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**Making Buildings Part of the Climate Solution by Pricing Carbon Efficiently**  
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**ABSTRACT**

This report examines the impact of instituting an economy-wide tax on CO<sub>2</sub> emissions in the United States, focusing especially on the changes such a tax would have on the energy and carbon profile of the commercial buildings sector. In terms of energy intensity, a carbon tax is estimated to deliver faster and deeper reductions in the commercial sector than in the rest of the economy. Still, its 6.3% energy intensity improvement falls short of the Better Buildings goal of a 20% increase in the energy efficiency of commercial buildings by 2020. On the other hand, the carbon tax scenario nearly meets the Waxman-Markey and Copenhagen economy-wide carbon reduction goals for 2020, due partly to a more carbon-lean power sector. The effects of carbon taxes on commercial buildings would be technologically transformational and geographically widespread. While energy expenditures would rise and more capital would be required for energy-efficiency upgrades, the avoided pollution and the reduced CO<sub>2</sub> emissions would generate significant human health and ecosystem benefits. To be successful, a broad community of constituents would need to accept the temporal mismatch between immediate costs and long-term benefits.

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Any remaining errors in this report are the responsibility of the authors alone.

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## Executive Summary

This policy white paper examines the impact of instituting an economy-wide tax on CO<sub>2</sub> emissions in the United States, focusing especially on the changes such a tax would have on the energy and carbon profiles of the commercial buildings sector. By charging emitters for the damages caused by their actions, a carbon tax could efficiently stimulate carbon abatement through more energy-efficient technologies, low-carbon fuels and electricity, and carbon capture and sequestration.<sup>1</sup> But how would owners and occupants of commercial buildings likely respond to a carbon price signal? Could a carbon tax achieve the Administration's Better Buildings goal of a 20% improvement in the energy efficiency of commercial buildings by 2020?<sup>2</sup> The ability of the commercial buildings sector to become more energy-efficient and less carbon-intensive in response to a carbon tax could have widespread implications for the development and growth of the U.S. economy, given the likelihood of a continued transition to a service economy embedded in a highly competitive global marketplace. Yet little previous research has examined the impact of such a policy on commercial buildings.

The Georgia Institute of Technology's version of the National Energy Modeling System (GT-NEMS) is the principal modeling tool used in this study to examine the likely impacts of carbon taxes on the energy and carbon profile of commercial buildings. The GT-NEMS "bottom-up" engineering and economic modeling approach is well suited to a carbon tax analysis focused on understanding the likely response of the commercial buildings sector (Cullenward, Wilkerson, and Davidian, 2009). By characterizing nearly 350 distinct commercial building technologies, and by enabling the separate analysis of nine Census division, ten end-uses (e.g., lighting and air conditioning), and eleven building types, GT-NEMS offers the potential for a rich examination of policy impacts. Top-down modeling of the energy economy produces fewer insights about the role of specific technologies and detailed end-use effects (Energy Modeling Forum, 2011).

An economy-wide tax on CO<sub>2</sub> emissions is modeled. Based approximately on an Interagency Working Group estimate of the social cost of carbon (EPA, 2010), the carbon tax starts from \$25 per metric ton of CO<sub>2</sub> in 2015 and increases 5% annually; in 2035, the tax would reach \$66 per metric ton (real dollars), generating the "Main Tax" scenario. In addition, we use the suite of technologies from the Energy Information Administration (EIA)'s "High Tech" side case that assumes higher efficiencies for equipment, and earlier availability of some advanced equipment. Together with the carbon tax, this makes up the "Main Tax + High Tech" scenario that is the principal focus of our analysis.

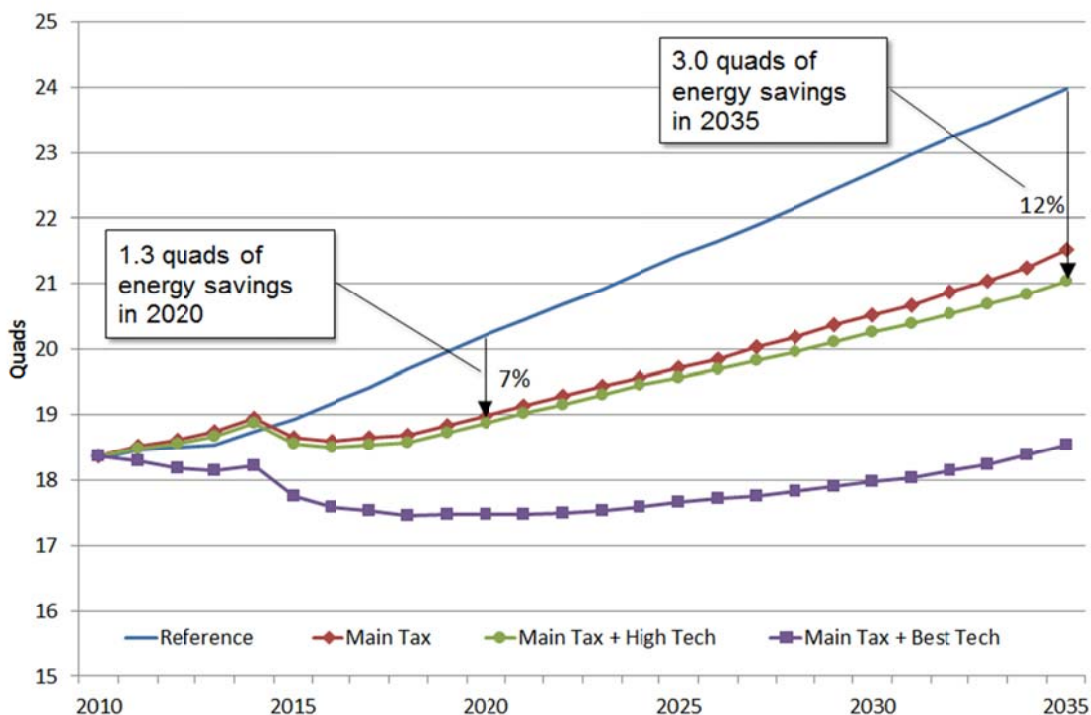
The commercial buildings sector appears to respond quickly to a carbon tax. Following a pre-2015 rise in energy consumption relative to the Reference case (reflecting lower electricity rates resulting from higher coal use in the power sector), the Main Tax alone is estimated to achieve a

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<sup>1</sup> We use the terms, "carbon price" and "carbon tax" because they are widely recognized terms, but note that the terms are intended to encompass multiple greenhouse gases.

<sup>2</sup> Commercial buildings are projected to consume 20.2i quads of energy in 2020, so in 2020, the goal would be to reduce consumption to 16.2 quads – that is, 4.0 quads less than EIA's forecast.

6% reduction in commercial building energy consumption in 2020 and a 10% reduction in 2035, compared to the Reference case projection. The Main Tax + High Tech scenario achieves deeper energy consumption reductions: 7% in 2020 and 12% in 2035 (Figure ES.1).<sup>3</sup> In 2020, the carbon tax is estimated to produce an 6.3% improvement in energy intensity compared with the Reference case projection, measured as energy use per square foot of commercial buildings. While a carbon tax would cause energy intensity to drop more rapidly in commercial buildings than in other sectors of the economy, these achievements would nonetheless fall short of the Better Buildings goal of being 20% more efficient by 2020 and would not contribute adequately to limiting the impacts of global climate change.



**Figure ES.1. Commercial Energy Consumption (in Quads): Carbon Tax Scenarios Versus Reference Case**

In the Main Tax + High Tech case, commercial buildings would reduce their CO<sub>2</sub> emissions by 18% relative to the Reference case in 2020 and by 38% in 2035. Thus, the Main Tax + High Tech scenario nearly meets the Waxman-Markey and Copenhagen economy-wide carbon reduction goals of 17% below 2005 levels; it reduces emissions to 13.5% below 2005 levels in 2020 for the economy as a whole.

Despite the reductions in commercial energy use that could be prompted by the Main Tech + High Tech scenario, commercial energy expenditures increase by 12% in 2020 and by 20% in

<sup>3</sup> The initial (pre-2015) rise in energy consumption in the Main Tax + High Tech case relative to the Reference case results, in part, from the lower electricity rates associated with higher coal use, in anticipation of higher energy prices.

2035, above and beyond the expenditure increases projected in the Reference case. This reflects the rising energy prices that are only partially offset by the declining energy use.

- In the Main Tax + High Tech case, natural gas prices in the commercial sector increase by 33% above the 20% rise that is forecast in the Reference case (from \$8.8/MMBtu in 2015 to \$14.6/MMBtu in 2035). This causes a 4% decline in demand for natural gas from commercial buildings compared to the Reference case.
- A similar increase in electricity rates on top of a fairly flat Reference case price forecast causes electricity rates to increase from 9.2¢/kWh in 2015 to 12.3¢/kWh in 2035. Compared with natural gas, this precipitates a much greater drop in demand (an 11% decrease in commercial sector electricity consumption relative to the Reference case).

An analysis of implicit price elasticities of demand suggest that an increasing sensitivity to rising electricity prices is coupled with an increasing proneness for consumers to switch to natural gas as the relative gap between natural gas and electricity prices increases under a carbon tax. Under the Main Tax + High Tech case, energy consumption falls in all nine of the end-uses examined here (space heating, space cooling, water heating, lighting, ventilation, cooking, refrigeration, PC office equipment, and non-PC office equipment). In addition, the relative importance of natural gas in meeting energy demand grows because of the significant fuel switching from electric to natural gas space heating.

The societal benefits of avoided emissions, including CO<sub>2</sub> and criteria pollutants (SO<sub>2</sub>, NO<sub>x</sub>, PM<sub>2.5</sub>, and PM<sub>10</sub>), are estimated using published values from EPA (2010) and the National Research Council (2010). The criteria pollutant analysis accounts for public health and crop damages, but not climate change, mercury, ecosystem impacts, and other environmental damages. For CO<sub>2</sub>, the Interagency Working Group estimates intend to include changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change. The avoided pollution is estimated to deliver more than \$150 billion in cumulative human health and other benefits through 2035, and the reduced CO<sub>2</sub> emissions would avoid damages worth close to \$200 billion over the same period.

The technology trends envisioned by the Main Tax + High Tech scenario would bring about a significant increase in the average energy efficiency of the equipment used in commercial buildings.<sup>4</sup> Of particular note, electric water heating efficiencies increase in the first decade because of a surge of improved heat pump and solar water heaters. That trend strengthens in the last decade when electric resistance water heaters largely vacate the marketplace. Although lighting efficiencies improve only slightly above the Reference case in the first decade (when new federal standards mandate more efficient lighting beginning in 2012), by the second decade, the onset of light-emitting diodes (LED) light bulbs and super fluorescents in the Main

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<sup>4</sup> A carbon tax would also affect the design, construction and operation of buildings by influencing the selection of windows, walls, glazing fractions and other building shell technologies. However, one of the limitations of GT-NEMS is the scarce characterization of building shell technologies, so we emphasize equipment selections, a strength of the model.

Tax + High Tech scenario would increase the efficiency of lighting by an estimated 22% by 2035, above and beyond the Reference case.

