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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_2 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_2 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_2 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.[1] 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?[2] 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_2 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_2 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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[1] 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.
[2] 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).[3] 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.

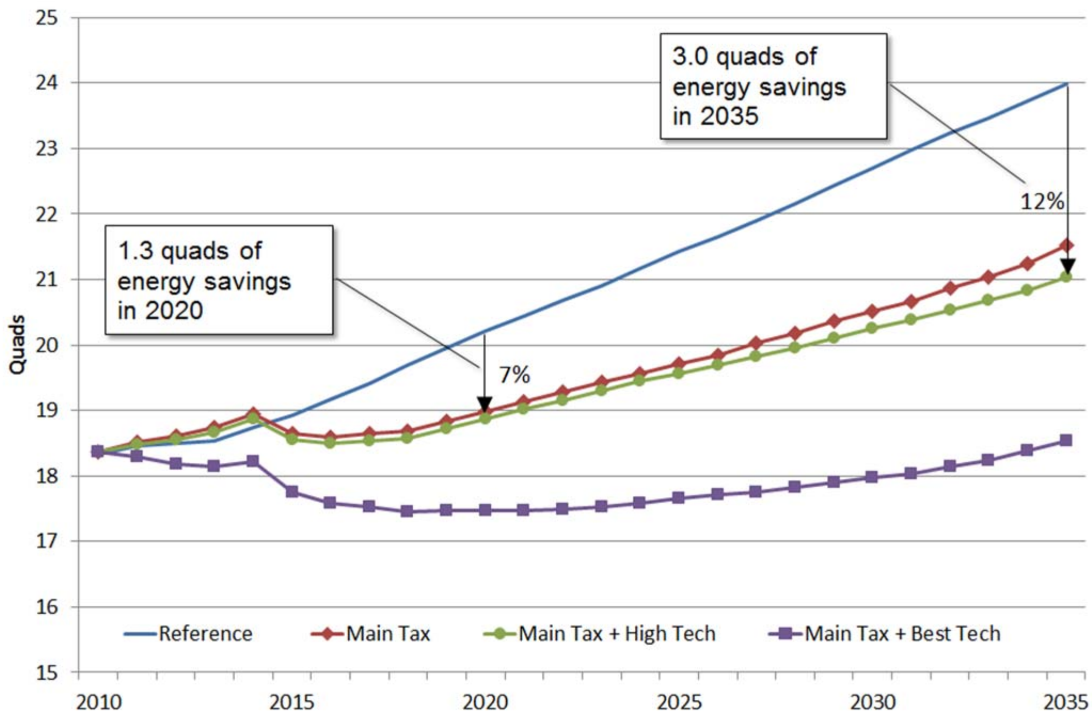

Figure ES.1. Commercial Energy Consumption (in Quads): Carbon Tax Scenarios Versus Reference Case

In the Main Tax + High Tech case, commercial buildings would reduce their CO_2 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

[3] 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_2 and criteria pollutants (SO_2, NO_x, $PM_{2.5}$, and PM_{10}), 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_2, 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_2 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.[4] 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

[4] 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**

End Use	2010-2020	2020-2035
Electric Space Heating		
– 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)
Natural Gas Space Heating		
– 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%)
Electric Cooling		
– 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
Electric Water Heating		
– 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
Natural Gas Water Heating		
– 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)
Electric Water Heating		
– 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
Natural Gas Water Heating		
– 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)
Lighting		
– 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_2 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_2 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.

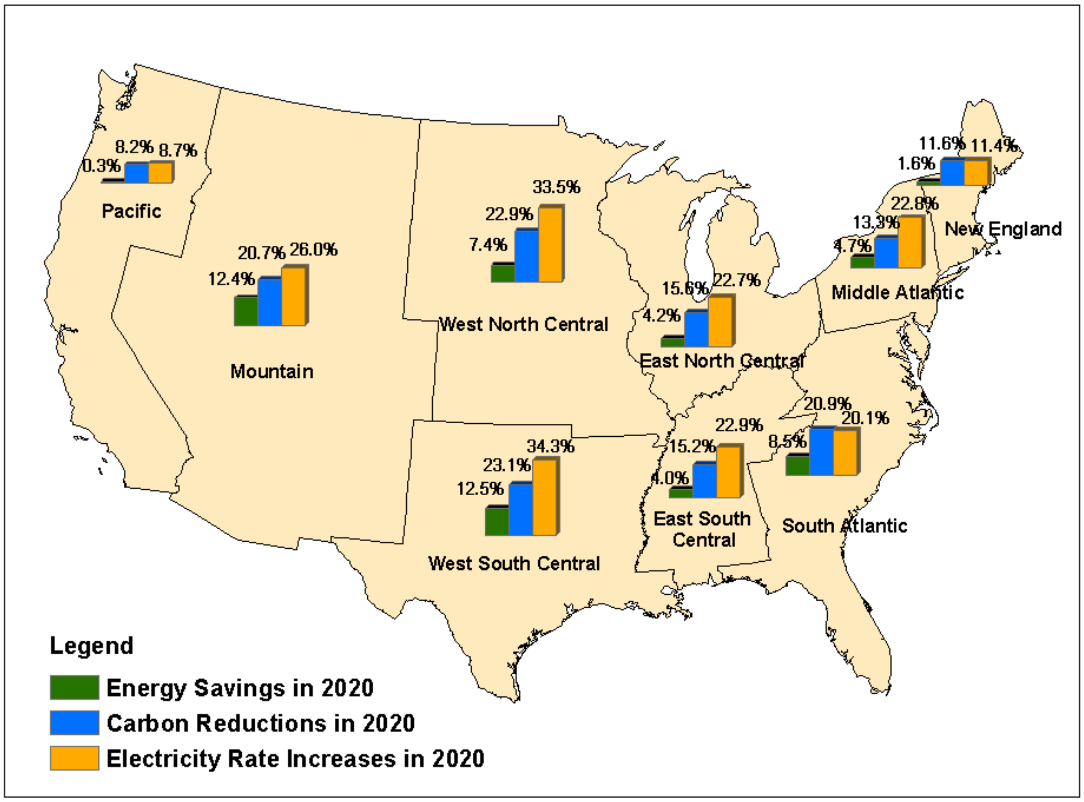

Figure ES.2. Commercial Energy Consumption, Carbon Emissions and Electricity Rates by Census Division in 2020

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_2 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_2 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_2 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).[5] 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

[5] 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_2 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_2 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_2 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_2-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.[6]
- 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_2-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.[7]

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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[6] http://www.nytimes.com/2012/07/05/opinion/a-carbon-tax-sensible-for-all.html?_r=2
[7] 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_2 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 (Granger 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".[8] 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).

[8] 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_2 emissions is modeled, starting from $25 per metric ton of CO_2 (in 2009-$) 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_2, 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_2, rising to $56.1 in 2035.
- EIA GHG Scenario: the *AEO 2011* GHG Price Economy-wide Case (EIA, 2011). The CO_2 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_2)

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_2 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_2 and three criteria pollutants – sulfur dioxide (SO_2), nitrogen oxides (NO_x), 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.

