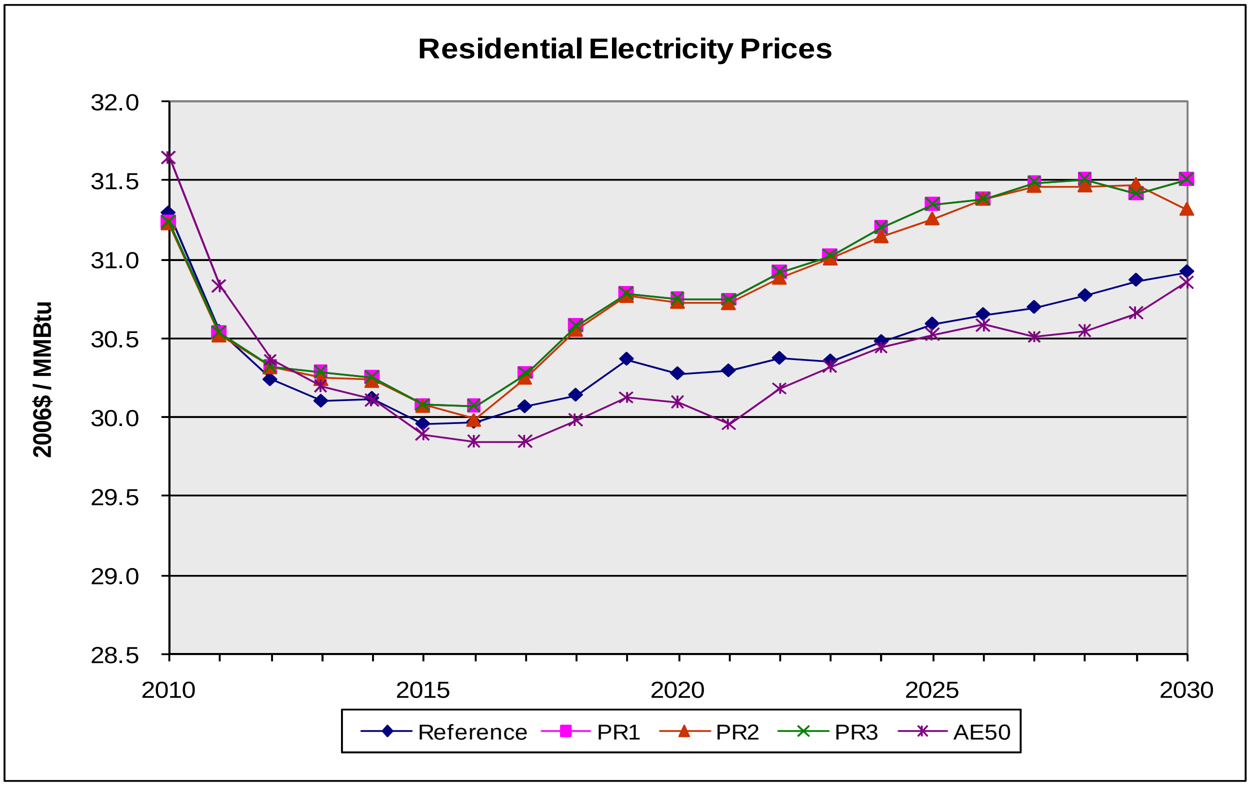

Figure A-35 Residential Electricity Prices

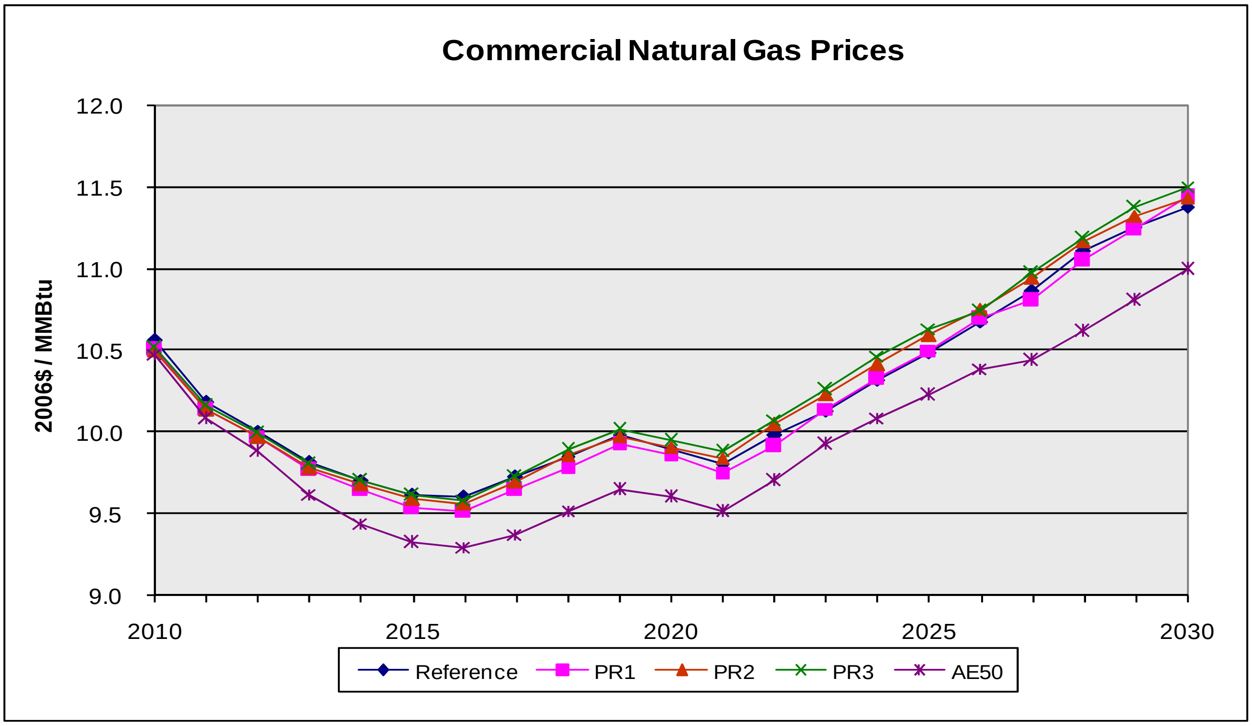

Figure A-36 Commercial Natural Gas Prices

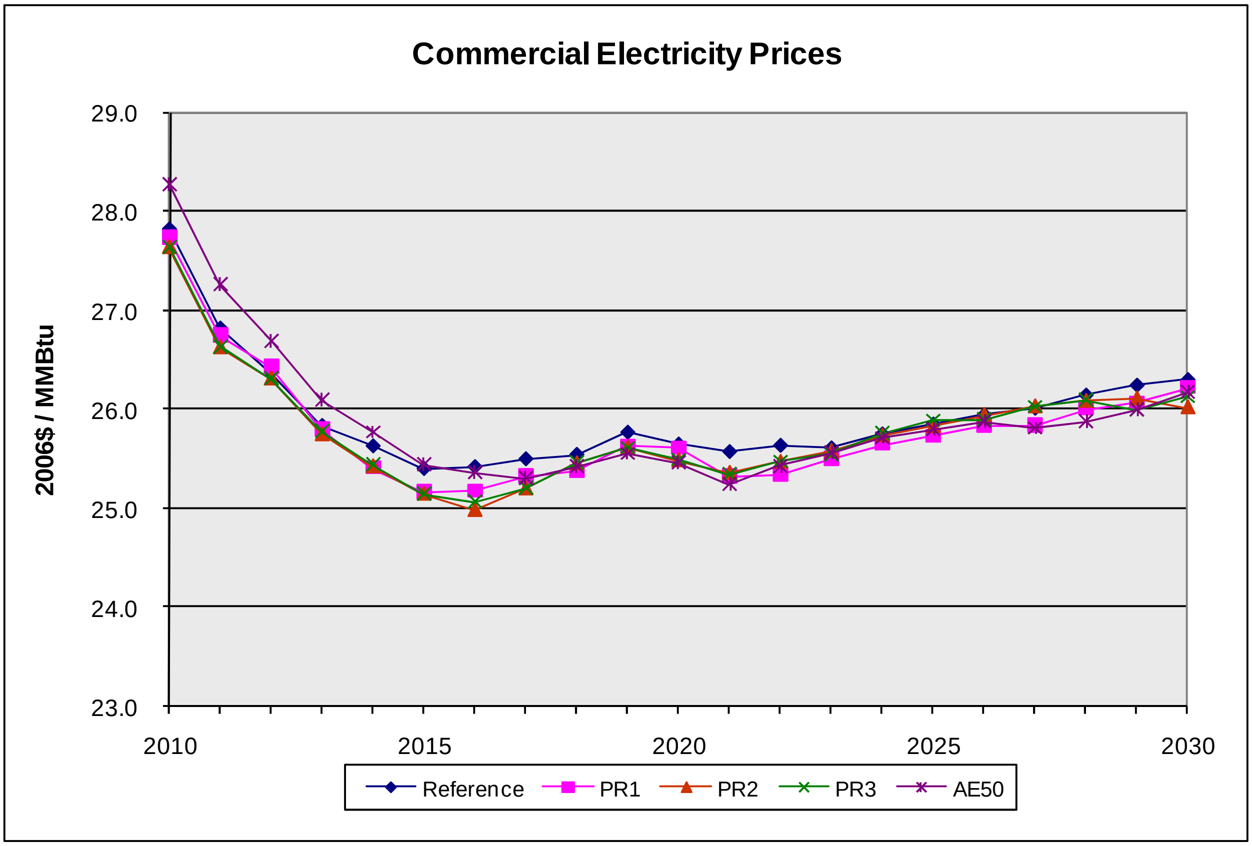

Figure A-37 Commercial Electricity Prices

A.6.10 Residential Natural Gas Consumption

Figure A-38 and Figure A-39 show that residential natural gas consumption is higher under PR3 in all regions compared to the baseline. In the aggregate, PR2 and PR3 show an increase over the baseline due to changes in bias and new technology development. In 2030, the greatest consumption,1.4 Tcf , is in the East North Central region, followed by Mid-Atlantic and Pacific regions.