The shift to more efficient technologies throughout the major end-uses is a clear trend in Table ES.1. Analysis of these shifts identifies four underlying transformations:

- First, carbon taxes shift energy use from less efficient technologies to more efficient technologies. For example, between 2010 and 2020, wall and window air conditioners (AC) lose market share to mid-efficiency (3.28 COP) rooftop AC units.
- Second, the carbon tax scenario produces cost savings by enabling consumers to move from more expensive to less expensive high-efficiency technologies. This is the case in 2035 when service demand shifts from an earlier-generation, more expensive rooftop air conditioning unit to a later generation, less expensive rooftop AC unit with the same efficiency (from 72 to 67 2007-\$/1000 Btu Out/hour unit with a COP of 3.28).
- Third, carbon taxes enable consumers to gravitate to more efficient models within the same class of technology. As an example, in electric space heating, there is a second-tier of winners in 2035; centrifugal (COP 7.0) and reciprocating (COP 3.2) chillers that enter the market in 2020 gain market share against the less efficient centrifugal (COP 4.69) and reciprocating (COP 2.34) chillers first available in 2003.
- Finally, carbon taxes can cause fuel switching. For example, there is a significant shift from electric space heating to gas space heating in the 2020-2035 timeframe. This finding underscores the fact that the most important building technologies based on carbon dioxide emission reductions may not be the most cost-competitive high-efficiency technologies, but rather the technologies that can displace fossil fuels or enable a switch to less-intensive fossil fuels, as with the switch from electric heat pumps to gas furnaces, or from natural gas water heaters to solar water heaters.

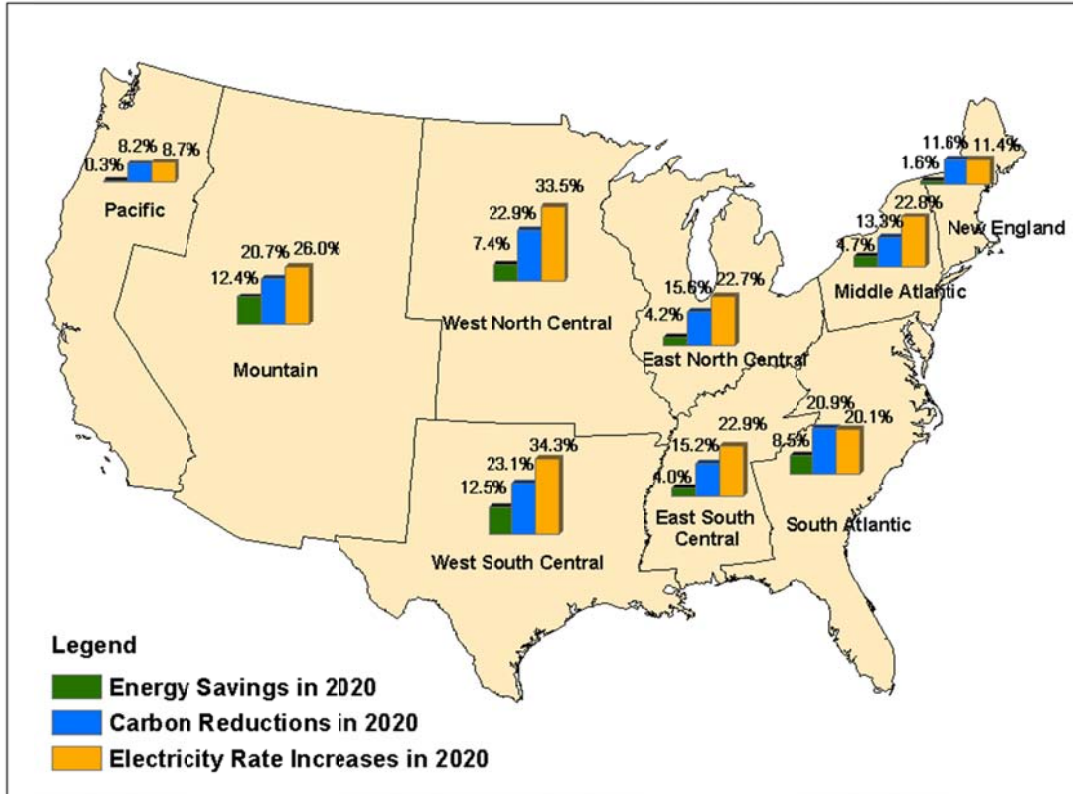
This technological transformation of commercial buildings requires the infusion of additional expenditures on energy-efficient designs and equipment. GT-NEMS generates estimated investment costs for individual technologies and vintages, and for major end-uses, including space heating, space cooling, water heating, refrigeration, cooking, ventilation, and lighting. These seven major end-uses account for the majority (50-60%) of energy consumption in commercial buildings between 2020 and 2035, both in the Reference case and in the Main Tax + High Tech scenario. The Main Tax + High Tech case is estimated to stimulate an additional expenditure of 13 to 14% over this planning horizon, rising slightly over time reflecting the increasing level of carbon taxation.

**Table ES.1. End-Use Technology Shifts:  
Main Tax + High Tech Scenario Versus Reference Case**

<b>End Use</b>	<b>2010-2020</b>	<b>2020-2035</b>
<b>Electric Space Heating</b>		
– Ascendent Technologies	Ground source heat pumps (COP 3.5)	High efficiency air source heat pumps (COP 3.8)
– Declining Technologies	Less-efficient air source heat pumps (COP 3.3)	Less-efficient air source heat pumps (COP 3.3)
<b>Natural Gas Space Heating</b>		
– Ascendent Technologies	High efficiency furnaces (94%) and boilers (95%)	High efficiency gas furnaces (94%) and boilers (95%)
– Declining Technologies	Low efficiency furnaces and boilers (78-84%)	Low efficiency furnaces and boilers (78-84%)
<b>Electric Cooling</b>		
– Ascendent Technologies	Mid-efficiency (COP 3.28) rooftop AC	Mid-efficiency (3.28 COP) rooftop AC; centrifugal (COP 7.0) and reciprocating (COP 3.2) chillers
– Declining Technologies	More expensive mid-efficiency rooftop AC; wall & window AC	More expensive mid-efficiency rooftop AC, Reciprocating (COP 2.34) and centrifugal (COP 4.69) chillers
<b>Electric Water Heating</b>		
– Ascendent Technologies	Solar and heat pump water heaters with 2011 costs	High efficiency (2.5 COP) solar water heater; heat pump water heater (2.3 COP)
– Declining Technologies	Solar water heaters with 2010 costs (higher than 2011 costs) and standard electric water heater	Standard electric water heater
<b>Natural Gas Water Heating</b>		
– Ascendent Technologies	High efficiency gas water heater with 2007 costs and efficiencies (COP 0.93)	High efficiency gas water heater with 2020 costs and efficiencies (COP 0.95)
– Declining Technologies	Standard gas water heater (COP 0.75-0.78)	High efficiency gas water heater with 2007 costs and efficiencies (COP 0.93)
<b>Electric Water Heating</b>		
– Ascendent Technologies	Solar and heat pump water heaters with 2011 costs	High efficiency (2.5 COP \$176) solar water heater; heat pump water heater (2.3 COP \$210)
– Declining Technologies	Solar water heaters with 2010 costs and standard electric water heater	Standard electric water heater
<b>Natural Gas Water Heating</b>		
– Ascendent Technologies	High efficiency gas water heater with 2007 costs and efficiencies (COP 0.93)	High efficiency gas water heater with 2020 costs and efficiencies (COP 0.95)
– Declining Technologies	Standard gas water heater (COP 0.75-0.78)	High efficiency gas water heater with 2007 costs and efficiencies (COP 0.93)
<b>Lighting</b>		
– Ascendent Technologies	F32T8 Super Fluorescents; LED 2011-2019 Typical for high tech	F32T8 Super Fluorescents; LED 2020-2029 Typical
– Declining Technologies	F32T8 HE – standard, LED 2011-2019 Typical	26W Compact Fluorescent Lamps; F32T8 HE – standard; 70W HIR PAR-38

The effects of carbon taxes on commercial building energy efficiencies would be geographically broad, based on estimates of their impacts across the nine U.S. Census divisions (Figure ES.2). In 2020, energy savings range from 0.3% in the Pacific division to 12.4% in the Mountain division and 12.5% in the West South Central division, corresponding with the carbon intensity of these regions. In 2035, energy savings range from -1.0% in the Pacific division to 20.2% in the Mountain division. As a general rule, the percentage energy savings is lower than the percentage reduction in CO<sub>2</sub> emissions, consistent with the shift to low-carbon energy resources that would be precipitated by a carbon tax. The degree of this change varies over time and by region, but the direction is consistent, and the gap between energy savings and CO<sub>2</sub> grows over time.

The projections show that regions of the country generally develop the ability to rely on less carbon-intensive forms of electricity. However, the interactions between all the Census divisions are not always straightforward. For example, in 2020, the division with the highest percent increase in electricity rates (West North Central) is not the region with the highest carbon reductions (West South Central), and neither of those regions has the highest energy savings – which are experienced by the Mountain division. In 2035, the highest carbon reductions are anticipated to occur in the Mountain division, which is second only to the West North Central division in the carbon intensity of its power sector and commercial buildings. The West North Central division, in turn, experiences the highest electricity rate increase and the highest energy savings. (consistent with microeconomic principles). Altogether, the central divisions experience greater impacts from a carbon tax than the coastal divisions. Clearly the geographic consequences of imposing a carbon tax are complex and uneven.



**Figure ES.2. Commercial Energy Consumption, Carbon Emissions and Electricity Rates by Census Division in 2020**

The effects of carbon taxes on the energy efficiency of commercial buildings could be technologically transformational and geographically widespread. While energy expenditures would rise and more capital would be required for energy-efficiency upgrades, the avoided pollution and the reduced CO<sub>2</sub> emissions would generate significant human health, ecosystem, and other benefits. The Main Tax + High Tech scenario would shift commercial buildings toward greater energy efficiency, but they would likely not deliver the magnitude of energy savings envisioned by the Better Buildings Initiative. In addition, the impacts are estimated to fall short of meeting the Waxman-Markey and Copenhagen carbon reduction goals. Some combination of higher taxes, better technologies, and complementary policy measures would be needed to address ongoing financial, regulatory, and information barriers to energy-efficiency investments in commercial buildings, if these aspirations are to be realized.

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## 1. Introduction

Reducing the threat of climate change will require providing the right incentives for behaviors and investments that drive a transition to a carbon-lean economy. One of the most effective actions countries could take to respond to climate change would be to provide a price for greenhouse gas (GHG) emissions that charges emitters for the damages caused by their actions. Carbon pricing is an important mechanism for providing companies and individuals with an incentive to invest in carbon abatement. Currently, GHGs can be emitted into the atmosphere for free in most countries, but the impacts of these emissions impose real costs on society. A carbon tax for internalizing externalities from energy consumption could help address barriers connected to unpriced costs and benefits related to carbon emissions. The National Research Council in their America's Climate Choice report states that in fact, the best way to amplify and accelerate emission reductions and minimize the overall cost is to implement a comprehensive, nationally uniform and increasing price on CO<sub>2</sub> emissions (NRC, 2011, p. 3). Such an approach would increase the competitiveness of energy-efficient technologies and low-carbon fuels and power. Also, it would place greater value on carbon capture and sequestration projects and technologies for reducing non-CO<sub>2</sub> GHGs. In addition, implementation of such mechanisms would help to address the policy uncertainty that has become an important barrier to the domestic deployment of low-carbon technologies.