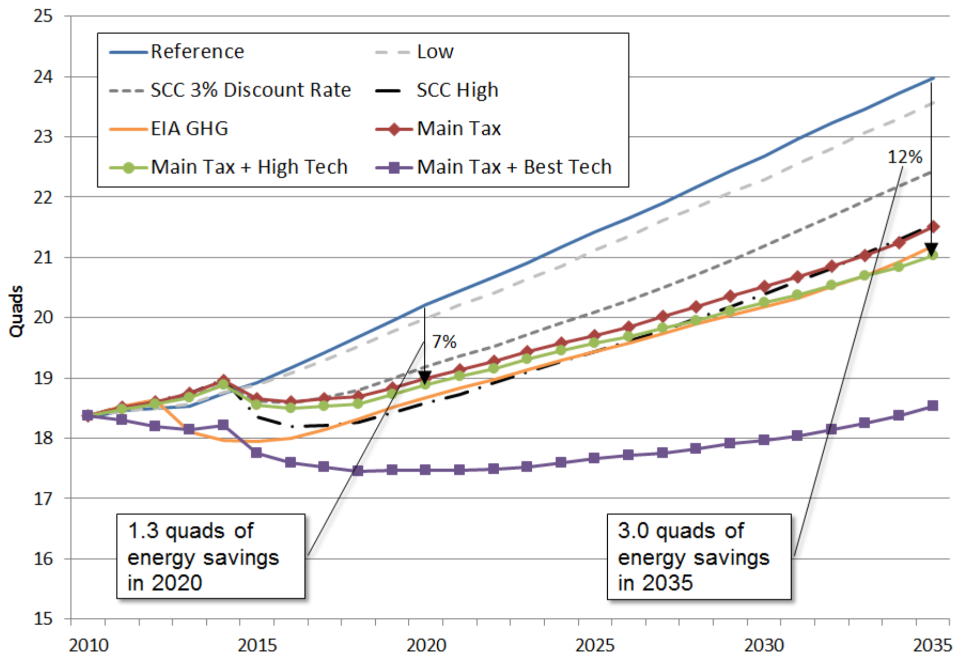


Figure 1. Commercial Energy Consumption (Quads): Carbon Tax Scenarios Versus Reference Case

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.

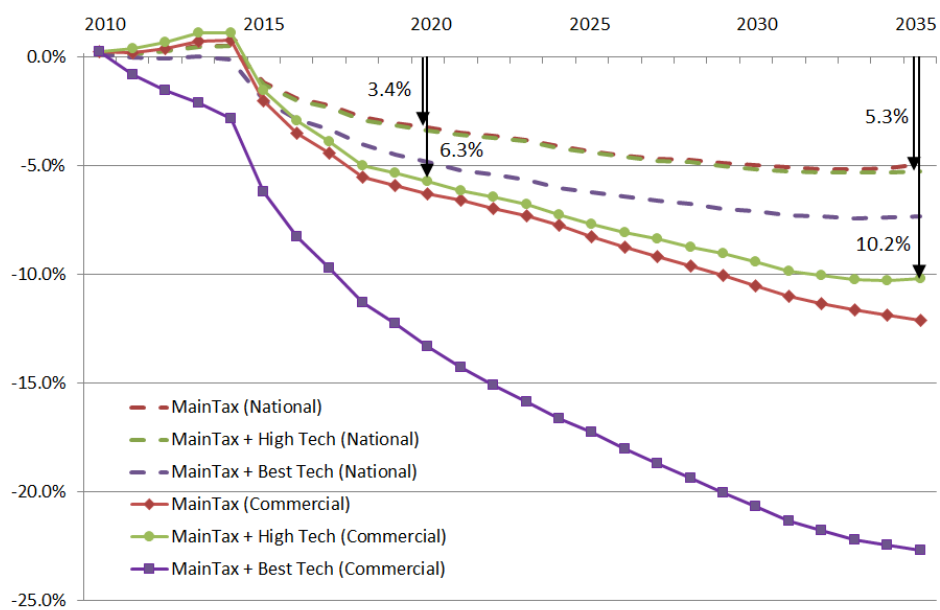


Figure 2. Carbon Tax's Impacts on the Energy Intensity of the Commercial Buildings Sector and the Nation

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.

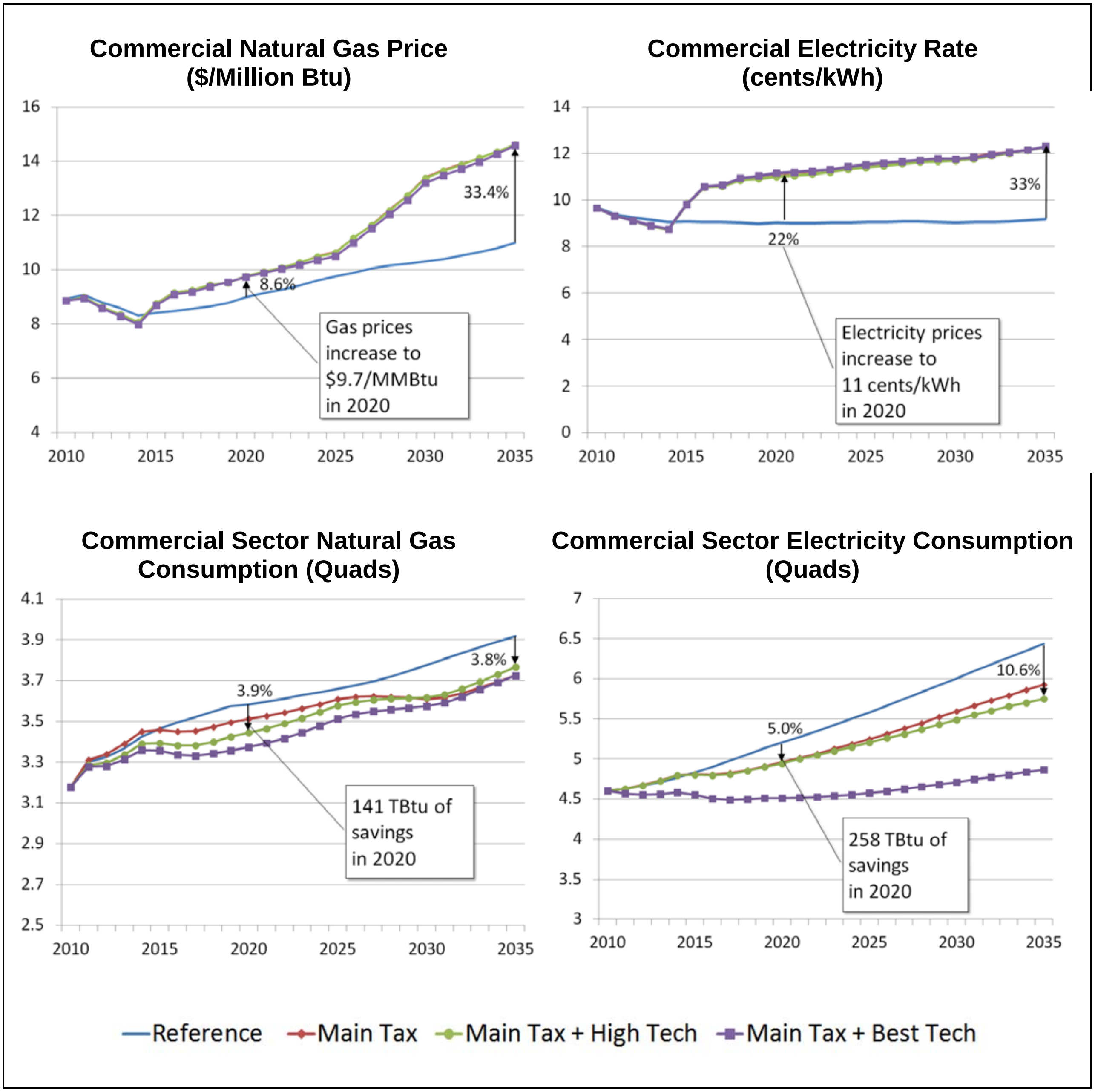


Figure 3. Commercial Sector Natural Gas and Electricity Rates and Consumption Main Tax Scenarios Versus Reference Case

(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.