Under the electric scenario, natural gas consumption decreases by about 50% in the residential markets.

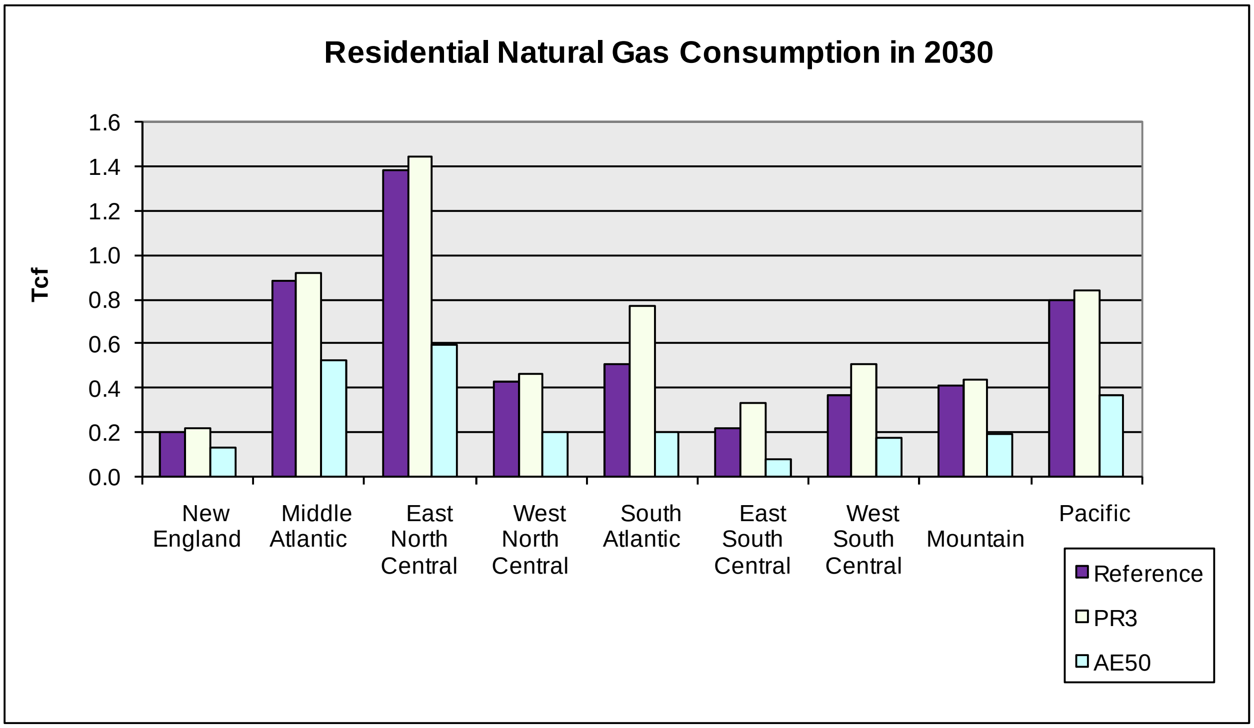

Figure A-38 Residential Natural Gas Consumption 2030

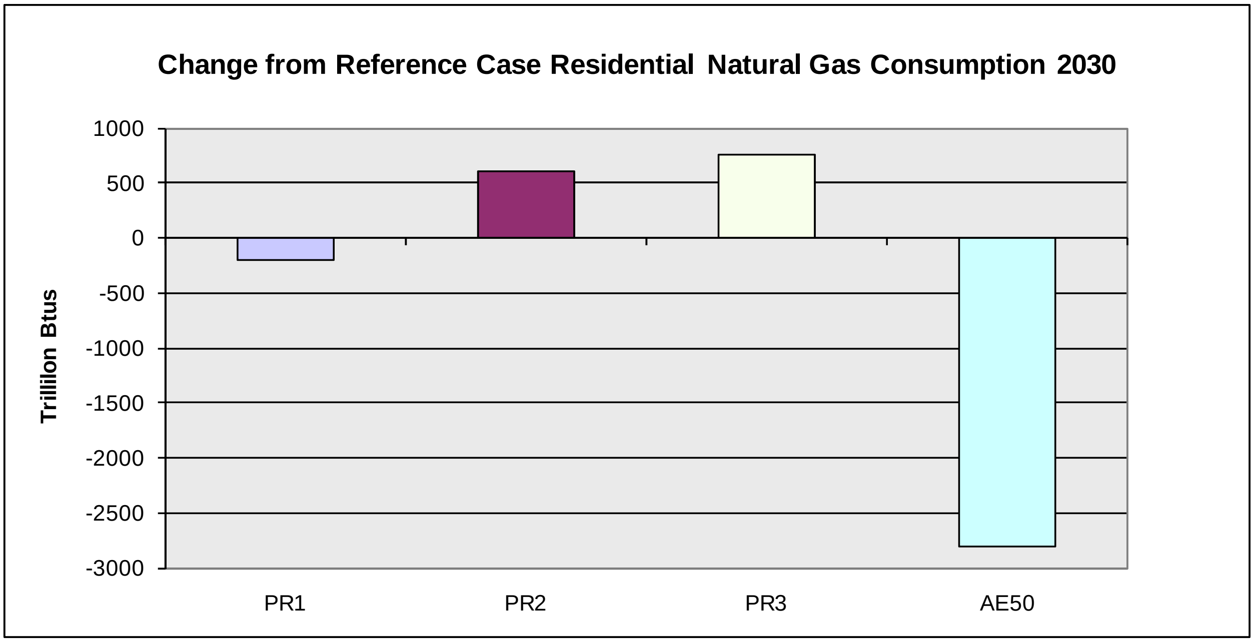

Figure A-39 Residential Natural Gas Consumption 2030 - Change from Reference Case

A.6.11 Commercial Natural Gas Consumption

Figure A-40 and Figure A-41 show commercial natural gas consumption is less impacted under PR1-PR3 scenarios because there is less flexibility in fuel choice.