This policy white paper examines the impacts of instituting an economy-wide carbon tax, focusing especially on the changes such a tax would have on U.S. commercial buildings. "Making our buildings more energy efficient is one of the fastest, easiest, and cheapest ways to save money, combat pollution and create jobs..." (President Obama, The White House, 2011).<sup>5</sup> With the Better Buildings Initiative, the President has established a goal of reducing commercial building energy use 20% by 2020 relative to EIA's reference case forecast. Commercial buildings are projected to consume 20.2 quads of energy in 2020, so the goal is to reduce that consumption to 16.2 quads by the end of this decade (that is, a reduction of 4.0 quads). In combination with the sustainability goals of federal agencies required by Executive Order 13514 (*Federal Leadership in Environmental, Energy, and Economic Performance*), the State Energy Efficiency Action Plan/Blueprint, the Recovery by Retrofit Program, and the Quaternary Technology Review, opportunities for energy efficiency in commercial buildings are drawing increased attention. How would a carbon tax motivate improvements in the energy efficiency of commercial buildings, and what would the various costs and benefits of such investments be?

Numerous federal, state, and local policies and programs seek to encourage more efficient energy usage in commercial buildings (NAS, 2010). These include building and appliance labeling, audits, and workforce training to address information gaps; financial subsidies and loan guarantees to address financial barriers; and building codes and appliance standards to tackle principal/agent problems. Strengthening these policies and measures and implementing new policies may be required to effectively address the market and policy failures that continue to

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<sup>5</sup> [www.whitehouse.gov/blog/2011/12/02/president-obama-announces-4-billion-investment-make-buildings-more-energy-efficient](http://www.whitehouse.gov/blog/2011/12/02/president-obama-announces-4-billion-investment-make-buildings-more-energy-efficient)

inhibit energy-efficiency improvements in the commercial buildings sector. This paper focuses on the option of establishing a carbon tax aimed at internalizing the costs of climate change damages. Subsequent policy white papers will examine the ability of other policy initiatives, alone and in conjunction with carbon taxes, to achieve the Administration's goals for Better Buildings.

## **2. Background on Carbon Taxes**

In 2007, the Supreme Court ruled (in *Massachusetts v. EPA*) that the U.S. Environmental Protection Agency (EPA) has the authority to regulate heat-trapping gases. Indeed, the Supreme Court stated that the EPA cannot sidestep its authority to regulate GHGs unless it can provide a scientific basis for its refusal. Following this ruling, EPA deemed GHG emissions to be threats to public health and welfare under the Clean Air Act. In December 2010, the EPA announced a schedule for setting GHG standards for power plants and oil refineries over the next two years. That means the agency can require emitters to reduce their GHG emissions, rather than pricing carbon. In June 2012, a three-judge panel of the U.S. Court of Appeals for the District of Columbia declared that EPA was "unambiguously correct" that the Clean Air Act requires the federal government to impose limits on emissions once it has determined that emissions are causing harm.

By relying on a federal mandate instead of a market response to price signals, this approach may not put the U.S. on the most cost-effective path to sustainable energy production. Also, such a rule does not raise revenues; therefore, the government cannot easily compensate consumers for the disparate costs imposed by the regulations, such as those imposed on low-income households. In addition, new administrations might move to weaken the mandates, leading to the type of regulatory uncertainty that frustrates business today. As a result, it is appropriate to evaluate the pros and cons of implementing a carbon tax.

### **2.1 Appropriateness of the Federal Role**

"As a general matter, government remedies are most suited to overcoming genuine market failures or government failures." (CCCSTI, 2009, p. 5). Externalities exist when the action of an individual or a firm affects the production or consumption of another party that did not agree to the action. An example of an externality is the inability of the developer of a technology to capture the full benefits of that technology when competitors can reverse engineer the system, limiting the payback to R&D investments by the private sector and justifying public intervention. Another example involves the free emission of pollutants that impose a cost on society, as is the case with GHG emissions in a world where such emissions are not priced to mitigate that cost. Indeed, according to the Stern Review, "Climate change is the greatest and widest-ranging market failure ever seen." (Stern, 2007)

### **2.2 Market Barriers and Failures Addressed**

A national carbon tax would address two of the most important barriers to the adoption and use of low-carbon technologies: their high up-front or "first" costs relative to competing technologies and their lack of marketplace compensation for mitigating climate change damages. High up-

front costs represent a barrier when a combination of the capital cost of the technology, its cost of operations, or other aspects of a project that employs the technology yields a product that costs too much relative to other technologies or products that perform essentially the same purpose. A national carbon tax would make low-carbon technologies more cost-competitive by more aggressively taxing the high-carbon alternatives. External costs occur when the full cost of using a good or capital is not included in its price. Low-carbon technologies generate fewer external costs, but this is not reflected in the marketplace. In addition, fiscal and regulatory uncertainties and infrastructure limitations can also add to their expense, as when critical infrastructure such as transmission lines and smart grid metering is inadequate or supply channels for the purchase and maintenance of advanced lighting, solar water heaters, and high-efficiency heat pumps are insufficient (Brown et al., 2007).

### **2.3 Carbon Tax versus Cap and Trade**

The pricing instruments most commonly considered, carbon taxes and cap-and-trade programs, both create incentives that are compatible with cost-effective reduction of GHG emissions (NAS, 2010). A carbon pricing system provides economic incentives to limit emissions, while a cap and trade policy puts a limit on the quantity of emissions allowed (Nordhaus, 2007). Thus, the choice of policy instruments centers on uncertainty over prices and quantities (Weitzman, 1974). If regulators are more certain about the economically efficient quantity of pollutant emissions required to account for social damages, a cap-and-trade program may be favored, with the market establishing the price of a permit (Keohane, 2009). Alternatively, if regulators know the economically efficient tax needed to account for social damages, or are willing to experiment to find the efficient level, pollution taxes may be favored (Tietenberg, 2006).

For maximizing GHG emission reductions at minimum cost, broad coverage is best. The Kyoto Protocol identifies six GHGs, which can be included in a single pricing system by translating them into CO<sub>2</sub> equivalents. In practice, this is accomplished using estimates of Global Warming Potential (GWP), defined as the cumulative radiative forcing effects of a unit mass of gas relative to CO<sub>2</sub> over a specified time horizon (commonly 100 years). Including multiple gases under a single cap has the advantage of significantly reducing the cost of reaching a specific concentration target (Reilly et al., 1999; Weyant et al., 2006).

Worldwide, none of the existing programs involve universal coverage of all GHG sources. The Regional Greenhouse Gas Initiative (RGGI) in the Northeast United States covers only large power generators. The European Union Emissions Trading Scheme (EU ETS) covers only power generators and combustion installations, production and processing of ferrous metals, pulp and paper, and some mineral industries such as cement; in addition, aviation will be covered starting in 2012.

Tax systems and auctioned cap-and-trade systems both force users to pay for their GHG emissions (NAS, 2010). The implicit logic behind this approach is that the atmosphere belongs to all the people and the wealth created by allocating scarce access rights should be returned to the people or used for public purposes. This is the approach taken by the RGGI program, in which all participating states are auctioning at least the majority of allowances. The alternative is

to gift some or all of the allowances to parties based upon some eligibility criteria (e.g., allocations to firms with best practices in an industry, actual historic emissions, or even allocations targeted directly to households).

An extensive academic literature suggests that macroeconomic efficiency favors a carbon tax with socially productive revenue recycling over other forms of regulation (CBO, 2005). However, carbon taxes have many opponents in the U.S., with some of this resistance deeply rooted in a strong distaste for taxation, in general. At the same time, cap-and-trade programs focusing on carbon and other GHGs have taken hold in several regional programs and have been incorporated into draft federal legislation, including the American Clean Energy and Security Act of 2009 (the “ACES Act”). Because emissions trading uses markets to determine how to deal with the problem of pollution, cap-and-trade is often touted as an example of effective free-market environmentalism (Ellerman et al., 2003). Since individual companies are free to choose whether and how they will reduce their emissions, least-cost compliance pathways are generally chosen (NAS, 2010). While each approach has its advocates, it can be persuasively argued that the choice of a policy instrument is less important than having an effectively designed instrument (Aldy et al., 2009).

#### 2.4 Political Feasibility and Historical Experience

It is unlikely over the near-term that a strong majority in Congress will accept the political risks associated with implementing a carbon tax (Nisbet, 2009). A committee of the American Academy of Arts and Sciences (2011) concluded that renewable portfolio standards and cap-and-trade programs have higher political feasibility than a carbon tax, based on the experience of states to date. While more than a dozen U.S. states are involved in a carbon tax-and-trade program, none have adopted a carbon tax. The same committee rated a carbon tax as less economically desirable than cap-and-trade, while the table below reflects the bulk of recent assessments that portray cap-and-trade and carbon tax policies as being similarly efficient for managing GHG emissions, if properly designed (Aldy and Stavins, 2011) (Table 1).

**Table 1. Administrative Feasibility: Three Carbon Reduction Policies**

	Economic Desirability*			
		High	Medium	Low
Political Feasibility	High			Renewable portfolio standards (29)
	Medium	Cap and trade (13-23)		
	Low	Carbon tax (0)		

\*Numbers in parentheses indicate the number of states that have adopted each regulatory approach.

On global issues such as climate change, state governments, sometimes driven by anticipated federal actions, are often the first to develop policies. Renewable portfolio standards (RPS) are an inefficient means of regulating carbon emissions, but they have gained the greatest acceptance among state legislatures. Twenty-nine states have instituted RPSs and many of

these include surcharges on electricity bills that fund renewable energy programs. State policy makers tend to frame these policies not in terms of energy or climate goals but as economic development initiatives that contribute to broadly popular goals such as job growth.

The U.S. has considerable experience with cap-and-trade programs extending back to the mid-1970s and including the highly successful sulfur allowance program (Ellerman et al., 2000; Tietenberg, 2006). In addition, 23 U.S. states are participating in the design or implementation of a regional carbon cap and trade program. The first such initiative is RGGI, which was established in 2009 and covers CO<sub>2</sub> emissions from large power plants in ten U.S. states. The Western Climate Initiative (WCI) is to be scoped to cover 90% of the region's stationary emissions and to involve seven U.S. states, four Canadian provinces, and numerous observers including six Mexican states. In the interim, California has implemented its own cap-and-trade program in compliance with AB 32. The Midwestern Greenhouse Gas Reduction Accord has a similar scope to the WCI and covers six U.S. states as well as a Canadian province and several observers; however, its participants have yet to propose the program for adoption (Litz et al., 2011, pp. 14-17).

While the U.S. does have a well-honed infrastructure and vast experience with levying taxes in general, it does not have similar depth of experience with using taxation to control pollution. (Environmental regulations have led to significant reductions of chlorofluorocarbons and other ozone depleting substances, leaded gasoline, ground-level ozone, and sulfur dioxide). While carbon taxes have been debated, the U.S. has never levied a nation-wide carbon tax and no state has yet instituted a blanket carbon tax. However, there has been some experience at the local level.

- In 2008, the Bay Area Air Quality Management District (BAAQMD) – which includes nine counties in the San Francisco bay area – established a carbon fee covering approximately 780 facilities. The fee raises revenues for BAAQMD climate protection activities (Sumner, Bird, and Dobos, 2011).
- Babylon, New York, rewrote its municipal solid waste code to declare carbon a 'solid waste' and start to collect fees for carbon emissions. The tax revenues were used to finance a program of home energy retrofits, staffed by local unemployed youth.
- In 2006, Boulder, Colorado, adopted a municipal 'carbon tax' that is imposed on electricity consumption and paid through utility bills, with deductions for using electricity from renewable sources. The tax revenues are used to fund community-wide GHG emission reduction programs.