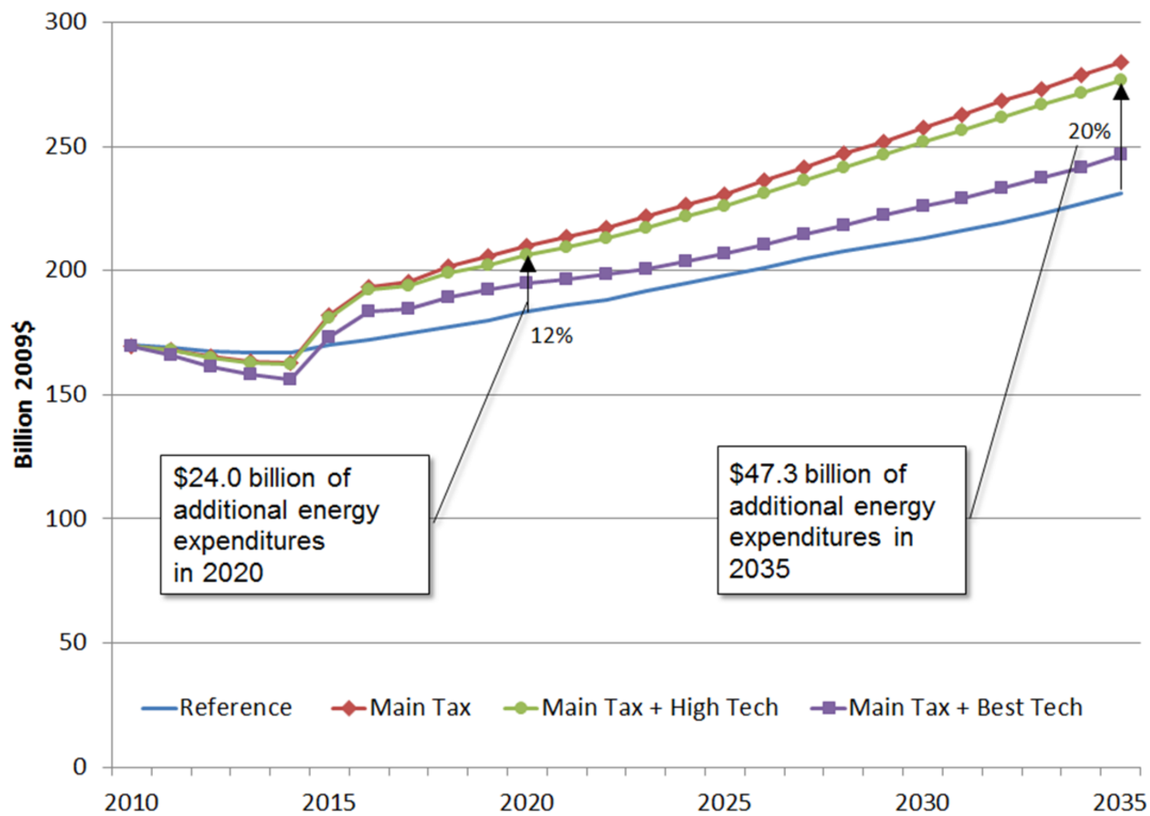


Figure 4. Commercial Sector Energy Expenditures (Billions 2009-$): Main Tax Scenarios Versus Reference Case

(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_2 Emissions from Commercial Buildings

Our analysis suggests that a carbon tax would have significant impacts on the CO_2 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. Cooing 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_2 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_2 emissions continues to grow in all Main Tax scenarios while the electricity related CO_2 emissions shows a general declining trend over time. Compared to the Reference case, the CO_2 emissions from natural gas used in commercial buildings shrinks by only 4% in 2035. In the meantime CO_2 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_2 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_2 emissions (Figure 5) because of the shift of electricity generation to lower carbon fuels.

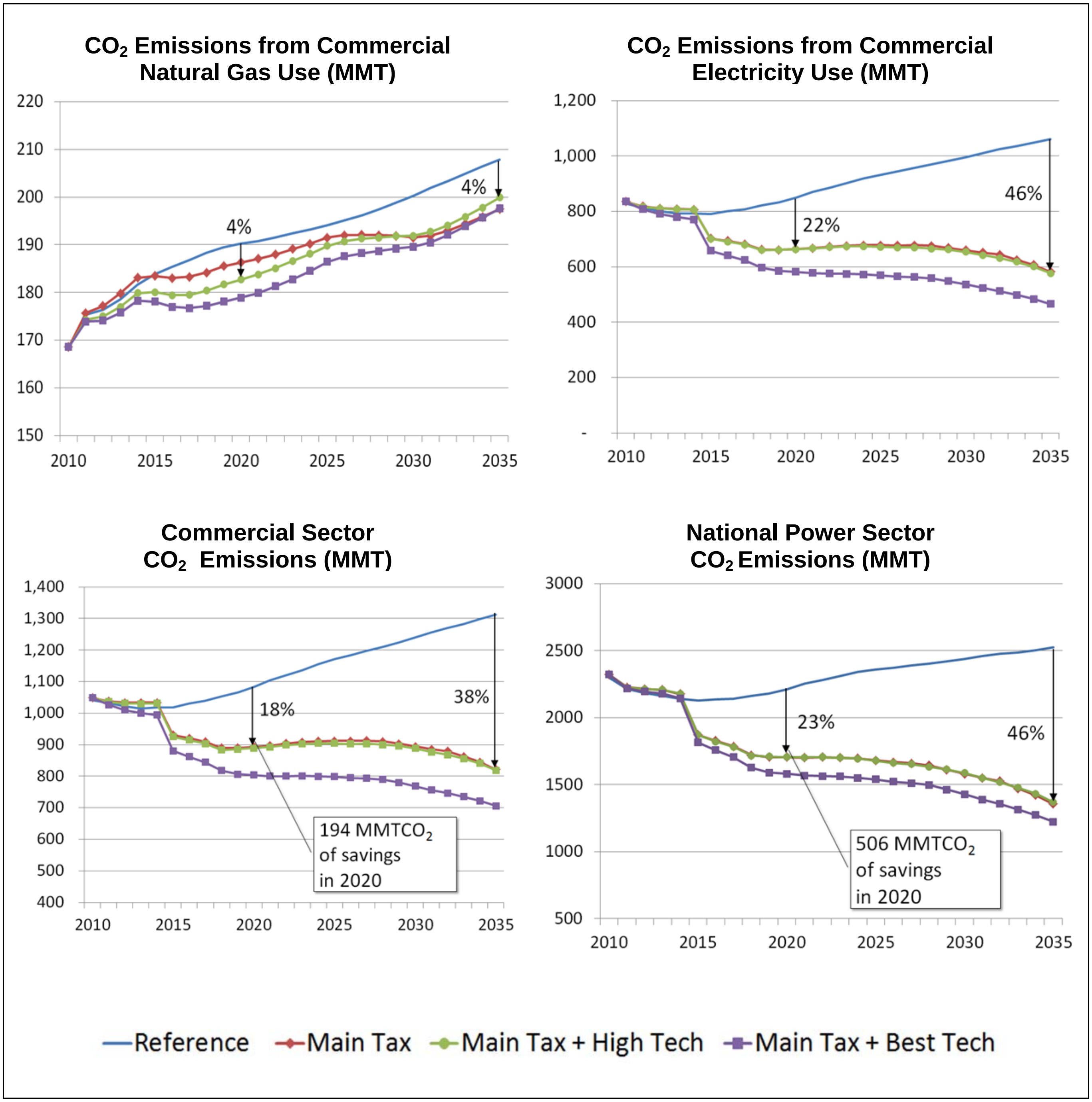


Figure 5. CO_2 Emission Reductions from the Commercial and Power Sectors
(Percentages are with respect to the *AEO 2011* reference case in the same year)