The Middle Atlantic and South Atlantic regions benefit the most from scenario PR3 increases in natural gas consumption in the commercial sector due to substitution of natural gas for electric technologies.

In the AE50 scenario there are fewer options to substitute electric for natural gas and existing gas technologies did not benefit from the efficiency improvements in PR3, thus natural gas consumption in the commercial sector is the highest in the AE50 scenario.

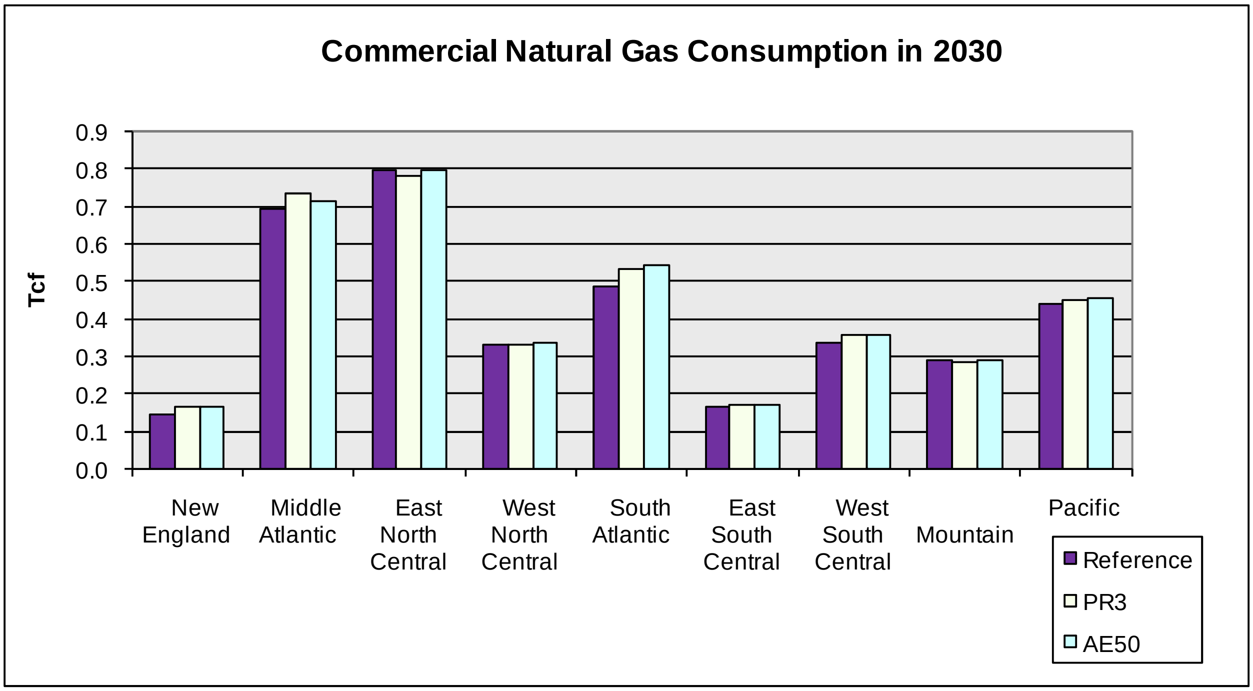

Figure A-40 Commercial Natural Gas Consumption 2030

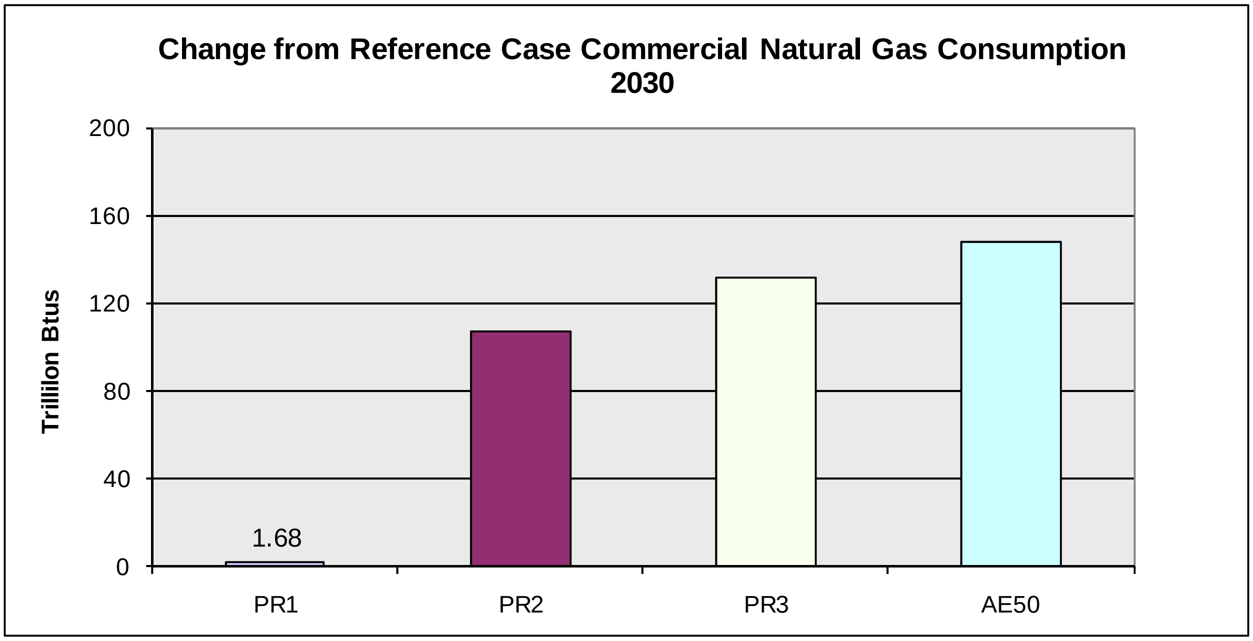

Figure A-41 Commercial Natural Gas Consumption 2030 - Change from Reference Case

A.6.12 Scenario Impact by Census Region

Figure A-42 through Figure A-50 show that the impact of the three gas scenarios and one electric option by census region varies significantly. The South Atlantic and East South Central regions are the prime beneficiary of the investments and attitude changes in the gas scenarios as they increase demand for natural gas. This trend mirrors population growth and the demand for cooling technologies such as natural gas heat pumps.

The North Central and Mid-Atlantic regions are most negatively impacted in terms of natural gas demand, mirroring efficiency and thermal envelope improvements in traditional heating climates.

The electric case, AE50, shows the largest impact in the East North Central region followed by the Pacific and then Mid-Atlantic regions, the two regions with the greatest gas consumption.