There is also a growing body of international experience. In the early 1990's, five Northern European countries (Finland, the Netherlands, Norway, Sweden, and Denmark) established carbon taxes, and in 2001, the U.K. followed suit with the implementation of its Climate Change Levy (CCL). The CCL applies to all non-domestic energy consumption (that is, the industrial, commercial, agricultural, public, and service sectors). The tax raised approximately \$1.17 billion in revenues in 2007/8 and 2008/9, which were used to offset a cut in National Insurance

Contributions (Sumner, Bird, and Dobos, 2011). Thus, the policy was policy revenue neutral (Newey, 2011). In addition:

- In July 2008, British Columbia, Canada, started the only large-scale carbon tax in North America. It began by requiring purchasers and users of fossil fuels to pay \$20 per metric ton of CO<sub>2</sub>-equivalent. In July 2012, the tax was increased to \$30 per metric ton, and the additional tax revenues were used to reduce taxes for individuals and businesses, achieving the lowest corporate income tax rate among the G-8 nations.<sup>6</sup>
- Australia passed national carbon tax legislation in November 2011. It came into effect in July 2012 when the country's 294 biggest polluters faced a carbon price of \$23.00 per metric ton of CO<sub>2</sub>-equivalent. The tax will increase by 2.5% a year in real terms for the following three years before being turned into an emissions trading system in 2015 (Meltzer, 2012). The mechanism covers approximately 60 per cent of Australia's carbon emissions, including emissions from electricity generation, stationary energy, landfills, wastewater, and heavy industry.<sup>7</sup>

U.S. stakeholders who might support a national carbon tax include: environmental groups; designers, builders, and manufacturers of energy-efficient buildings and technologies; and other green energy industries including energy-service companies and renewable energy companies, outdoor-focused businesses, and insurance companies. Some federal policymakers might view the policy favorably because it offers a way to buy down the public debt. Stakeholders who might oppose a carbon tax include: electric utilities (especially those reliant principally on fossil fuels), natural gas utilities, oil companies, and other carbon-intensive industries, as well as labor groups who may be concerned about job losses. Opposition will come from groups that do not believe in anthropogenic climate change, and from regions that would experience the highest carbon taxes. Opposition will depend upon the timing, coverage, and size of the tax. To be successful, the temporal mismatch between immediate costs versus long-term benefits requires buy-in from a broad community of constituents, as to why pricing carbon is important.

## **2.5 Complementary Policies**

Putting a price on carbon is an efficient policy because it addresses the principal market failure that has prevented individuals and firms from responding effectively to the damages precipitated by GHG emissions. Evidence suggests, however, that pricing alone will not be sufficient to achieve the necessary emission reductions (Fischer and Newell, 2008; Goulder and Parry, 2008). Even a well-designed pricing strategy will have limitations that restrict the timing and scope of its effectiveness. For example, high taxes on gasoline do not stop Europeans from commuting to work in single-occupancy cars, and adjusted for population growth, vehicle miles travelled (VMT) in Europe has been increasing. The price effect is simply overwhelmed by the income effect – people are wealthy enough to absorb the increased prices. Thus, carefully tailored complementary policies will be needed to address shortcomings in a pricing system,

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<sup>6</sup> [http://www.nytimes.com/2012/07/05/opinion/a-carbon-tax-sensible-for-all.html?\\_r=2](http://www.nytimes.com/2012/07/05/opinion/a-carbon-tax-sensible-for-all.html?_r=2)

<sup>7</sup> <http://www.cleanenergyregulator.gov.au/Carbon-Pricing-Mechanism/About-the-Mechanism/What-emission-types-are-in-and-out/Pages/default.aspx>

and to ensure the speed, scope, and scale of response required to “avoid dangerous anthropogenic interference in the Earth’s climate” as called for in the UN Framework Convention on Climate Change.

The first argument for complementary policies is based on the insufficiency of current cap-and-trade programs. Policy makers do not appear to be willing to act quickly to cut emissions deeply. There are many factors in this reluctance, including skepticism about the reality of the climate threat, anticipated costs to emitters, possible impacts on competitiveness, challenges to enforcers including measurement difficulties, and concerns about risks of gaming and cheating. Emissions-pricing policies can also have deleterious distributional effects that complementary policies can ameliorate.

Another persuasive line of argument suggests that the tendency for the obstacles facing GHG-reducing technologies to be technical as well as political and economic means that policy instruments should be similarly multidimensional. The impediments to more sustainable forms of energy supply and use are often social and cultural. Until these remaining barriers are targeted in the same way that engineers and scientists tackle technical impediments, the promise of new climate-proof systems will remain unfulfilled. Consumer attitudes, values, beliefs, and expectations are just as important as improved tires, better fuel economy, longer-lasting batteries, and tougher and lighter wind turbines in explaining why people embrace some forms of technology but not others.

## **2.6 Price, Cost, and Policy Stability**

One desirable aspect of any GHG pricing strategy is a stable policy platform designed to reduce regulatory uncertainty associated with energy investments. In principle both a tax and a cap-and-trade mechanism would provide policy stability, but the form differs (Fell and Morgenstern, 2009). While a carbon tax fixes the price of CO<sub>2</sub> emissions and allows the quantity of emissions to adjust, a cap-and-trade system fixes the quantity of aggregate emissions and allows the allowance price to adjust. Thus, a cap-and-trade policy provides more certainty that the GHG reduction goal would be met, but it provides less certainty about the costs. Conversely, a tax policy provides more inherent certainty about cost, but less certainty about the resulting emissions levels.

## **2.7 Using Funds from Taxes or Auctions**

The distribution of revenue from auctioned allowances or carbon taxes can, in principle, enhance policy efficiency or help reduce the regressive financial burden of emissions reduction efforts (Grainger and Kolstad, 2010; Burtraw et al., 2008; Chamberlain, 2009; Shammin and Bullard, 2009). A carbon price is consistently regressive, because lower income households use a larger proportion of their earnings to purchase energy intensive products (gasoline and electricity being the most important). The extent of regressivity depends on whether initial allowances are given away, and how tax revenues are spent. Grainger and Kolstad (2010) add that if the effects of carbon trading are estimated on a per capita basis, the regressive effects are even more relevant. Those benefits, however, depend upon what is done with the revenue. Evidence presented by the Congressional Budget Office suggests that rebating the funds back

to households (on a per capita lump-sum basis) converts the regressive policy associated with gifting allowances to firms into a progressive policy. That evidence also suggests that a rebate to households is more progressive than reducing the payroll tax and much more progressive than reducing the corporate income tax (Dinan, 2009; CBO, 2000). CBO analysis of the American Clean Energy and Security Act of 2009 also showed a semi-progressive tax structure as a result of direct and indirect spending, with the lowest income quintile receiving an average net benefit of \$40 in 2020 (CBO, 2009). In a tax system, concerns about equity and appeasing certain constituencies are handled by tax exemptions, which generally undermine economic efficiency because exempted emissions are uncontrolled.

Focusing exclusively on distributional goals and returning all revenue to households requires a trade-off with the efficiency gains from reducing distortionary taxes (Dinan and Rogers, 2002). Some recent work, however, suggests it is possible to do both, while still protecting vulnerable industries. Goulder and Parry (2008) suggest, for example, that vulnerable industries could be protected by gifting 15% or less of the allowances and auctioning the rest to raise revenue for pursuing the distributional and efficiency goals. Competition from other uses of tax or allowance revenues is inevitable. To name a few:

- Energy-intensive, trade-vulnerable firms may seek financial rebates as protection against competition from foreign firms that are not subject to control of GHG emissions.
- States running their own cap-and-trade programs will seek to replace funds lost if a federal preemption results in the demise of these programs (and in the funding dedicated to promoting energy efficiency and renewable resources that states have raised from auctions).
- Negotiators seeking to bring developing countries into a binding international agreement will be looking for funds to facilitate the transition.
- Universities and Federal departments charged with promoting new technologies or strategies will be looking for funds for R&D, for start-up incentives, and for demonstration projects.
- Funds from GHG control are tempting to use as incentives as Congress tries to build coalitions of legislators to assure the passage of climate change legislation.
- Other public issues such as health care may seek sources of funding, based on the rationale that climate change does affect health (NAS, 2010).

In comparison to the residential and industrial sectors, little attention has been directed towards the impacts that carbon prices might have on the future of commercial buildings. Firms with a limited ability to pursue financing such as small and start-up enterprises may bear a disproportionate burden because they have trouble investing in low-carbon technologies. The ability of the commercial sector to become more energy efficient in response to a carbon tax could have widespread implications for the development and growth of the U.S. economy, especially if the transition to a service economy continues to expand.

### 3. Methodology for Modeling the Impacts of a Carbon Tax

The Georgia Institute of Technology's version of the National Energy Modeling System (NEMS) is the principal modeling tool used in this study to examine the likely impacts of carbon taxes on the energy efficiency of commercial buildings, supplemented by spreadsheet calculations. Since the model is run on Georgia Tech computers, we call it the "GT-NEMS".<sup>8</sup> Specifically, we derive GT-NEMS from the version of NEMS that generated EIA's *Annual Energy Outlook 2011* (EIA, 2011), which projects energy supply and demand for the nation out to 2035. The GT-NEMS "bottom-up" engineering economic modeling approach is well suited to a carbon tax analysis focused on understanding the likely response of the commercial buildings sector. By characterizing nearly 350 distinct commercial building technologies, and by enabling the separate analysis of nine Census division, ten end-uses (e.g., lighting and air conditioning), and eleven building types, GT-NEMS offers the potential for a rich examination of policy impacts. Its "bottom-up" technology configuration enables an assessment of technology investments, energy prices, energy consumption and expenditures, carbon abatement, and pollution prevention over time and across regions of the U.S. Many studies evaluate the impact of carbon taxes by using Computable General Equilibrium (CGE) modeling (Energy Modeling Forum, 2011; Weyant, et al., 2006). None of these have as detailed a technology inventory as GT-NEMS.

NEMS models U.S. energy markets and is the principal modeling tool used to project future U.S. energy supply and demand. Twelve modules represent supply (oil and gas, coal, and renewable fuels), demand (residential, commercial, industrial, and transportation sectors), energy conversion (electricity and petroleum markets), and macroeconomic and international energy market factors. A thirteenth "integrating" optimization module ensures that a general market equilibrium is achieved among the other modules. Beginning with current resource supply and price data and making assumptions about future consumption patterns and technological development, NEMS carries through the market interactions represented by the thirteen modules and solves for the price and quantity of each energy type that balances supply and demand in each sector and region represented (EIA, 2009). Outputs are intended as forecasts of general trends rather than precise statements of what will happen in the future. As such, NEMS is well suited to projecting how alternative assumptions about resource availability, consumer demand, and policy implementation may impact energy markets over time.

In the commercial demand module, NEMS employs a least-cost function within a set of rules governing the set of options from which consumers may choose technologies. Capital costs are amortized using "hurdle rates." There are six commercial sector sub-modules (Cullenward, et al. 2009).

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<sup>8</sup> This nomenclature recognizes that even when the same NEMS code is used on two hardware systems with the supporting software programs – e.g., FORTRAN and the IHS Global Insights macroeconomic optimization tool – the results could be distinct from those of the EIA. In addition, the authors modify the NEMS code in order to reflect the impact of a carbon tax.