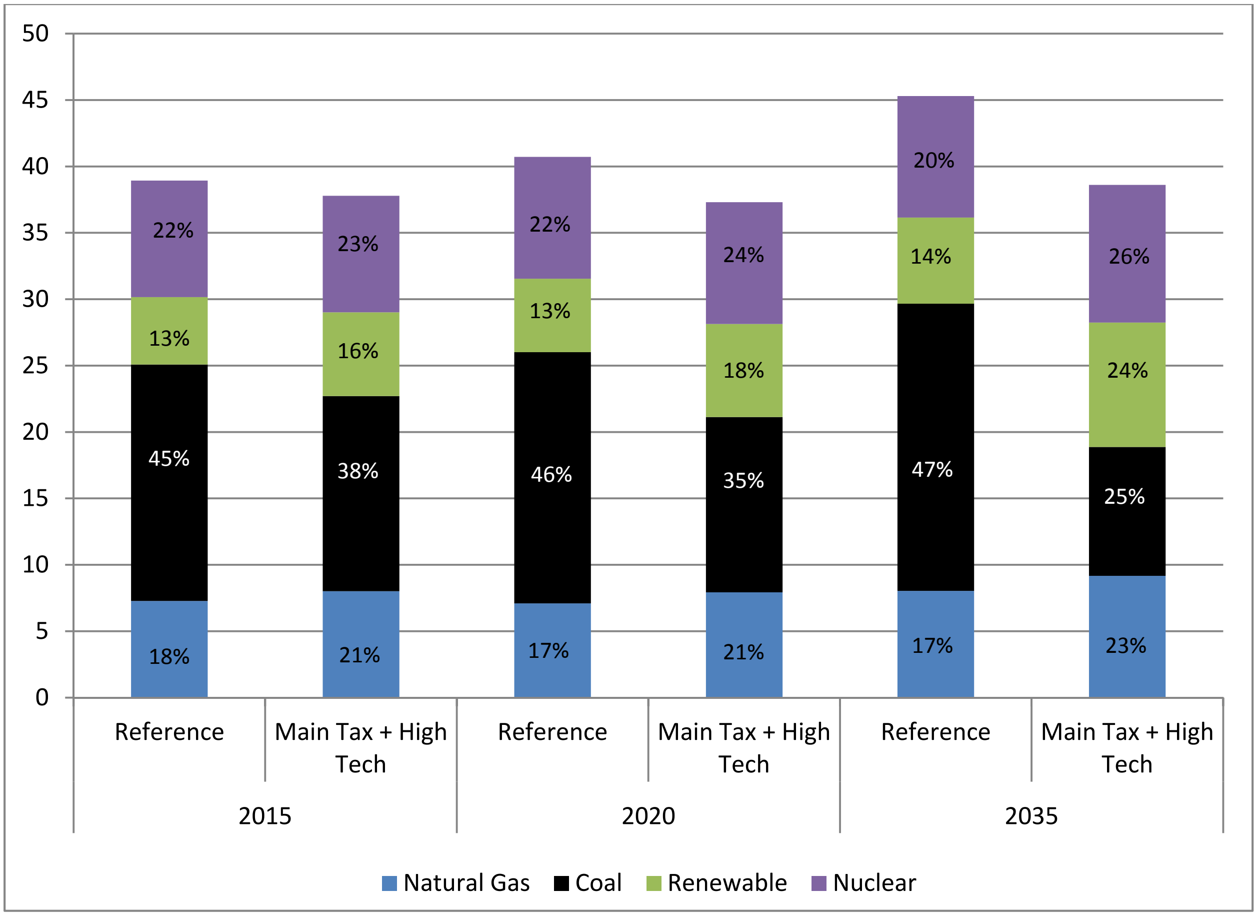


Figure 6. Energy Consumed in the Power Sector (Quads)

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_2 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_2 emission reductions. The gap between the GDP trend and Commercial Building Energy Intensity shows the CO_2 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.

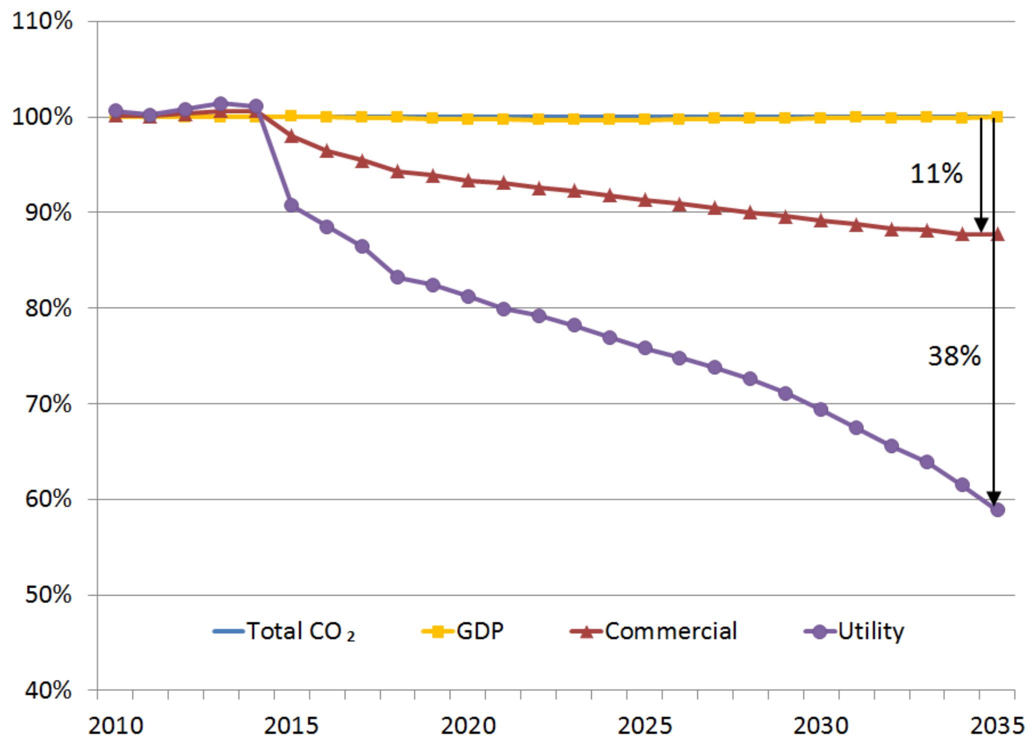


Figure 7. Decomposition of Carbon Dioxide Emission Reductions in the Commercial Buildings Sector in a Main Tax + High Tech Scenario

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_2 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 growth slightly (Table 6). The carbon tax scenarios would exert their largest impacts on GDP in the first five years of their implementation, with a cost of about 0.8 -1.0% of GDP in 2020 with respect to the *AEO 2011* Reference case (EIA, 2011). The estimated GDP penalties are much smaller in later years, declining to 0.3 to 0.4% of GDP in real terms by 2035. GDP influences the rate of growth of new construction, which in turn is an important determinant of future energy consumption and emissions. Similar to the timeline of overall GDP impacts, commercial buildings floorspace in 2020 is estimated to shrink by 0.3% (a loss of 240 million square feet) in the Main Tax + High Tech case. By 2035 this effect is less prominent, with an estimated shrinkage of 0.1% (100 million square feet). At an average commercial building size ranging from 5,000 (median) to 14,700 (mean) square feet (EIA, 2003, Table A1), this would suggest that commercial real estate would have 6,800 to 20,000 fewer buildings in 2035.

The cost of the Main Tax scenarios can be calibrated by considering the number of days that the nation's economy would have to operate in 2020 before GDP rises to the level it would have been in the absence of the carbon tax. As shown in Table 6, the Reference case GDP grows from $16.8 to $19.1 trillion between 2015 and 2020. In the Main Tax + High Tech case, GDP would rise to only $19.0 trillion in 2020, requiring the nation to wait three days before achieving a $19.1 trillion level of economic activity. In 2035, the delay is only 1.2 days. It is worth noting that GT-NEMS does not take into account potential damages from climate change that would reduce GDP, perhaps substantially. To the extent that greenhouse gas emissions avoided by the presence of a carbon tax reduce or eliminate these damages, we are unable to characterize the positive effect on GDP of climate change mitigation.

Table 6. GDP Impact

Scenario	GDP (Billion 2009-$)	2015	2020	2035
Reference	GDP	16,850	19,140	28,220
Main Tax	GDP	16,790	18,970	28,130
	Change*	-0.33%	-0.86%	-0.32%
	Delay (day)**	1.2	3.1	1.2
Main Tax + High Tech	GDP	16,790	18,970	28,120
	Change*	-0.36%	-0.86%	-0.34%
	Delay (day)**	1.2	3.1	1.2
Main Tax + Best Tech	GDP	16,790	18,960	28,090
	Change*	-0.34%	-0.95%	-0.44%
	Delay (day)**	1.2	3.5	1.6

* Numbers are percentage change relative to the Reference case

** "Delay" in GDP growth is defined as the number of days in a year required to make up the difference between GDP in the Reference case versus GDP in the carbon tax policy scenarios.