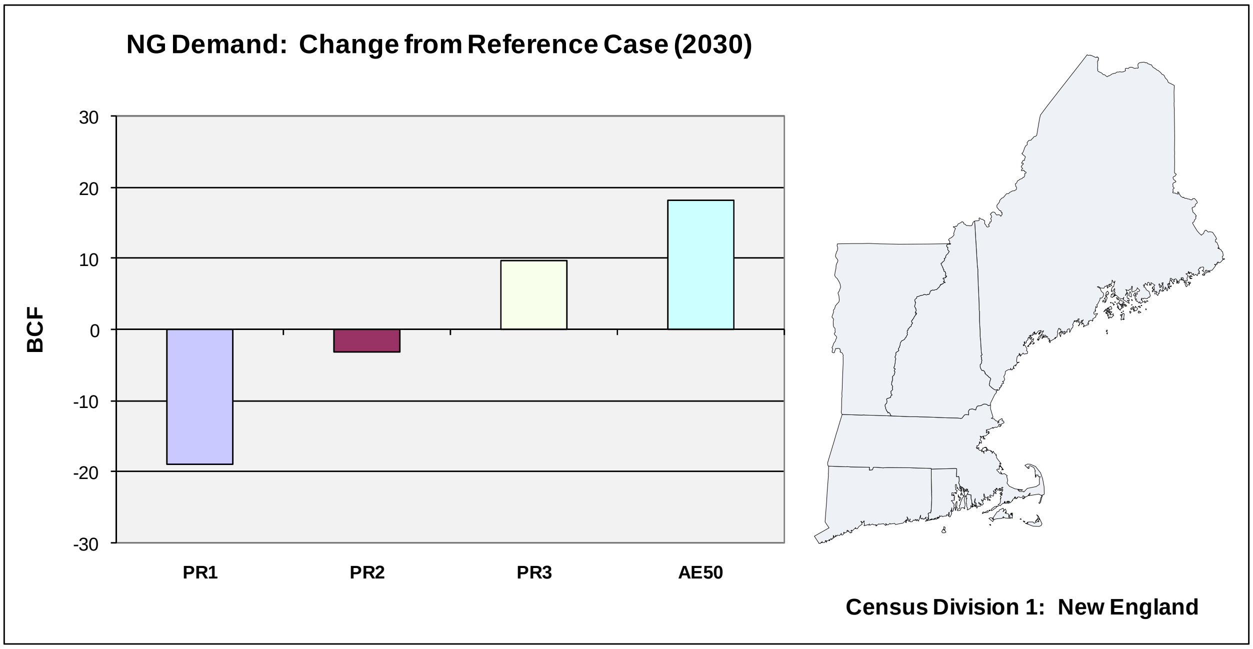

Figure A-42 Natural Gas Demand 2030 - New England

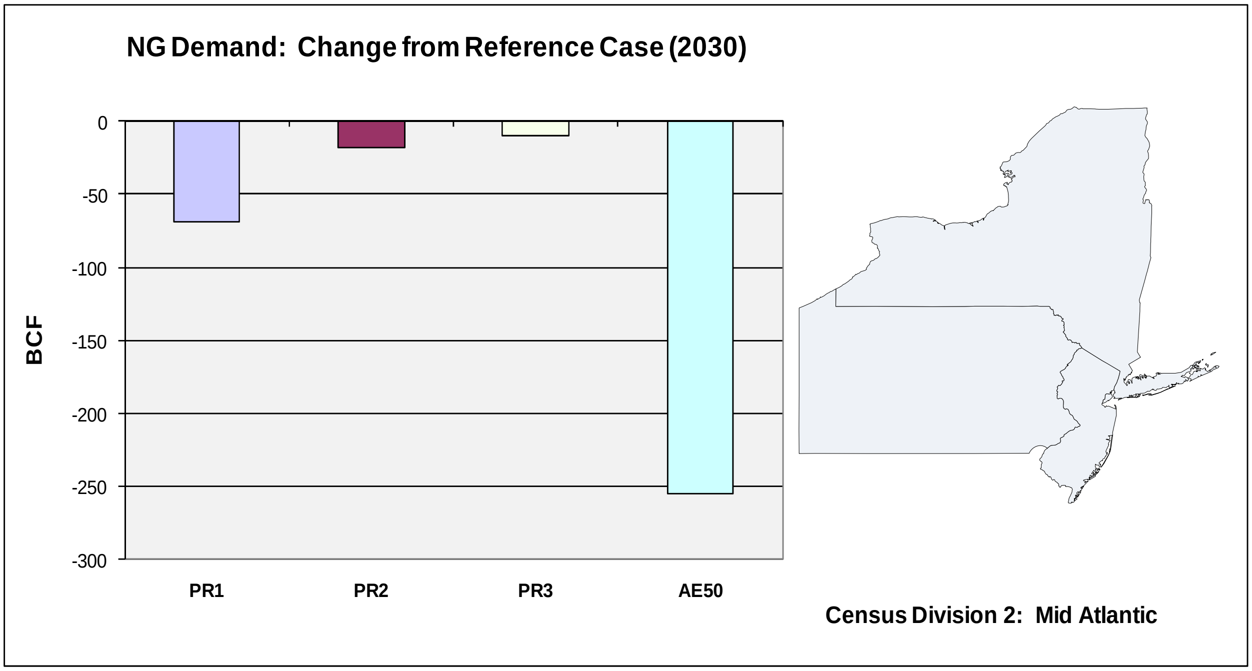

Figure A-43 Natural Gas Demand 2030 - Mid Atlantic

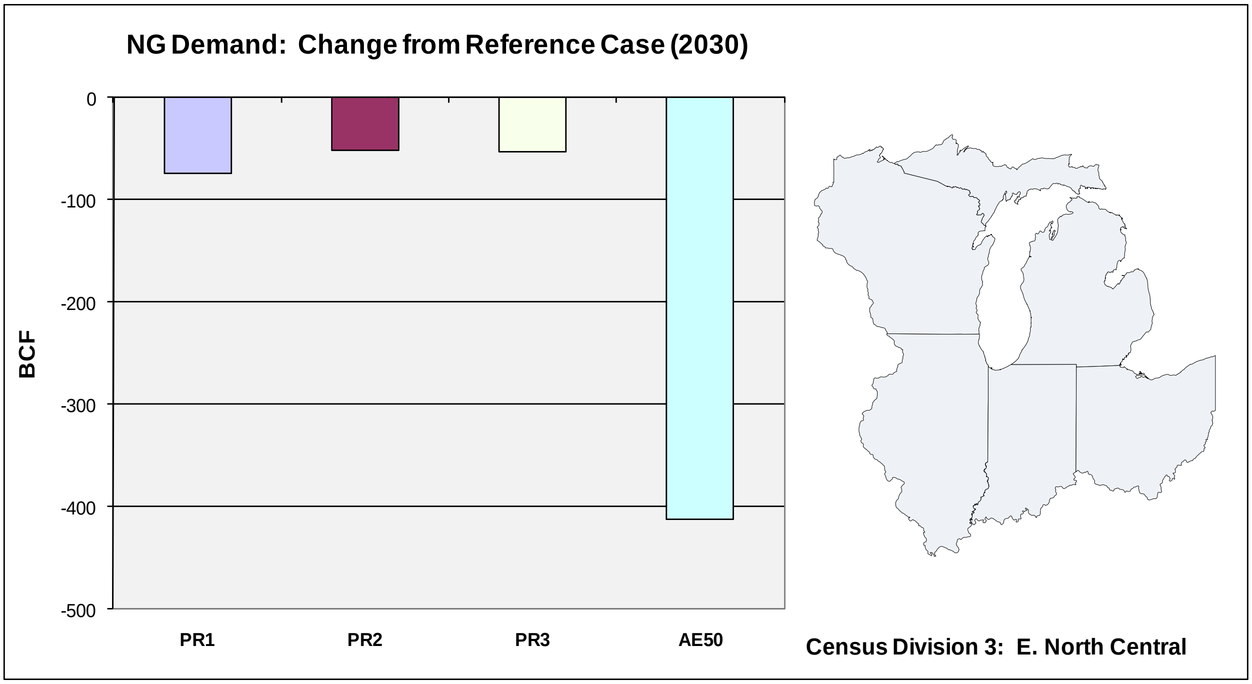

Figure A-44 Natural Gas Demand 2030 – E. North Central

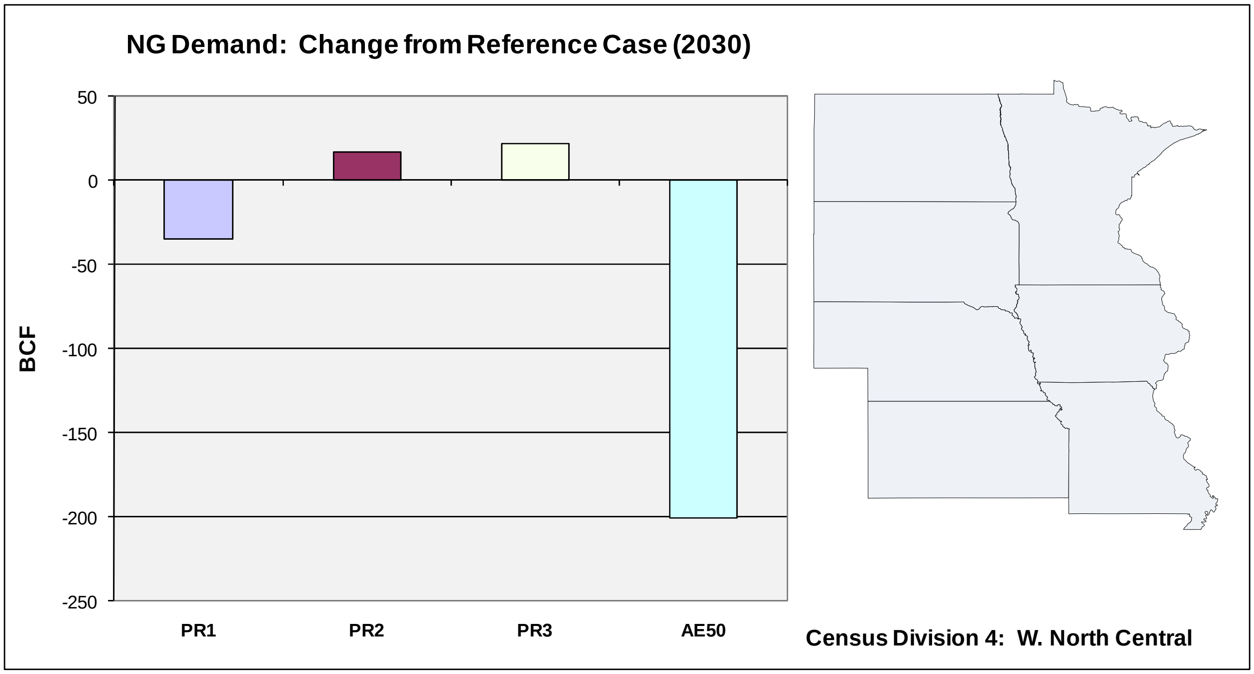

Figure A-45 Natural Gas Demand 2030 - W North Central

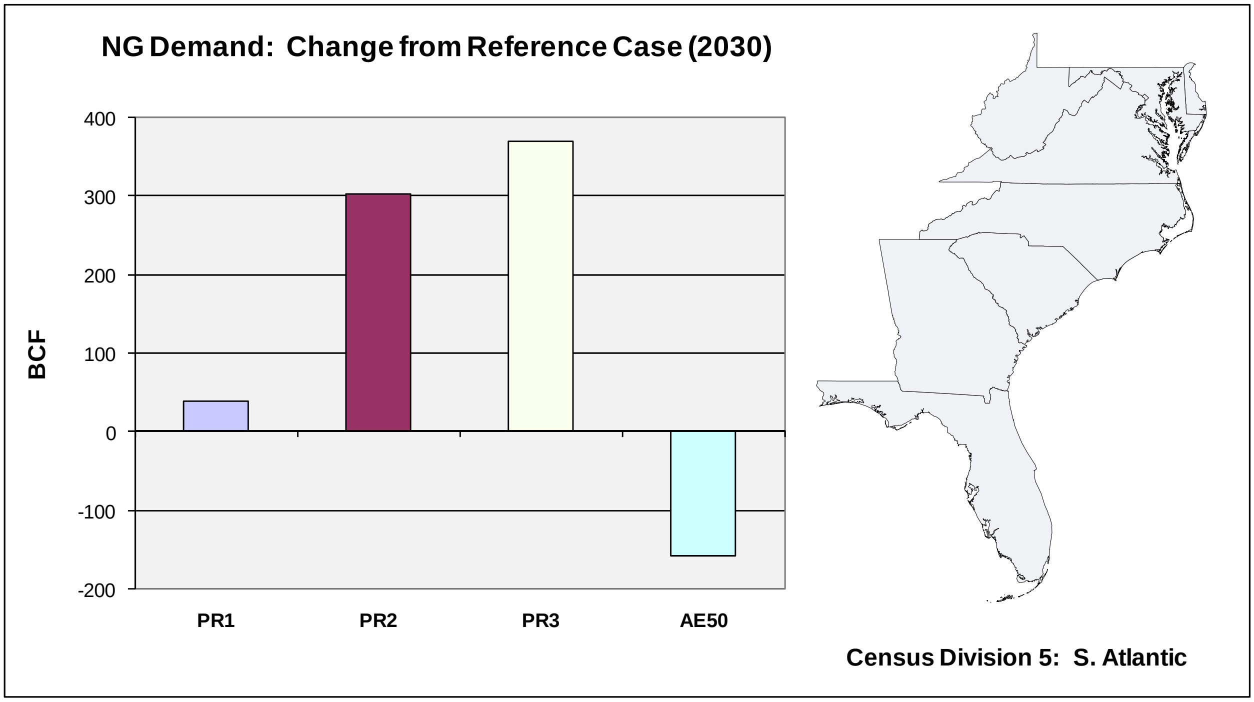