- The **Commercial Floor Space Sub-module** provides forecasts of floor space by Census Division and building types based on population, economic effects, and historic growth patterns.
- The **Service Demand Sub-module** estimates service demand (SD) based on service demand intensity (SDI) and floors space projection for each major service, building type, and region.
- The **Distributed Generation and Combined Heat and Power Sub-module** estimates the fuel consumption and energy production of eleven types of distributed generation (DG), using information from the Form EIA-860 Database.
- The **Technology Choice Sub-module** determines the equipment chosen to meet service demand. Commercial consumers purchase equipment to meet three classes of demand: new, which represents the demand in newly-constructed buildings; replacement, which represents the demand formerly met by retiring equipment; retrofit, which represents the demand met by equipment at the end of their economic life. The choice of a technology in NEMS is partly determined by the discount rates employed by consumers. Discount rates are calculated for end uses by year for different subsets of the population by summing the yield on U.S. government ten-year notes (endogenously determined) and the time preference premium of consumers (exogenous inputs to the model). Then the sub-module divides service demand using three behavior rules: least cost, where consumer decisions are determined by the lowest annual cost of the equipment; same fuel, where consumer decisions are determined by the lowest annual cost of equipment using the same fuel currently employed by the consumer; and same technology, where consumer decisions are determined by the lowest annual cost of equipment using the same technology class currently employed by the consumer. In combination, the demand class, discount rate, and behavior rule determine the technology selected to meet a given service demand.
- The **End-Use Consumption Sub-module** determines the amount of fuel used to provide energy services. The energy consumed for each end use and fuel type is primarily decided by service demand and the efficiency of the chosen technology. Weather, price elasticity (ranging from 0 to 0.25 with mean of 0.17), building shell efficiency and distributed generation all impact the final end use fuel consumption.
- The **Benchmarking Sub-module** compares projected consumption with historical data and data collected from EIA sources, and adjusts the final energy consumption estimates so that the totals reconcile.

The GT-NEMS “Reference case” projection described in this study uses the same computer code as is used in creating the published Reference case used by EIA. It is based on federal, state, and local laws and regulations in effect at the time of the analysis. For the carbon tax scenarios, GT-NEMS incorporates changes specific to this study, including a range of carbon taxes as described below, and a range of alternative assumptions about the efficiency and cost of end-use energy technologies (described below). We do not change the discount rates,

technology choice equations or other features of the commercial buildings module, but rather use the standard features of NEMS to attempt to model the most likely energy-efficiency response of investors and consumers who want other attributes besides energy efficiency and who confront market failures and barriers that would not exist under ideal conditions.

### **3.1 Alternative Commercial Technology Assumptions**

In the Reference case, minimal change occurs in overall commercial energy use per capita between 2009 and 2035. Commercial floorspace grows by 1.2% annually, which is faster than the forecast population growth rate (0.9% annually), but because of efficiency improvements in equipment and building shells, energy use per capita remains fairly steady. According to EIA (2011, p. 66), “Efficiency standards and the addition of more efficient technologies account for a large share of the improvement in the efficiency of end-use services, notably in space cooling, refrigeration, and lighting.”

EIA (2011) offers two technology “side cases” that are characterized by more advanced equipment. In the High Technology (“High Tech”) case, there are two major differences from the Reference case: technologically, lower costs, higher efficiencies, and earlier availability for equipment and building shells are assumed; behaviorally, commercial consumers place greater importance on the value of future energy savings. In the Best Available Technology (“Best Tech”) case, future equipment choices are limited to the most efficient model for each technology available in the year of replacement and the efficiency of building shells improve more rapidly for new and existing buildings than in the High Tech case. As a result, commercial energy consumption per capita in 2035 is 12.5% lower in the High Tech case and 17.9% lower in the Best Tech case than in the Reference case (EIA, 2011, p. 66). We examine the impact of a carbon tax when using only the technology assumptions embodied in the Reference, High Tech and Best Tech cases, maintaining the Reference case behavioral assumptions. We conclude that the High Tech scenario provides the most fitting forecast. As stated by Jeff Harris (personal communication, November 29, 2011), if the government were to commit to placing a price on carbon, the market would interpret this as an opportunity to profit from the development of more energy-efficient products.

Much modeling and analysis to date has emphasized the importance of accelerated technology development in making the stabilization of GHGs in the atmosphere more feasible and affordable. This was one of the themes of a special issue of *Energy Economics* in 2011, and it was stressed in the National Academies’ 2011 report on *America’s Climate Choices* (NRC, 2011). The pace and extent of technology improvements spurred by creating a price on carbon is difficult to forecast, but lessons from pricing other environmental pollutants such as sulfur dioxide suggest that it could be significant (Burtraw, 2000; Porter and van der Linde, 1995).

### **3.2 Alternative Carbon Tax Schedules**

An economy-wide tax on CO<sub>2</sub> emissions is modeled, starting from \$25 per metric ton of CO<sub>2</sub> (in 2009-\$) in 2015 and increasing by 5% annually through 2035 when it reaches \$66 per metric ton. This carbon tax schedule is referred to as the “Main Tax” scenario. Several other tax schedules are considered, including:

- Low-tax Scenario: a tax of \$5 per metric ton CO<sub>2</sub>, starting in 2015 with a 5% annual increase, and reaching \$12 per ton in 2035.
- Social Cost of Carbon (SCC) 3% Discount Scenario: Based on the SCC estimates, with a 3% discount rate, starting at \$5 per metric ton in 2015 and increasing to \$25.5 per metric ton in 2035 (EPA, 2010).
- SCC High-tax Scenario: Based on the SCC estimates, with a 2.5% discount rate, starting in 2015 at \$39.7 per metric ton CO<sub>2</sub>, rising to \$56.1 in 2035.
- EIA GHG Scenario: the *AEO 2011* GHG Price Economy-wide Case (EIA, 2011). The CO<sub>2</sub> price starts at \$25 per metric ton in 2012 and increases to \$75 per metric ton in 2035.

**Table 2. Alternative Carbon Tax Schedules**  
(in 2009-\$ per metric ton of CO<sub>2</sub>)

In 2009-\$	Low	SCC (3% Discount Rate)	Main Tax	SCC (2.5% Discount Rate)	EIA GHG
2015	5.0	23.3	25.0	39.7	27.6
2020	7.8	25.8	31.9	43.2	35.5
2025	9.0	28.7	40.7	47.3	45.5
2030	10.5	32.1	52.0	51.7	58.4
2035	12.1	35.5	66.3	56.1	75.0

The Main Tax and EIA GHG carbon taxes grow at an exponential rate, not linearly as with the others. The SCC 2.5% discount case starts with the highest carbon tax in 2015. The EIA GHG tax begins in 2012, while the others all start in 2015. The low-tax scenario uses values similar to those discussed by Roger Pielke (2010) of the University of Colorado. (See Appendix A for further details on the derivation of these carbon price schedules.)

### 3.3 Advantages and Disadvantages of GT-NEMS

The detailed characterization of commercial building technologies, along with the separate treatment of new construction, replacement, and retrofit investments in nine Census divisions, ten end-uses, and eleven building types, makes GT-NEMS well suited to energy and climate policy analysis. It also incorporates macro-economic and financial factors as well as world energy markets.

GT-NEMS is limited by its lack of a holistic building design and operation perspective, its simplistic treatment of building shell improvements, and its overestimation of the discount rates used to evaluate commercial end-use investments. For analyzing the effects of a carbon tax on

the commercial building sector, the 25-year timeframe of GT-NEMS is limiting, as are the options for evaluating alternative carbon tax revenue recycling schemes – i.e., retaining tax revenues within the business sector, returning them to households, or some combination of the two. We assume that tax revenues are retained within the business sector.

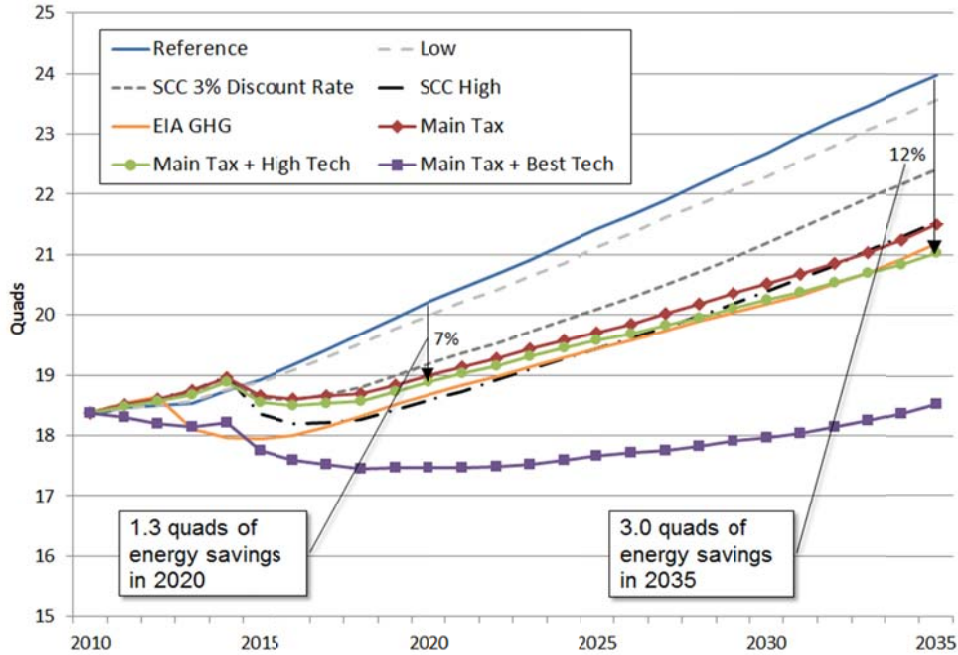
## **4. Results**

We begin this section by presenting the estimates of commercial building energy consumption under Main Tax scenarios. We then turn to a discussion of the impacts of a carbon tax on energy prices and the energy bills paid by commercial building owners and tenants. After describing the impacts on CO<sub>2</sub> emissions from commercial buildings, we discuss the GDP impacts. Attention then turns to changes in commercial energy end-uses and the technology shifts that underpin them. After estimating impacts on GDP and equipment expenditures, we estimate the value of the avoided damages from CO<sub>2</sub> and three criteria pollutants – sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), and particulate matter (PM) – that could result from the Main Tax + High Tech case. This section ends by comparing and contrasting the impacts of the Main Tax across ten building types and nine regions of the country.

### **4.1 Impacts on Commercial Energy Consumption**

The commercial building sector appears to respond quickly to a carbon tax. An initial (pre-2015) rise in energy consumption in the Main Tax + High Tech case relative to the Reference case results from the lower electricity rates resulting from higher coal use, in anticipation of higher energy prices (perhaps in response to the need to reduce coal stockpiles.) Deep reductions of fossil fuel consumption are estimated to occur immediately following implementation of a carbon tax, with reductions continuing until the end of the period (Figure 1).

Figure 1 illustrates the energy reductions that would be achieved by the five different carbon tax schedules itemized in Table 2 as applied to the GT-NEMS Reference case technology assumptions. It also includes the Main Tax schedule when applied to the Best and High Tech cases. The Main Tax alone is estimated to achieve a 10% reduction in commercial building energy consumption in 2035. When the same tax schedule is applied to the High Tech scenario, it would reduce energy consumption further: by 7% in 2020 and 12% in 2035. Table 3 shows the energy consumption reductions in the commercial sector from different energy sources under the Reference and Main Tax + High Tech scenarios.