As shown earlier with respect to energy savings and price escalation, the GDP results from GT-NEMS suggest that improved technological options can significantly mitigate the cost of achieving carbon-lean commercial buildings. The Main Tax scenario reduces energy consumption by 6% in 2020 and 10% in 2035 at a cost of 0.86% of GDP in 2020 and 0.32% of

GDP in 2035. The Main Tax + High Tech scenario, on the other hand, produces a greater reduction in energy consumption (7% in 2020 and 12% in 2035) compared to the Reference case, for essentially the same GDP cost in 2020 and for a relatively small increase in cost (a difference of 0.02% of GDP) in 2035. The impact on CO_2 emissions is even greater.

Carbon taxes offer the possibility of socially productive revenue recycling. As noted earlier, 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.

The estimated carbon tax revenues that would be collected from the commercial buildings sector (or the energy suppliers serving this sector) could be substantial. We estimate the magnitude by multiplying the annual CO_2 emissions associated with the commercial buildings sector in each year by the value of that year's carbon tax in the Main Tax + High Tech scenario. These values range from $25/metric ton of CO_2 in 2015 to $31.9/metric ton in 2020 and $66.3/metric ton in 2035 (all values are in 2009-$).

In 2015, an estimated $134 billion in carbon taxes could be collected from the commercial buildings sector, rising to $165 billion in 2020 and $327 billion in 2035. To put these values into perspective, consider the forecasts of total federal tax revenues and public debt for these same two years (OMB, 2011). Since a carbon tax would reduce expected tax revenues in the future because it would slightly depress GDP, we use the decreased GDP estimate from the Main Tax + High Tech scenario to proportionately reduce the estimate of expected tax revenues. We do not adjust the public debt, since it tends to be less dependent upon annual tax revenues. With these adjustments, we estimate that the carbon tax revenues would be 4.3 and 4.5% of total tax revenues in the U.S. in 2015 and 2020, and 1.1 and 1.2% of public debt in these same two years.

4 .5 Changes in Commercial Energy End-Uses

The consumption of energy to heat and cool buildings and to provide water heating changes very little between 2010 and 2035 in the Reference case, where the policy environment does not change. Lighting and other end uses, on the other hand, increase significantly in the absence of carbon pricing.

In contrast, implementing the Main Tax +High Tech scenario is estimated to significantly decrease energy use in all of the end-use categories except "other uses", which includes ATMs, elevators, medical imaging equipment, among others.[9] The decrease in primary energy used for lighting between the Reference case and the Main Tax + High Tech case is particularly notable, dropping 22% from 3.8 to 2.9 quads in 2035. Primary energy consumption levels for lighting are lower in 2035 than in 2010 in this scenario (Table 7).

[9] "Other uses" also includes the difference between commercial buildings and the commercial sector, which includes uses of energy that pay commercial electricity rates but are not buildings or in buildings – street lighting, sewage treatment, and agricultural pumping. See the following for additional details: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-16820.pdf.

**Table 7. Energy Consumption by Commercial End-Use:
Main Tax + High Tech Scenario Versus Reference Case**

End Use	Energy Consumption (in Quads)	2010	2020			2035		
		Reference	Reference	Main Tax + High Tech	Percent Change	Reference	Main Tax + High Tech	Percent Change
Space Heating	Delivered Energy	1.9	2.1	1.9	-7%	2.0	1.7	-16%
	--Purchased Electricity	0.2	0.2	0.2	-10%	0.2	0.1	-20%
	--Natural Gas	1.6	1.8	1.6	-7%	1.8	1.5	-16%
	--Other Fuels	0.1	0.1	0.1	5%	0.0	0.1	15%
	Electricity Related Losses	0.4	0.3	0.3	-9%	0.4	0.3	-22%
	Primary Energy	2.3	2.4	2.2	-8%	2.4	2.0	-17%
Space Cooling	Purchased Electricity	0.6	0.5	0.5	-8%	0.6	0.5	-14%
	--Delivered Energy	0.6	0.6	0.5	-7%	0.6	0.6	-13%
	Electricity Related Losses	1.3	1.1	1	-9%	1.3	1	-13%
	Primary Energy	1.9	1.7	1.5	-10%	1.9	1.6	-17%
Water Heater	Delivered Energy	0.6	0.7	0.6	-4%	0.8	0.6	-15%
	--Purchased Electricity	0.1	0.1	0.1	-7%	0.1	0.1	-15%
	--Natural Gas	0.5	0.6	0.5	-4%	0.6	0.5	-15%
	Electricity Related Losses	0.2	0.2	0.2	-13%	0.1	0.2	14%
	Primary Energy	0.8	0.9	0.8	-6%	0.9	0.8	-16%
Lighting	Purchased Electricity (Delivered Energy)	1.0	1.1	1.0	-7%	1.2	1.0	-19%
	Electricity Related Losses	2.2	2.2	2	-10%	2.6	1.9	-27%
	Primary Energy	3.2	3.3	3.0	-9%	3.8	2.9	**-22%**
Other	Delivered Energy	4.4	5.1	5.0	-2%	6.4	6.3	-1%
	--Purchased Electricity	2.7	3.3	3.2	-4%	4.3	4.0	-7%
	--Natural Gas	1.1	1.3	1.3	1%	1.5	1.7	15%
	--Other Fuels	0.6	0.5	0.5	-1%	0.6	0.6	-1%
	Electricity Related Losses	5.8	6.8	6.3	-7%	8.6	7.5	-13%
	Primary Energy	10.2	11.9	11.3	-5%	15.0	13.8	-8%
Commercial Sector	Delivered Energy	8.5	9.5	9.1	-4%	11.1	10.2	-8%
	--Purchased Electricity	4.6	5.2	4.9	-5%	6.4	5.7	-11%
	--Natural Gas	3.2	3.6	3.4	-4%	3.9	3.8	-4%
	--Other Fuels	0.7	0.7	0.8	9%	0.8	0.7	-10%
	Electricity Related Losses	9.8	10.7	9.8	-8%	12.9	10.8	-16%
	Primary Energy	18.3	20.2	18.9	-7%	24.0	21.0	-12%

Fuel switching from electric to natural gas space heating is another strong trend precipitated by the carbon tax. In the Main Tax + High Tech scenario, service demand of electric space heating decreases by 17 and 29 trillion Btu in 2020 and 2035, respectively, relative to the Reference case, while natural gas space heating service demand gains 15 and 28 trillion Btu in those same years. Table 7 summarizes the energy consumption for the commercial sector by major end use.

In general, the presence of a carbon price increases the significance of natural gas in the commercial sector. As can be seen in Table 7, energy consumption falls in almost every end use and fuel source under a carbon price, but the relative importance of natural gas in meeting energy demand grows. This in turn is reflected in the technology shifts shown below.

4.6 End-Use Technology Shifts

The energy efficiency of end-use technologies in the commercial buildings sector is generally measured as a ratio of energy output to energy input, although there are variations across classes of technologies (see Box 1 for definitions).

Box 1: Measuring the Energy Efficiency of End-Use Technologies in Commercial Buildings, A Short Primer

The energy efficiency of all commercial building end-use technologies except lighting can be measured by a Coefficient of Performance (COP). In general, COP is the ratio of the energy output to the energy input. However, the specific form of COP varies from technology to technology.

The COP of furnaces and boilers is measured as the ratio of the heat output energy supplied to the heat input energy provided.

Chiller efficiency (COP) is measured as the ratio of the heat removal to the energy input to the compressor. Alternatively, COP is a function of the energy efficiency rating (EER) of a chiller: COP = EER / 3.412.

Heat pumps are also measured using a COP, but the equation is heat output /compressor's dissipated work. Since heat output is the compressor's dissipated work + heat input, COP = heat output / (heat output – heat input). Thus, its COP >= 1 and its efficiency >= 100%.

Lighting energy efficiency is measured as "luminous efficacy", which is the ratio of light output in lumens to electrical power input in watts.