Figure A-46 Natural Gas Demand 2030 - S Atlantic

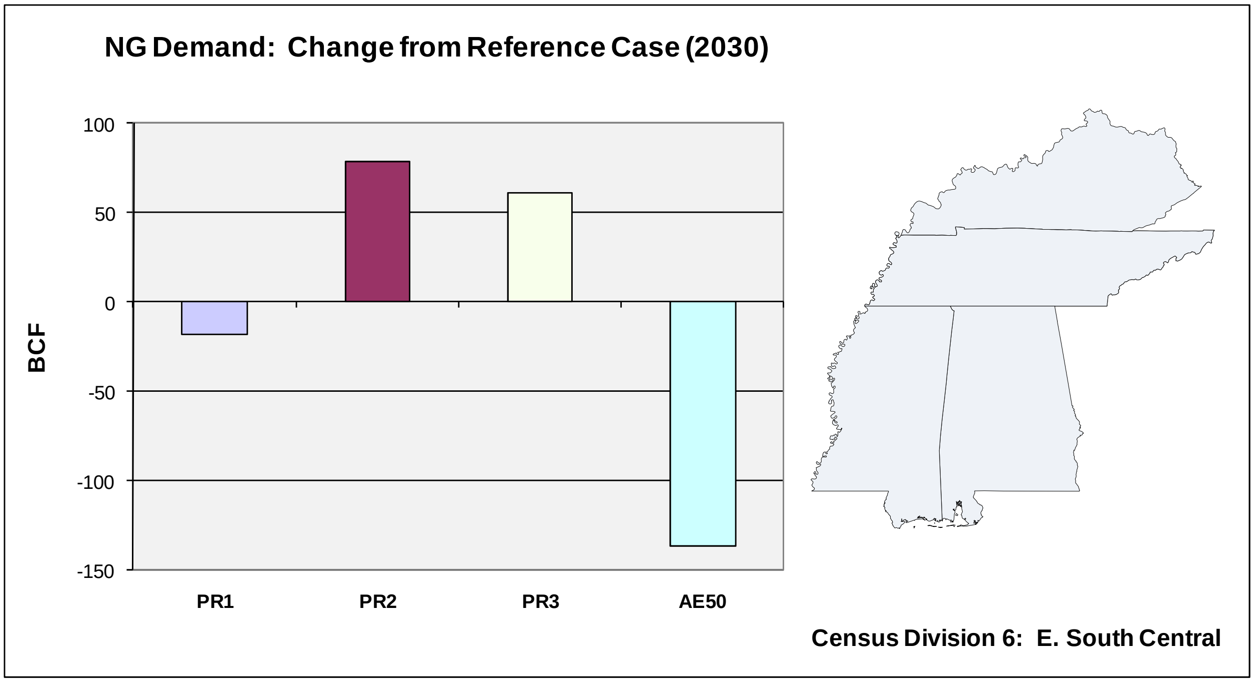

Figure A-47 Natural Gas Demand 2030 - E South Central

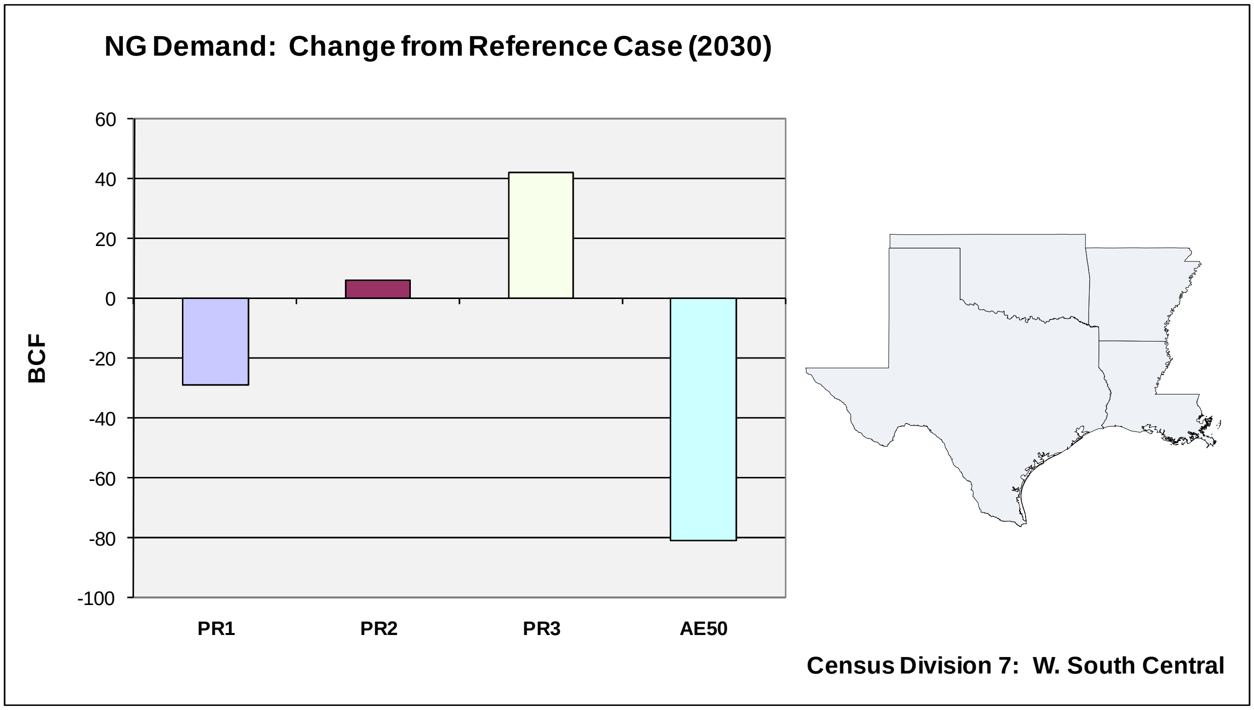

Figure A-48 Natural Gas Demand 2030 - W South Central

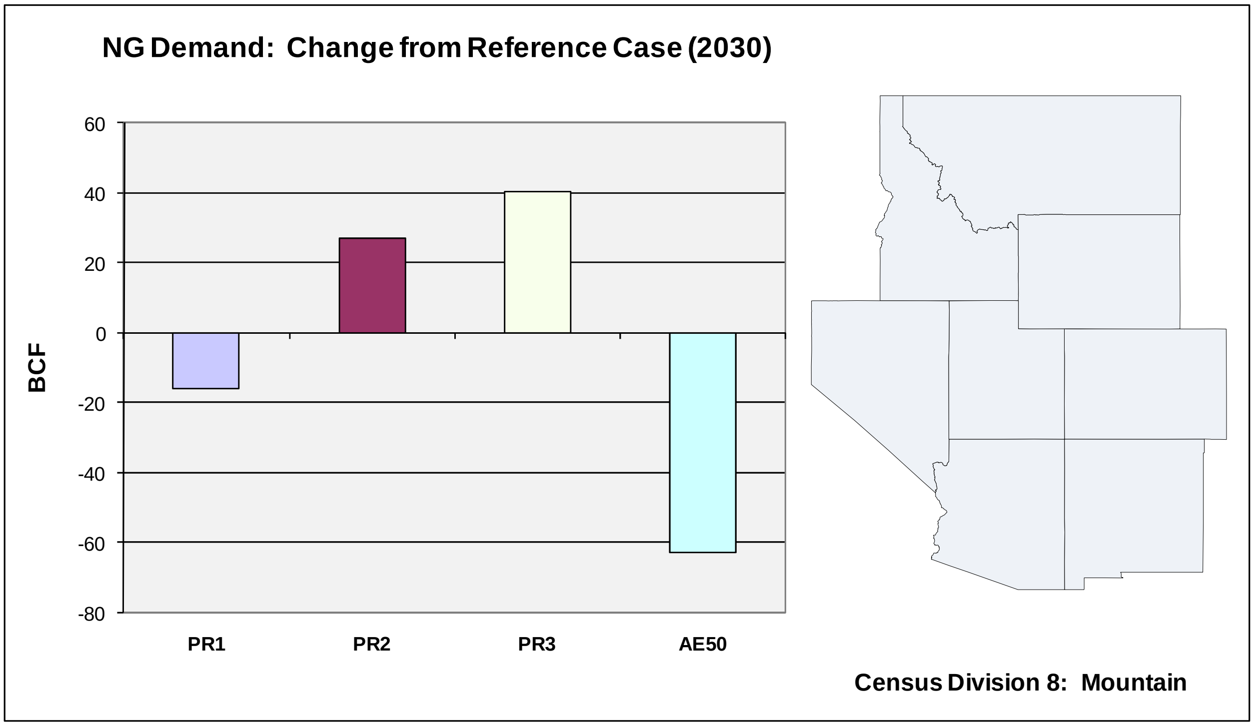

Figure A-49 Natural Gas Demand 2030 – Mountain

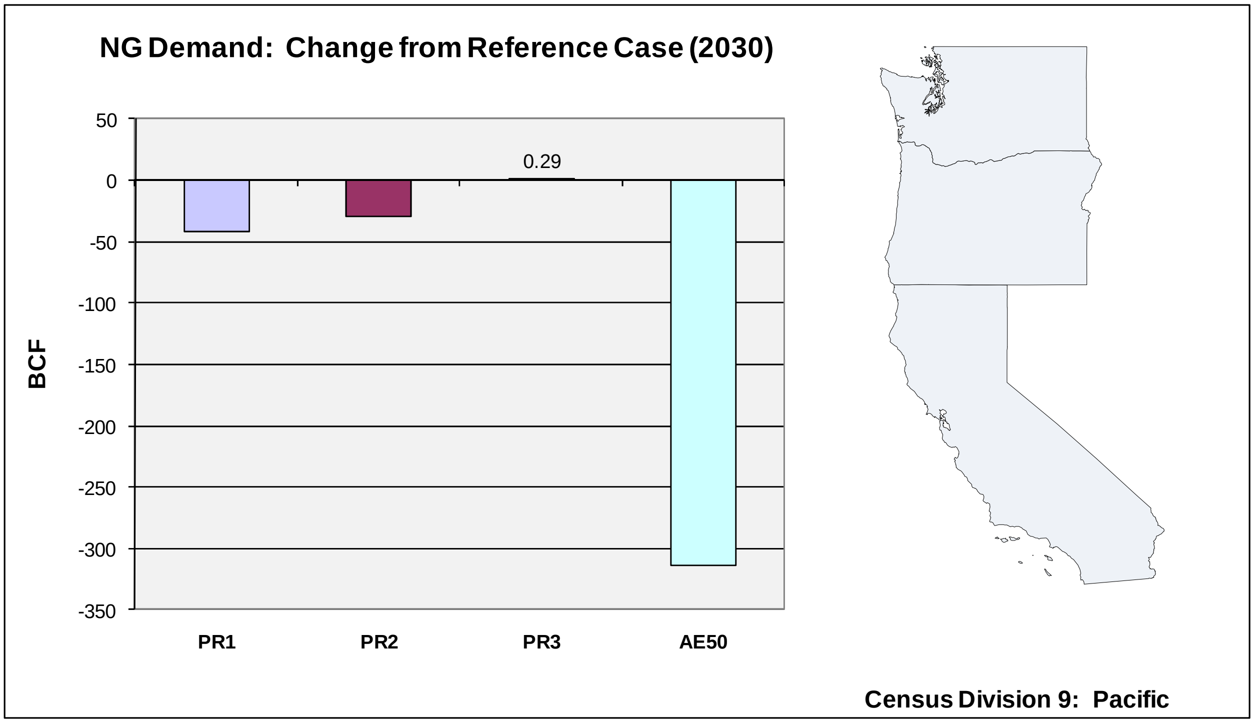

Figure A-50 Natural Gas Demand 2030 - Pacific

A.6.13 Electric Space Heating by Region- Stock and Efficiency

Figure A-51 and Figure A-52 display electric resistance furnace data by census region regarding both stock and average annual electricity usage. By region, the number of electric resistance furnaces increase as Heating Degree Days (HDD) decrease. So, although New England homes with electric resistance heat consume a significant amount of heating energy, there are less than 300,000 units in use, as of 2005.