**Figure 1. Commercial Energy Consumption (Quads): Carbon Tax Scenarios Versus Reference Case**

**Table 3. Carbon Tax’s Impact on Commercial Energy Consumption (Quads)**

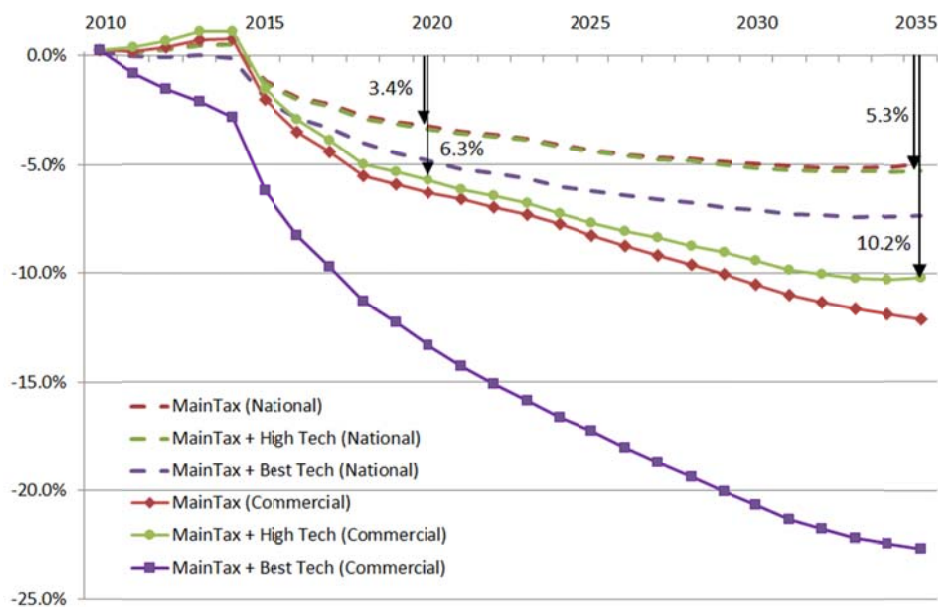
Commercial Sector Energy Use		Natural Gas	Electricity	Electricity Related Losses
	Reference	3.464	4.832	9.92
2015	Main Tax + High Tech	3.394	4.803	9.64
	% Change	-2.0%	-0.6%	-2.8%
	Reference	3.584	5.204	10.71
2020	Main Tax + High Tech	3.443	4.946	9.79
	% Change	-3.9%	-5.0%	-8.6%
	Reference	3.918	6.432	12.93
2035	Main Tax + High Tech	3.768	5.748	10.82
	% Change	-3.8%	-10.6%	-16.3%

By comparing energy intensity metrics, the impact of a carbon tax on different sectors of the economy can be compared. Primary energy use per square foot of commercial building space is the standard measure of commercial building energy intensity, while primary energy use per dollar of GDP is the standard for the economy, at large. Figure 2 suggests that a carbon tax would reduce the energy intensity of the commercial sector more than the energy intensity of the nation. In 2020, for example, energy use per square foot of commercial buildings declines by 6.3%, while energy use per dollar of GDP declines by only 3.4% relative to the Reference case. Changes in energy intensity in other sectors – also in 2020 and compared with the

Reference case – further illustrate the greater responsiveness of commercial buildings to a carbon tax policy:

- The residential sector's energy intensity (measured in thousand Btu/sq ft) would decline by 4.7%
- The energy intensity of the industrial sector (measured by energy use per dollar of shipment) would decrease by a modest 2.3%
- The transportation sector's energy efficiency (measured in miles/gallon for on-road new light-duty vehicle) would improve by only 0.5%.

This declining responsiveness of energy intensity across sectors of the economy reflects the impact of carbon pricing on the fuels that dominate each sector. Price elasticity also increases with the presence of alternatives. Transportation is currently dependent primarily on just one fuel, petroleum; other sectors such as commercial buildings have more options. From these comparisons, one could conclude that the Main Tax + High Tech scenario might be an effective strategy for improving the energy efficiency of commercial buildings, but a single economy-wide carbon tax could have quite uneven effects across the various sectors of the economy.



**Figure 2. Carbon Tax's Impacts on the Energy Intensity of the Commercial Buildings Sector and the Nation**

#### 4.2 Impacts on Energy Prices and Energy Expenditures

The energy price impacts of policies to promote GHG emission have been a focus of considerable debate and analysis. A major stimulus has been the series of proposals for climate policy legislation before the U.S. Congress in recent years, including the Low Carbon Economy Act of 2007 (Bingaman-Specter), the Climate Stewardship Act of 2008 (Lieberman-Warner), the Clean Energy Jobs and American Power Act of 2009, the American Clean Energy

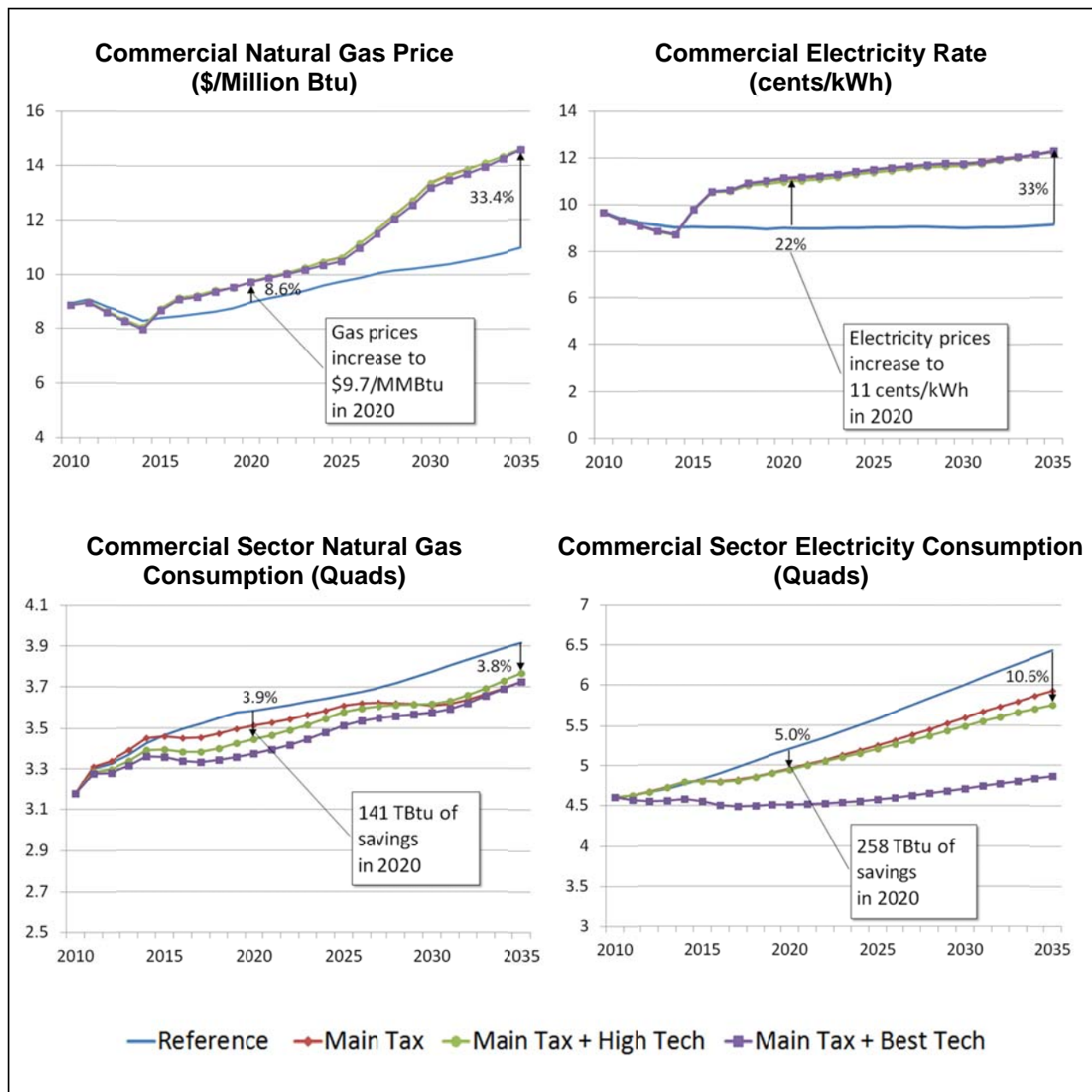
and Security Act of 2009 (Waxman-Markey), and the American Power Act of 2010, where impacts on electricity prices are a leading issue. In this analysis, we focus on the commercial buildings sector and examine the possible impact of carbon taxes on both electricity and natural gas prices, and energy expenditures.

In the Main Tax + High Tech case, natural gas prices in the commercial sector increase by 8.6% in 2020, rising to 33.4% in 2035 above the 20% rise that is forecast in the Reference case (Figure 3 and Table 4). Natural gas prices are estimated to increase \$8.8/MMBtu in 2015 to \$14.6/MMBtu in 2035. In combination with the improved suite of technologies, this price increase causes a 3.9% decline in demand for natural gas in 2020 and continuing through 2035 compared to the Reference case.

A similar escalation in electricity rates occurs, although more rapidly, increasing by 21.7% in 2020 and 32.8% in 2035, relative to the Reference case. On top of a fairly flat Reference case price forecast, the Main Tax + High Tech case causes electricity rates to increase from 9.2 ¢/kWh in 2015 to 12.3 ¢/kWh in 2035. These increases (along with the improved technologies) precipitate a much greater drop in demand (a 5.0% decrease in 2020 in commercial sector electricity consumption relative to the Reference case, expanding to a 10.6% reduction in 2035). In both cases, energy consumption continues to rise, it just increases at a slower pace than in the Reference case.

The values shown in Figure 3 and Table 4 enable the calculation of implicit single-fuel and cross-fuel price elasticities of demand. All of the price elasticities shown in Table 4 are between 0 and -1, suggesting that the demand for both electricity and natural gas is price inelastic. Price elasticities of demand are generally lower in the Main Tax case compared with the Main Tax + High Tech case when consumers have more cost-competitive demand-side technologies available to them. The exception to this trend is for natural gas in 2035, where price elasticities of demand are higher in the Main Tax case compared with the Main Tax + High Tech case.

The long-term elasticity of demand for electricity increases over time in both scenarios. In 2020, it varies from -0.21 (in the Main Tax case) to -0.24 (in the Main Tax + High Tech case), while by 2035 it varies from -0.23 (in the Main Tax case) to -0.32 (in the Main Tax + High Tech case). These implicit values suggest an increasing ability and willingness of consumers to reduce their electricity consumption in response to higher electricity prices over time. The pattern is different for natural gas. The decreasing single-fuel natural gas price elasticity varies from -0.24 to -0.45 in 2020 and from -0.11 to -0.15 in 2035. This suggests a loss of ability of the commercial sector to reduce its natural gas consumption in response to higher natural gas prices over time. This lower price responsiveness over time may be influenced by opportunities to shift from electricity to natural gas space heating and to natural gas water heating (as well as solar water heating), as electricity prices rise.