Carbon taxes shift technologies toward greater efficiency over time in four distinct ways. First, carbon taxes shift energy use from less efficient to more efficient technologies. For example, between 2010 and 2020, wall and window air conditioners (AC) are replaced by mid-efficiency (3.28 COP) rooftop AC units. In the same timeframe, we see less-efficient air source heat pumps (COP 3.3) losing out to ground source heat pumps (GSHPs) with a higher efficiency (COP 3.5). This transition is enabled by an IRS-implemented incentive that allows for accelerated depreciation of high-efficiency GSHPs, using a 5-year tax schedule. Similarly, the standard electric water heater is displaced by heat pump water heaters. This transition is accelerated by a new regulation going into effect in 2016 that will require electric storage water heaters with a capacity of 55 gallons or larger to have heat pumping efficiencies.[10] In addition, the standard F32T8 electronic ballast that operates 4-foot fluorescent lamps is displaced by light-emitting diodes. (Not shown is the transition currently underway from T-12 magnetic ballasts to the greatly improved T8 electronic ballasts.)

Second, economies of scale produce cost savings in the carbon tax scenario that enable consumers to move from more expensive to less expensive high-efficiency technologies. This is the case in 2035 when economies of scale shift service demand 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. In other instances, the carbon tax enables consumers to take advantage of a class of technology that experiences both cost reductions and efficiency improvements. For example, in 2035, consumers who tended to purchase a high efficiency gas water heater with 2007 costs and efficiencies (COP 0.93) in the Reference case, tend to choose a slightly cheaper higher efficiency gas water heater (COP 0.95) in the Main Tax + High Tech scenario once it is available in 2020.

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. In the Main Tax + High Tech scenario, service demand for electric space heating decreases by 29 trillion Btu in 2035 relative to the Reference case, while natural gas space heating service demand gains 28 trillion Btu in that same year. As noted earlier, natural gas consumption decreases relative to the Reference case because the average coefficients of performance of gas space and water heating are higher in the Main Tax and High Tech scenario.

This last 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 was also noted by Kyle et al. (2010). However, in the Kyle et al. (2010) study, the authors were referring to a switch from electric heat pumps to gas furnaces in the residential sector over the next century. In contrast, we've highlighted the possibility of a shift toward gas furnaces from electric heat pumps in the commercial sector over the next

[10] http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/htgp_finalrule_fedreg.pdf

several decades. The recent identification and exploitation of large quantities of affordable shale gas in the U.S. in recent years may explain these otherwise inconsistent findings, underscoring once again that unanticipated technology and resource breakthroughs and surprises can quickly undermine the validity of past energy forecasts.

Theoretically, the underlying technology and production cost improvements that enable these technology shifts can happen in three ways: through advances in R&D and general knowledge that result in improvements in technological performance; through economies of scale from increased size of production and operation; and lastly, through learning-by-doing or experience that is sometimes attributed to the cumulative experience of an entire industry. The High Tech portfolio of technologies is used to illustrate this technological progress. Without the impetus of the Main Tax, the High Tech case reduces the energy consumption of commercial buildings by 0.3 quads in 2035. When coupled with the carbon tax, it saves about 0.5 Q in 2035. Thus, the potential to consume less energy through better technology is amplified by a carbon tax.

The result of the technology trends brought about by the Main Tax + High Tech scenario is a significant increase in the average energy efficiencies of most end uses over time (Table 8). Of particular note, electric water heating efficiencies increase in the first decade when there is a surge of improved heat pump and solar water heaters. That trend strengthens in the last decade when standard resistance water heaters are largely eliminated from the marketplace. Although lighting efficiencies improve only slightly above the Reference case in the first decade (which is when the 2012-14 lighting standard takes hold), by the second decade, the onset of LED lighting and super fluorescents increase the average luminous efficacy from 55.9 lumens/watt in the Reference case to 62.1 lumens/watt in the Main Tax + High Tech scenario by 2035, an increase of 11%. Of course, with LED or solid state lighting, there are already a variety of product types with variable luminous efficiencies.[11]

Electric space heating in 2020 is the only exception to the trend toward greater efficiency under the Main Tax scenario compared to the Reference case. A significant fuel shift from electric to natural gas space heating explains this difference. Relatively expensive, highly efficient rooftop air-source heat pumps are responsible for most of the demand losses in electric space heating, which transition not to other electric space heating devices but to natural gas space heating. The result is an overall decline in the efficiency of electric space heating in 2020.

[11] See the following DOE website for details:
http://www1.eere.energy.gov/buildings/ssl/sslbasics_ledbasics.html#how_efficient

Table 8. Energy Efficiency and Cost for Different End Uses: Reference Versus Main Tax + High Tech Case

Average COP (Btu Out/Btu In)	2020		2035	
	Reference	Main Tax + High Tech	Reference	Main Tax + High Tech
Space Heating-Electricity	1.5	1.46	1.67	1.67
Space Heating-NG	0.79	0.85	0.82	0.89
Space Cooling-Electricity	3.18	3.19	3.4	3.47
Water Heating-Electricity	1.02	1.03	1.03	1.1
Water Heating-NG	0.84	0.85	0.86	0.89
Ventilation[1]	0.54	0.55	0.54	0.58
Cooking-Electricity	0.76	0.76	0.76	0.77
Cooking-NG	0.53	0.53	0.54	0.56
Lighting[2]	53.1	53.3	55.9	62.1
Refrigeration	2.66	2.7	2.92	3.13

1. Ventilation COP has a unit of 1000 cfm-hours output per 1000 Btu input.
2. Lighting COP has a unit of lumens/watt.

Average cost (2007-$/1000 Btu Out)	2020		2035	
	Reference	Main Tax + High Tech	Reference	Main Tax + High Tech
Space Heating- Electricity	50	48.3	55.1	55.9
Space Heating-NG	14.9	14.5	12.8	12.7
Space Cooling	49.8	48.8	47.8	46.9
Water Heating-Electricity	39.5	44	44.1	63.5
Water Heating-NG	21.2	21.5	22.1	23.2
Ventilation[1]	8407	8419	8406	8428
Cooking-Electricity	44	44.2	44.5	44.9
Cooking-NG	34.8	34.9	35.5	36.5
Lighting[2]	30.2	30.4	30.6	39.1
Refrigeration	696.6	656.7	729.2	684.3

1. Ventilation cost uses the unit of 2007-$/1000cfm.
2. Lighting cost uses the unit of 2007-$/thousand lumens

The Main Tax + High Tech scenario also causes the average cost of commercial equipment to increase for most end uses. While natural gas space heating and electric space cooling could see minor reductions in their average equipment cost in 2035, the average cost for all other equipment types is estimated to increase relative to the Reference case.

Table 9 characterizes the technology shifts that have taken place across the six main end uses. Additional tables in Appendix B present the differences in service demand when comparing the Main Tax + High Tech and Reference cases. Low efficiency boilers and furnaces, expensive rooftop air-conditioning units, and electric resistance water heaters see consistent declines in service demand. The shift to more efficient technologies throughout the major end-uses is a clear trend in Table 7.

High efficiency CO_2 heat pump water heaters (HPWHs) have been developed and commercialized in Japan, however, their viability in the U.S. market would depend on dramatic cost reduction and redesign for the U.S. market, as well as addressing safety and service concerns. The savings potential associated with advanced, super high efficiency electric HPWHs is very high: in Japan, the coefficients of performance are in the range of 4.0. This is roughly one and half to two times the performance of existing HPWHs, which themselves represent a major increase in efficiency over conventional electric water heaters. Rooftop air-conditioning units, and electric resistance water heaters see consistent declines in service demand. The shift to more efficient technologies throughout the major end-uses is a clear trend in Table 8 (Navigant Consulting Inc, 2011).

Table 9. End-Use Technology Shifts: Main Tax + High Tech Scenario Versus Reference Case

End Use	2010-2020	2020-2035
Electric Space Heating		
– 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)
Natural Gas Space Heating		
– 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%)
Electric Cooling		
– 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
Electric Water Heating		
– 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
Natural Gas Water Heating		
– 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)
Electric Water Heating		
– 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
Natural Gas Water Heating		
– 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)
Lighting		
– 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

4.7 Commercial Building Equipment Expenditures

Next we estimate the investments in commercial building energy equipment motivated by the Carbon Tax + High Tech scenario. These expenditures are associated with the purchase of more efficient space heating, space cooling, water heating, refrigeration, cooking, ventilation and lighting equipment and appliances. They also result from a shift in fuels for space heating, from electricity to natural gas.