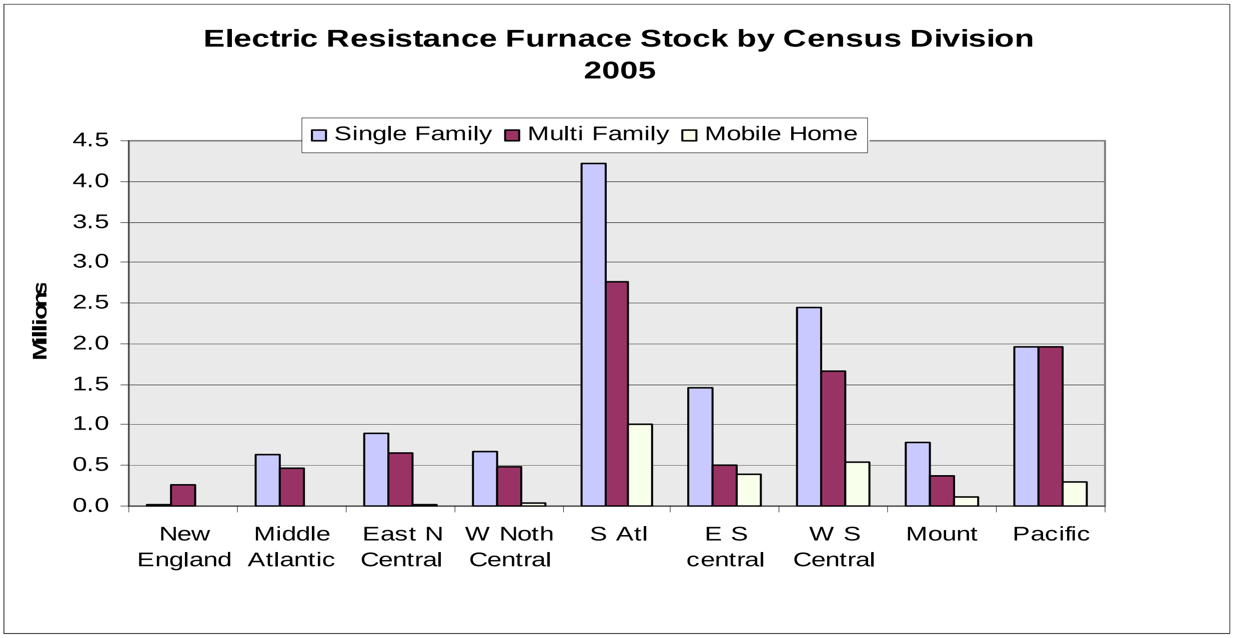

Figure A-51 Electric Resistance Furnace Stock 2005 by Census Division

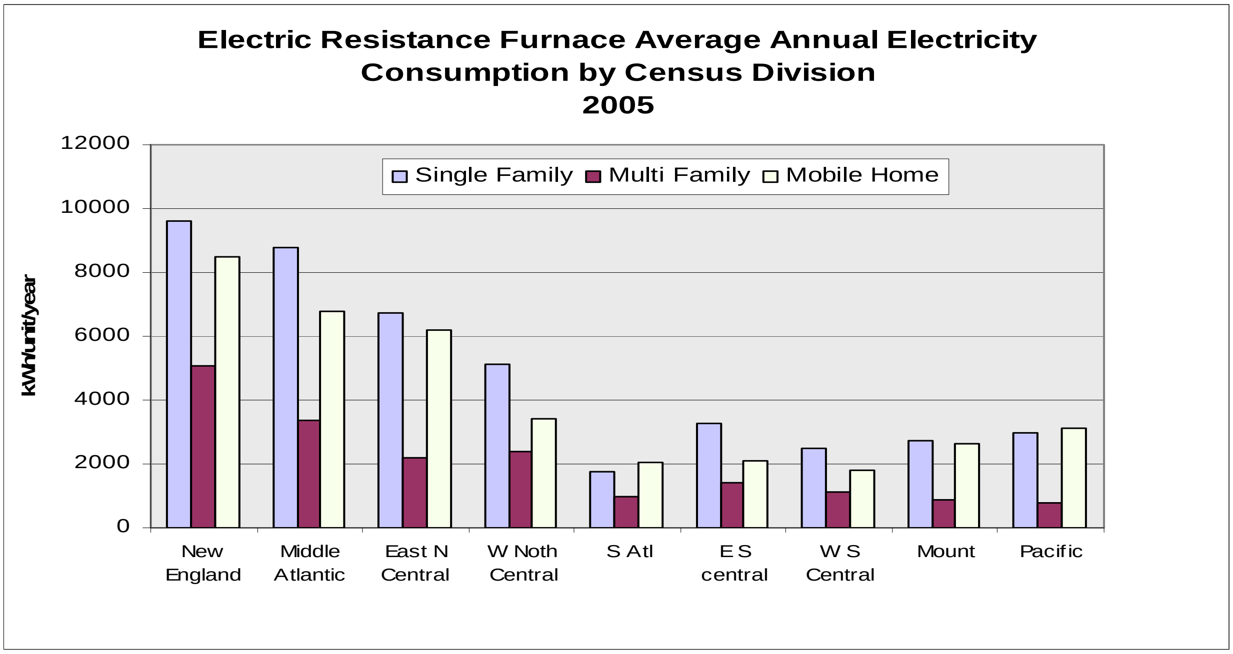

Figure A-52 Electric Resistance Furnace Average Yearly Electricity Use 2005 by Census Division

Figure A-53 and Figure A-54 display electric heat pump data by census region regarding both stock and average annual electricity usage. The South Atlantic region dominates electric heat pump