**Figure 3. Commercial Sector Natural Gas and Electricity Rates and Consumption Main Tax Scenarios Versus Reference Case**

(Percentages are with respect to the AEO 2011 reference case in the same year)

**Table 4. Implicit Long-run Elasticity of Demand for Commercial Sector Energy**  
(Percentages are with respect to the *AEO 2011* Reference case in the same year)

	Main Tax Case		Main Tax + High Tech Case	
	2020	2035	2020	2035
Electricity rate	22.8%	33.4%	21.7%	32.8%
Natural gas price	8.5%	32.8%	8.6%	33.4%
Electricity consumption	-4.7%	-7.9%	-5.0%	-10.6%
Natural gas consumption	-2.0%	-5.0%	-3.9%	-3.8%
Single fuel price elasticity				
Electricity	-0.21	-0.24	-0.23	-0.32
Natural gas	-0.24	-0.15	-0.45	-0.11
Cross-fuel price elasticity				
Electricity	-0.55	-0.24	-0.58	-0.32
Natural gas	-0.09	-0.15	-0.18	-0.12

This possibility can be explored by examining the cross elasticities of demand (XED), which measures the percentage change in demand for fuel A that occurs in response to a percentage increase in price of fuel B. Because natural gas and electricity are largely substitutes (rather than complementary goods) their XEDs should be positive. However, the GT-NEMS results are derived from a scenario where both fuels become more expensive simultaneously, and the dominant response is to consume less of both. Thus, the XEDs are negative. In addition, the XEDs for electricity increase over time. That is, when the price of natural gas increases, the consumption of electricity decreases, but its responsiveness is lower in 2035 than in 2020. Specifically, the XED for electricity drops from -0.55 to -0.58 in 2020 and from -0.24 to -0.32 in 2035.

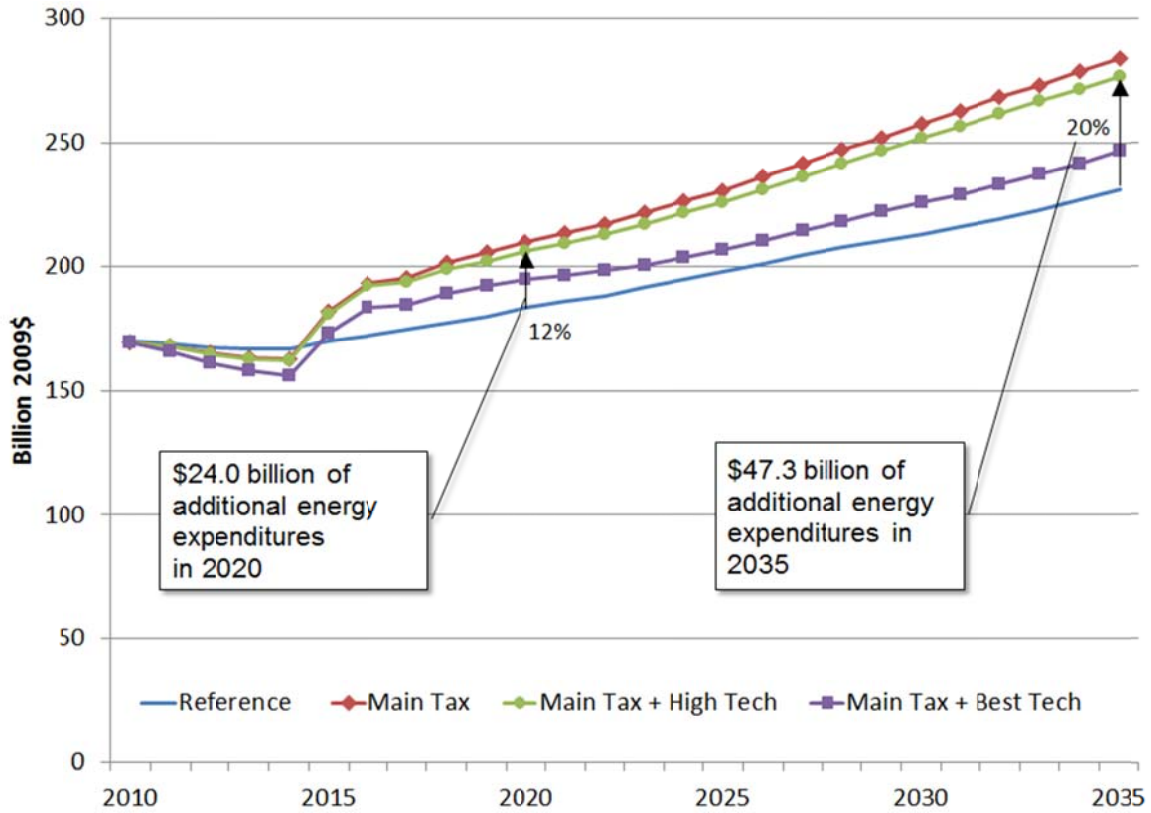
In contrast, the XED of natural gas demand is much lower than for electricity, ranging from -0.09 to -0.18 and it remains low in 2035, ranging from -0.12 to -0.15. Thus, a doubling of electricity prices would decrease natural gas consumption by only 9 to 18% in the 2020-2035 timeframe. These findings are consistent with the evidence we see of shifts from electricity to natural gas space and water heating technologies over time. Thus, while electricity has become the dominant fuel consumed by the commercial sector, rising electricity prices could dampen this trend.

As Newell and Pizer (2008) note, “The microeconomic literature on energy demand in the commercial sector is not very deep” (p. 528). As a result, it is difficult to draw comparisons with other studies. Newell and Pizer (2008) estimated much higher price elasticities of demand in the commercial sector, and the only three cross elasticities that they identified were also negative,

suggesting complementary relationships as we have also estimated. They note that the NEMS commercial demand module has implied own-price elasticities of -0.45 for electricity and -0.40 for natural gas, which are higher than our estimates.

Energy prices increase principally because of the carbon tax. Adding the “High Tech” and “Best Tech” assumptions about the availability of better technology options to the carbon tax does not change energy prices notably, but having better technology does increase energy savings (Figure 3). For example, the “Main Tax + Best Tech” case is estimated to reduce natural gas consumption by 1-2% more than the “Main Tax + High Tech” case. But the “Main Tax + Best Tech” case is estimated to reduce electricity consumption by 13% more than in the “Main Tax + High Tech” case in 2020 and by 24% in 2035. There is a greater fuel shift to natural gas with the “Main Tax + Best Tech” suite of technologies than with the less advanced “Main Tax + High Tech” suite. Thus, our modeling builds on previous literature suggesting that technological advancement offers an important means of reaching climate goals at lower cost.

The commercial sector energy expenditure in the Main Tax + High Tech scenario increases by 20% in 2035 relative to the reference scenario. Even though energy consumption in the same scenario decreases by 12% (Figure 4), the energy price escalation outweighs the consumption reduction, thereby leading to higher sector-wide energy expenditures. A similar situation occurs in the Main Tax scenario. However, the Main Tax scenario delivers less energy savings for a comparable energy price escalation because it does not have the advantage of better technologies.



**Figure 4. Commercial Sector Energy Expenditures (Billions 2009-\$):  
Main Tax Scenarios Versus Reference Case**

(Note: Percentages are the change between the Reference case and the Main Tax + High Tech case.)

**Table 5. Commercial Sector Energy Expenditures  
(Billions 2009-\$)**

Year	Increase in Energy Expenditures: Annual	Increase in Energy Expenditures: Cumulative*
2020	24.0	91
2035	47.3	417

\*Present values are calculated using a 3% discount rate.

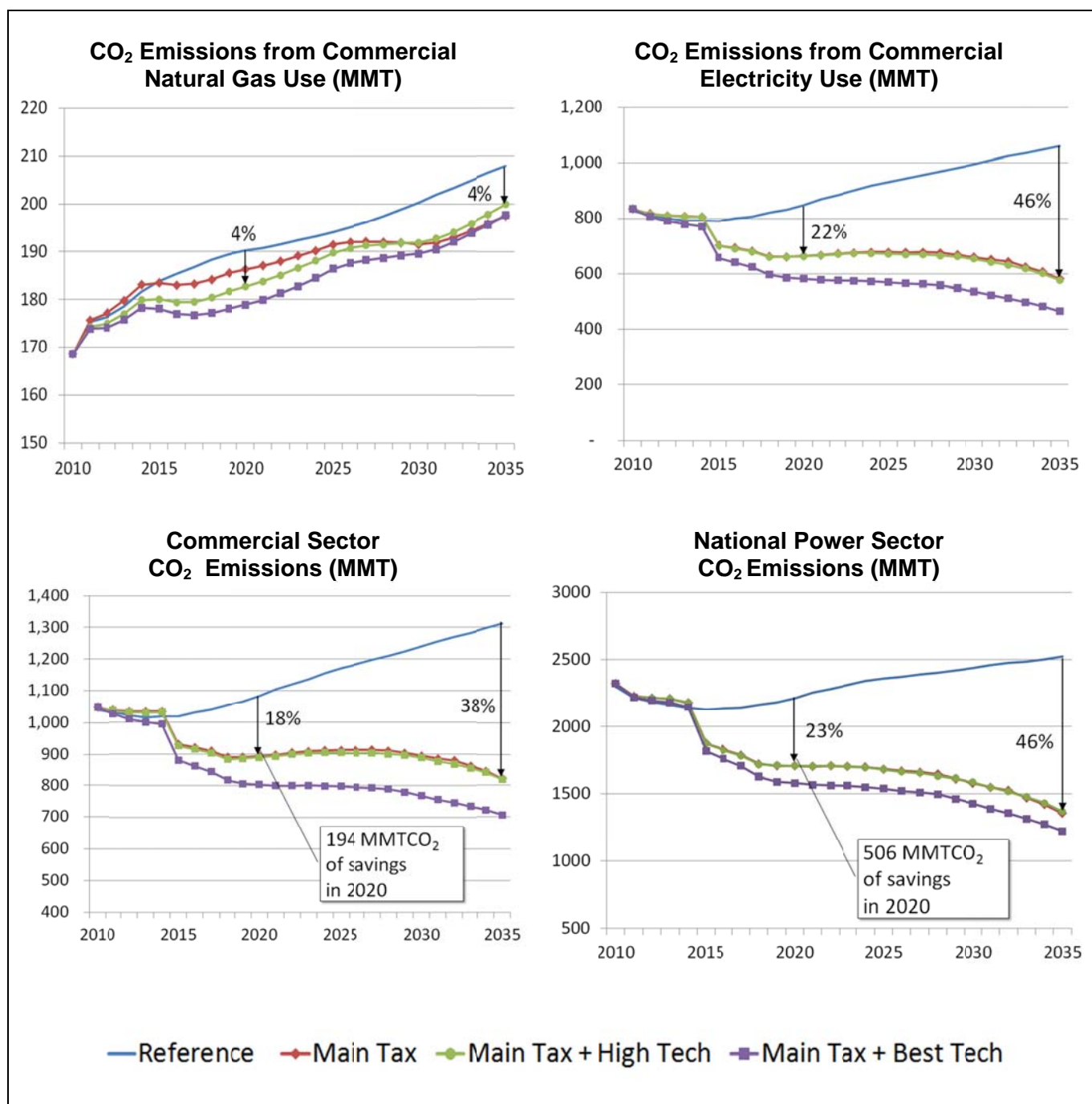
In sum, the energy bill savings from the strong investment in more efficient commercial buildings is offset by rising energy prices. The result is an increase in energy expenditures in the Main Tax + High Tech case, relative to the Reference case. We have also shown that the development and deployment of advanced commercial building technologies can cut the economic burden of reducing energy consumption.