These estimates of investment costs are derived from the outputs of the GT-NEMS Reference case and Main Tax + High Tech scenario (specifically, the KSDOUT, KTEK, and KCAPFAC files). 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 are estimated to account for 59% of total delivered energy consumption in 2020 in the Reference case, and 57% in the Main Tax + High Tech case. In 2035, the coverage is 55% in the Reference case and 50% in the policy case.

The annual and cumulative equipment expenditures are shown in Table 10. The Main Tax + High Tech case is estimated to stimulate an additional expenditure of $ 8.4 billion on commercial building equipment in 2020; this would raise the level of expenditure by 12.5% to $75.5 billion in that year. This incremental expenditure would rise by slightly more, 13.1% or $10.4 billion in 2035, presumably reflecting an increasing level of carbon tax over that 15-year period.

Table 10. Present Value of Increased Equipment Expenditures
(in Billions 2009-$)

Year	Total in Reference Case	Total in Main Tax + High Tech Scenario	Incremental Investment Cost: Annual	Incremental Investment Cost: Cumulative*
2020	67.1	75.5	8.4 (12.5%)	69
2035	79.1	89.5	10.4 (13.1%)	162

*Present values were calculated using a 3% discount rate.

4.8 Value of Avoided CO_2 and Criteria Pollutants

Next we estimate the value of the avoided damages from CO_2 and three criteria pollutants that could result from the Main Tax + High Tech case. We focus on sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter (PM). After describing our methodology and findings, we end with a discussion of limitations and uncertainties.

Reduction of carbon dioxide emissions. The carbon emissions associated with energy consumption are output from GT-NEMS, which estimates the commercial sector's energy consumption by type of fuel for each year through 2035. It also projects the changing electric grid fuel mix over time based on the energy resources used for electricity generation each year.

Over time, the electric fuel mix becomes slightly less carbon intensive. Using these trajectories of commercial sector fuel and electric grid mix over time, we derive the change in million metric tons of CO_2 emitted.

We estimate the economic value of reduced CO_2 emissions in each year by multiplying the decrement in emissions by the "social cost of carbon" (SCC) for that year. The SCC is defined as an estimate of the monetized damages caused by each incremental ton of CO_2 emitted. The SCC used in this analysis is the central value estimates of the U.S. Government Interagency Working Group on the Social Cost of Carbon (EPA, 2010). In this report, the SCC estimates are based on a 3% discount rate; these range from \$23/metric ton of CO_2 in 2011 to \$34/metric ton and \$47/metric ton in 2030 and 2050, respectively (all values are in 2008-\$). A summary of the methodology used to derive the SCC values is provided in Appendix A. The results are summarized in Table 11.

Table 11. Present Value of Avoided Damages from CO_2 Emissions
(in Billions 2009-$)

Year	Value of Avoided CO_2: Annual	Value of Avoided CO_2: Cumulative*
2020	5	23
2035	19	187
2055	0	363

*Present values were calculated using a 3% discount rate.

The present value of avoided CO_2 is estimated to be \$3 billion in 2020, rising to \$19 billion in 2035. On a cumulative basis, the CO_2 reductions are worth nearly \$200 billion through 2035 and \$363 billion through 2055. While we model a carbon tax that is implemented in 2015 and operates for 20 years, many of the benefits of this policy would extend much longer. For example, energy-efficient technologies have varying lifetimes, both less and more than 20 years (for example, natural gas water heaters last only 11-13 years and air conditioners last 15-24 years, but chillers last 20-25 years and boilers last 24-30 years).[12] Consistent with the assumed 20-year lifetime overall, our analysis assumes that energy savings degrade at 5% annually (Brown et al., 1996). Therefore, technologies installed in 2035 provide the greatest savings in that year, with a linear decline in savings out to 2055, when energy savings are no longer expected. The same rationale is applied to emissions benefits. The savings between 2035 and 2055 are added "externally" to the energy savings estimates produced by GT-NEMS, which ends in 2035. The value of a metric ton of avoided CO_2 in 2055 is greater than a metric ton avoided in 2035, which leads to the significant increase in benefits in the last two decades.

Reduction of criteria air pollutants. A recent report from the National Research Council (NRC, 2010) examined the damages of pollution from energy production and consumption in the U.S. The report estimated that pollution damages totaled \$120 billion in 2005, excluding

[12] See Tables 5.3.9 and 5.7.15 in the DOE Buildings Energy Data Book (http://buildingsdatabook.eren.doe.gov/).

damages from climate change, effects of mercury, impacts on ecosystems, and other difficult-to-monetize damages. The total costs are dominated by human health damages from air pollution associated with electricity generation and vehicle transportation. Also included in the estimates are damages sustained by grain crops and timber yields, buildings, and recreation. Altogether, non-climate damages from coal power plants are estimated to exceed $62 billion annually. These damages average 3.3 cents per kWh in 2008-$ (NRC, 2010).

Natural gas use in the commercial sector also generates significant human health and environmental externalities when combusted to produce heat. NO_x emissions are particularly high. Appendix A provides a more detailed description of the cost of avoided criteria air pollutants.

There is a great deal of regional heterogeneity in benefits per ton of emissions reduction, as emphasized by Fann and Wesson (2011). The three reasons for this are:

- heterogeneity in the emissions profile of electricity generation
- heterogeneity in meteorological conditions that affect the conversion of emissions to ambient concentrations of certain air pollutants (e.g., $PM_{2.5}$)
- heterogeneity in the distribution of populations relative to pollution sources

As shown in Table 12, the value of avoided SO_2, NO_x, and PM is estimated to be worth $6.2 billion (dominated by SO_2) in 2020, rising to $10.7 billion in 2035. On a cumulative basis, this reduced pollution is worth approximately $151 billion through 2035 and $234 billion through 2055, reflecting the 20-year longevity of energy savings following an efficiency upgrade. Thus, we estimate that the carbon tax would generate somewhat greater benefits from reduced pollution compared with avoided damages from carbon dioxide.

Table 12. Present Value of Avoided Criteria Pollution
(in Billions 2009$)

Year	Value of Avoided SO_2: Annual	Value of Avoided SO_2: Cumulative*	Value of Avoided NO_x: Annual	Value of Avoided NO_x: Cumulative*	Value of Avoided PM: Annual*	Value of Avoided PM: Cumulative**
2020	5.4	22	0.4	1.7	0.4	1.6
2035	9.3	133	0.7	9.3	0.7	9.0
2055	0	205	0	14.6	0	14.2

* Both PM_{10} and $PM_{2.5}$ are included
**Present values were calculated using a 3% discount rate.
Estimates do not include various non-monetized values (e.g. mercury pollution reduction, increased productivity, water quality impacts, etc.).

Limitations and Uncertainties. The avoidance of environmental damages that contribute to the high societal benefit-cost ratios of a carbon tax policy could be overstated if EPA regulations are tightened over the next several decades. The additional value provided by a carbon tax would be more limited because more pollution and GHG emissions reductions would take place in the absence of the Main Tax + High Tech policy.

The *AEO 2011* Reference case assumes that the long-term reduction goals of the Clean Air Interstate Rule (CAIR—now called the Cross State Air Pollution Rule or CSAPR) will be met through the existing cap-and-trade system specified in an earlier rule. Thus, reduced levels of SO_2 and NO_x over time are built into the Reference case (with SO_2 emissions capped at 2.5 million metric tons and NO_x emissions at 1.3 million metric tons in the affected 28 States). Any electricity rate impacts of CAIR/CSAPR are presumably also incorporated into the NEMS price forecasts.