stock, especially single family dwellings. Again, electric heat pumps use a significant amount of energy in heating dominated climates, but their market penetration is low making the aggregate influence minimal.

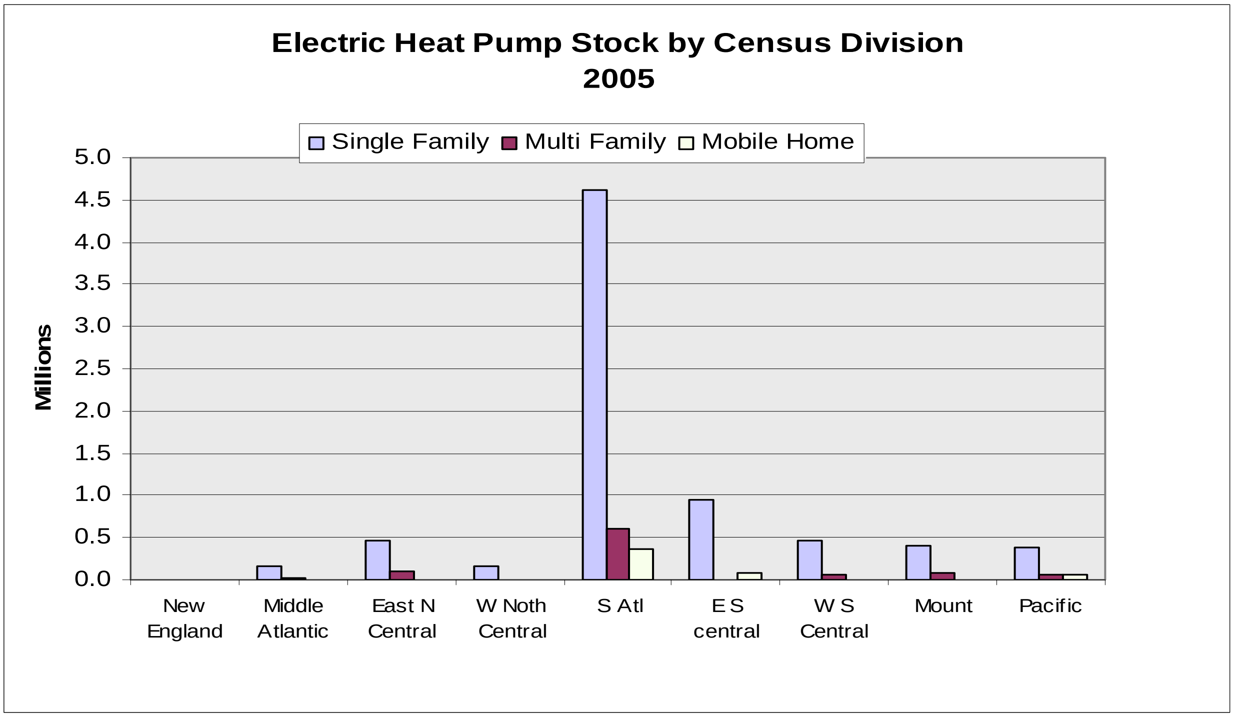

Figure A-53 Electric Heat Pump Stock 2005 by Census Division

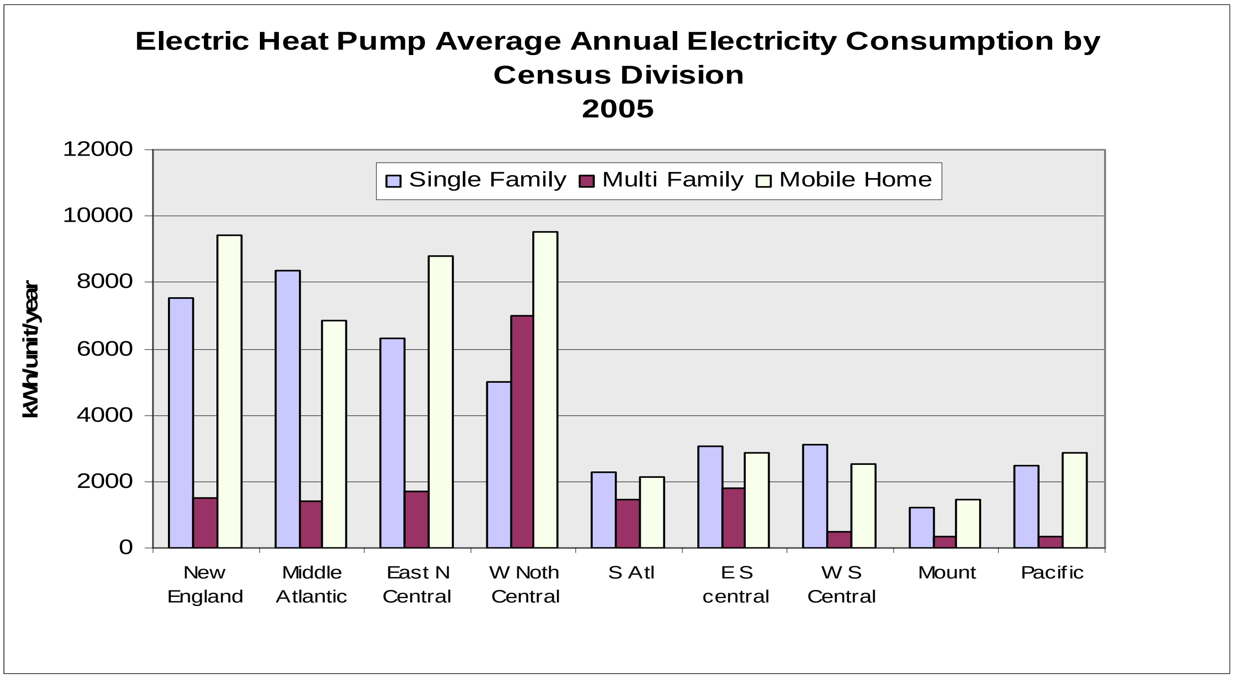

Figure A-54 Electric Heat Pump Average Yearly Electricity Use 2005 by Census Division