### **4.3 Impacts on CO<sub>2</sub> Emissions from Commercial Buildings**

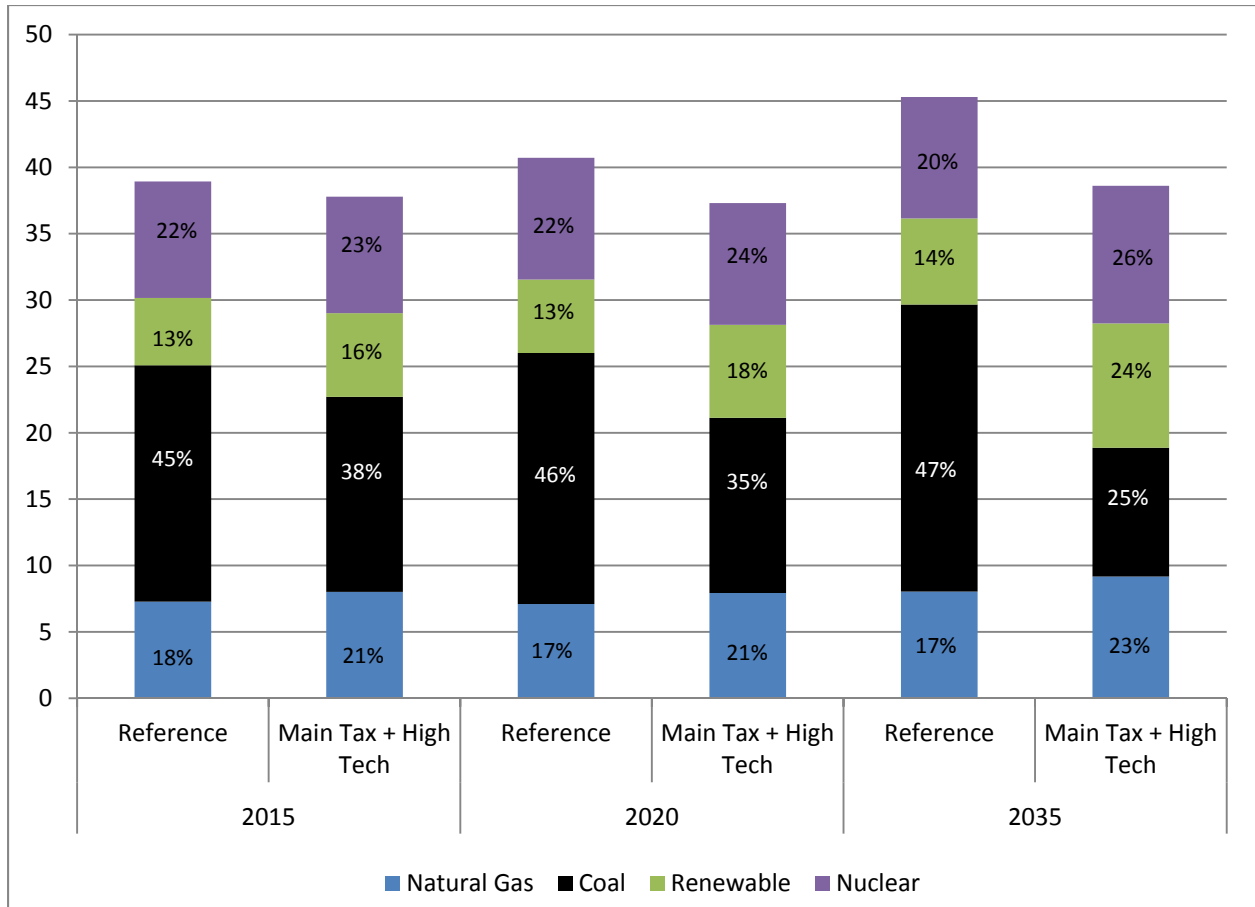
Our analysis suggests that a carbon tax would have significant impacts on the CO<sub>2</sub> emissions caused by the energy requirements of commercial buildings. Additional GHG reductions would occur, if the carbon tax were implemented as a more generic GHG tax, which would be an economically efficient approach. Cooling systems in commercial buildings often use refrigerants such as HFCs that have high global warming potentials (GWP). A tax on these refrigerants would accelerate the development and shift to low GWP environmentally friendly refrigerants such as hydrofluoroolefins (HFOs) (ORNL, 2011, p. 17). In the Main Tax + High Tech case, commercial buildings would reduce their CO<sub>2</sub> emissions by 38% relative to the Reference case by 2035. However, the emission reductions vary for the two major fuel types used in the sector. Figure 5 shows that the natural gas related CO<sub>2</sub> emissions continues to grow in all Main Tax scenarios while the electricity related CO<sub>2</sub> emissions shows a general declining trend over time. Compared to the Reference case, the CO<sub>2</sub> emissions from natural gas used in commercial buildings shrinks by only 4% in 2035. In the meantime CO<sub>2</sub> emissions from commercial electricity use are estimated to drop by at least 46% (partly as a result of decarbonization and efficiencies in the power sector as discussed below), which is 26% lower than the sector's electricity-related emissions in 2010.

The results indicate that carbon emissions associated with commercial buildings are deeply affected by the choice of energy sources to generate electricity. Figure 6 illustrates the major energy resources used to generate electricity, comparing the Main Tax + High Tech case with the Reference case. The share of coal, the most carbon-intensive fuel, declines significantly in the Main Tax + High Tech case (25%) compared to the Reference case (47%) between 2015 and 2035. At the same time, the use of renewable energy increases, especially in the later period of the study horizon, rising from a 2035 share of 14% in the Reference case to 24% in Main Tax + High Tech case.

As a result of decarbonization in the power sector, the impact of a carbon tax on CO<sub>2</sub> emissions from commercial buildings is much more significant than its impact on energy consumption. The Main Tax + High Tech case is able to reduce energy consumption by 12% in 2035 (Figure 1), while reaching a 38% decrease of CO<sub>2</sub> emissions (Figure 5) because of the shift of electricity generation to lower carbon fuels.



**Figure 5. CO<sub>2</sub> Emission Reductions from the Commercial and Power Sectors**  
 (Percentages are with respect to the AEO 2011 reference case in the same year)



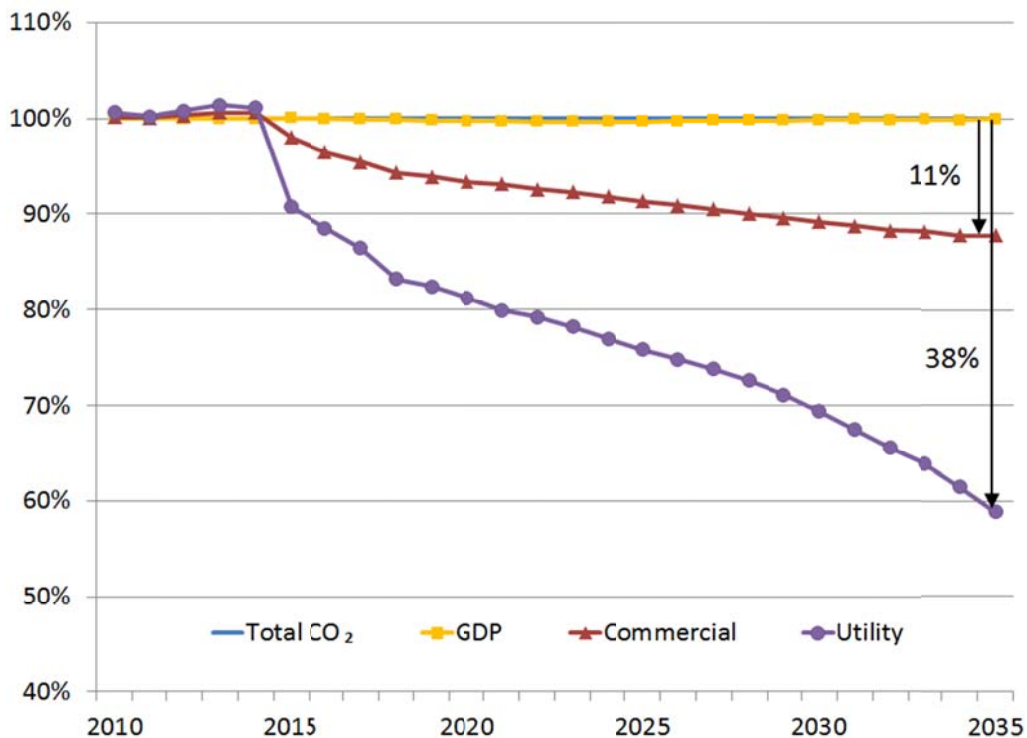
**Figure 6. Energy Consumed in the Power Sector (Quads)**

The difference between the energy and carbon dioxide trends can be illuminated by a “decomposition” exercise following the logic presented in *Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions* (National Laboratory Directors, 1997, Section 1.2). Net carbon is seen as a function of change in GDP, change in the energy intensity of the economy, change in the carbon intensity of the energy economy, and change in the amount of carbon sequestered. Ignoring the last term since carbon sequestration is not forecast to increase in the U.S. over the horizon of this study, the difference between the Reference forecast for commercial buildings and the carbon tax scenario can be decomposed into three components due to decreases in:

- aggregate economic output (GDP),
- energy intensity in commercial buildings, measured as total delivered energy divided by total square footage of commercial floorspace, and
- the carbon intensity of the economy’s energy supply.

The decomposition is shown in Figure 7. The “GDP” line represents the decline in emissions due to a slightly lower long-term path for inflation-adjusted commercial sector gross domestic

product, holding the sectoral energy intensity and the carbon intensity of the energy supply constant. The total CO<sub>2</sub> emission and the GDP related emission reduction trends essentially overlap with each other given the scale of this chart and the <0.5% change in the commercial sector's carbon emissions due to the reduction in GDP. Among the 38% sectoral carbon reduction in 2035, 11% can be attributed to the enhanced conservation behavior of commercial building owners and occupants, and their purchase of more efficient technologies. The use of lower-carbon energy sources in the power sector is responsible for about 27% (38% minus 11%) of the total CO<sub>2</sub> emission reductions. The gap between the GDP trend and Commercial Building Energy Intensity shows the CO<sub>2</sub> emissions that can be attributed to efficiency improvements that happened inside the commercial building sector. The most important factor that drives the emission reduction from commercial building, however, is the rapidly declining carbon intensity in the power sector, which accounts for over three quarters of the emission reduction in 2035.



**Figure 7. Decomposition of Carbon Dioxide Emission Reductions in the Commercial Buildings Sector in a Main Tax + High Tech Scenario**

The Energy Modeling Forum (2011) conducted a similar decomposition exercise, using a range of models. Their models with explicit technology profiles (similar to GT-NEMS) show a comparable result; that is, the energy intensity effect on CO<sub>2</sub> reduction is noticeably smaller than the effect resulting from power sector decarbonization.

#### 4.4 Value of the Carbon Tax and Its Impact on GDP

U.S. economic activity is forecast to continue to grow in both the Reference case and in the carbon tax policy scenarios; however, the carbon tax is anticipated to slow the rate of real GDP