On the other hand, the Mercury and Air Toxic Standards (MATS) is not represented in the *AEO 2011* projections. MATS places limits on emissions of mercury, arsenic, chromium, nickel and other heavy metals, and also limits acid gases, such as hydrogen chloride and hydrogen fluoride from new and existing generators. An earlier version of this ruling was "vacated" by the DC Circuit Court in February 2008 (EPA, 2011). If these EPA regulations are enacted over the next three to five years, our monetization of emission-reduction benefits may be overstated, but it is difficult to estimate the magnitude of such a potential bias. Interestingly, Burtraw, et al. (2012) suggest that recent downward adjustments in natural gas prices and electricity demand projections might have a larger impact on the electricity sector than might environmental rules such as CSAPR and MATS.

At the same time, the benefits from reduced externalities resulting from a carbon tax policy may be understated because they exclude land and water impacts, and only partially incorporate air pollution impacts. Also excluded are the benefits from reduced surface mining for coal, which leads to irreparable ecosystem damage (Bernhardt and Palmer, 2011), such as loss of topsoil (Negley and Eshleman, 2006), increased propensity for flooding (McCormick et al, 2009), declining water quality (Hartman et al, 2005), and biodiversity loss (Pond et al, 2008; Sams and Beer, 2000). Human health impacts, such as increased selenium levels from eating contaminated fish and elevated exposure to dust and particulates from mining operations, which lead to increased hospitalizations (Palmer et al 2010), are left out of our analysis. All policy options in this report would reduce damages associated with transmission and distribution (Sovacool, 2008; U.S. Office of Technology Assessment, 1993), also not quantified but acknowledged as an additional benefit.

4.9 Variations Across Building Types and Regions

Variations across Building Types. GT-NEMS estimates energy usage for ten specific types of commercial buildings; thus, the energy that could be saved by a Carbon Tax + High Tech scenario can also be estimated. Figure 8 illustrates the delivered energy savings for each building type, with an average of 8 percent in 2035 (12% in terms of primary energy).

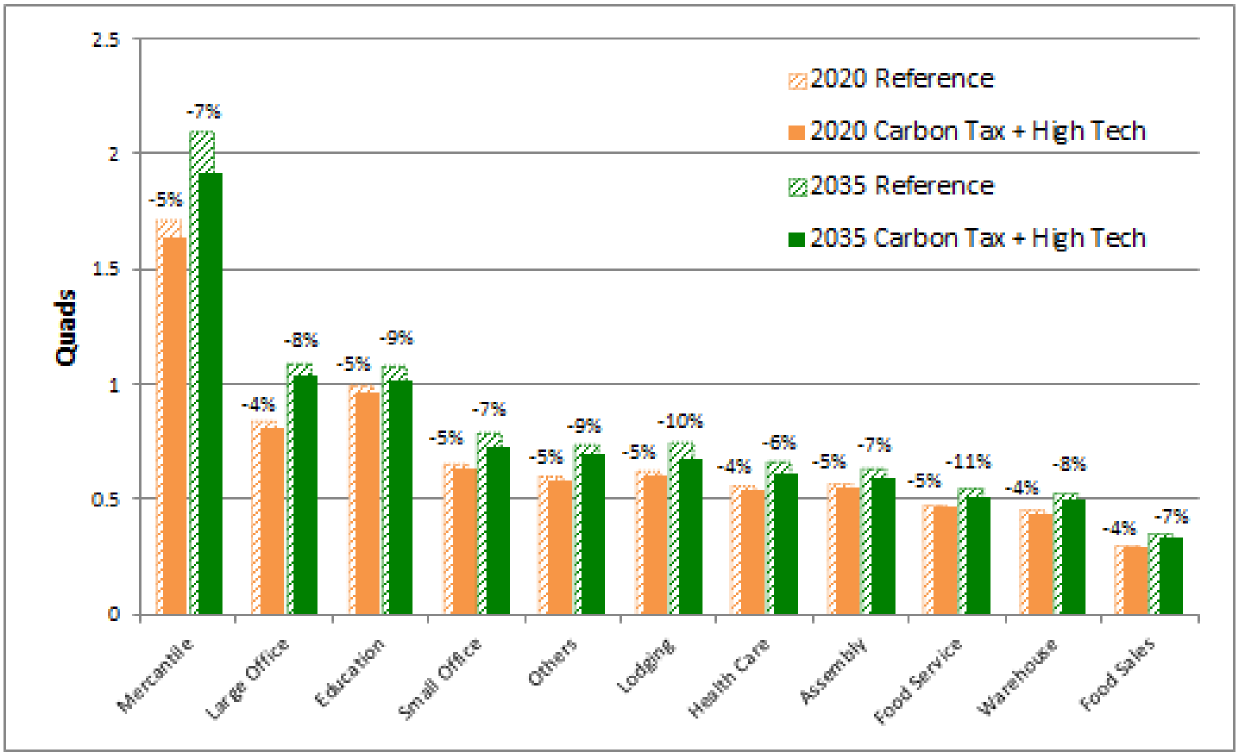


Figure 8. Delivered Energy Consumption (and Percent Savings) by Building Type

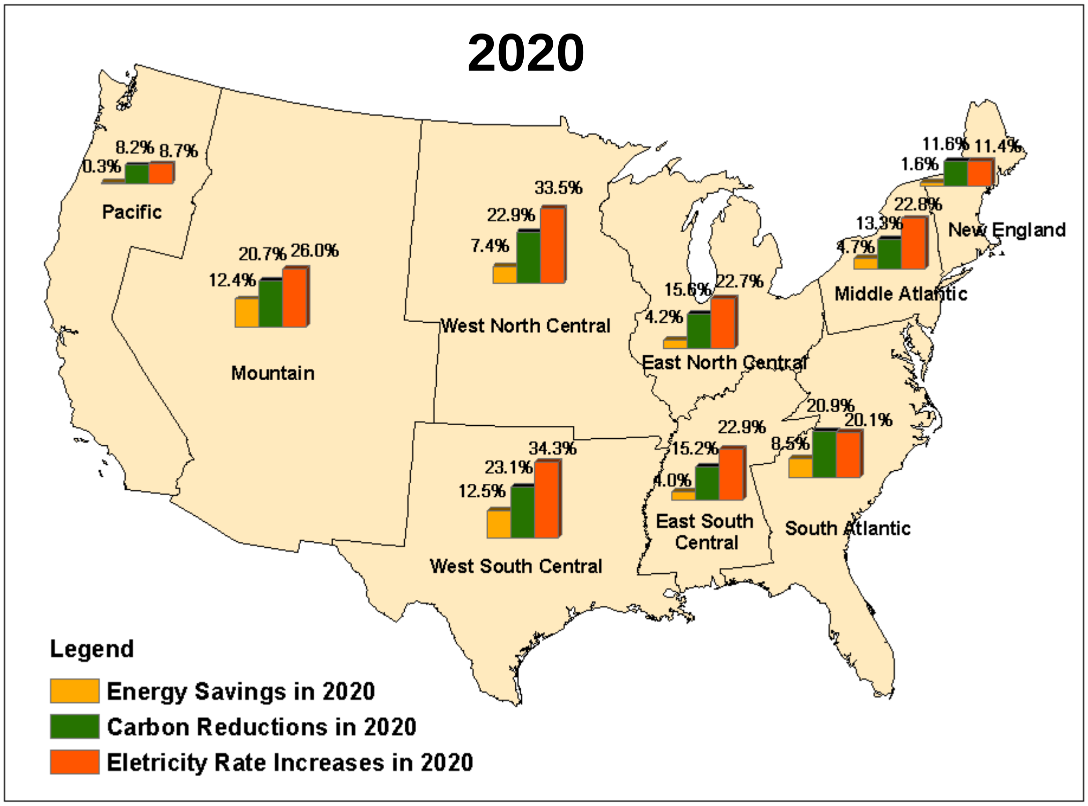
Mercantile, large office buildings, and educational buildings are the top three building types in terms of magnitude of energy consumption, and their savings are "average," ranging from 7 to 9% in 2035). On the other hand, food services and lodging are the building types that are estimated to save the most energy in the Main Tax + High Tech case, with 11% and 10% reductions, respectively. Food services are energy-intensive operations (DOE, 2010, Table 3.1.10), which may account for their high energy-savings potential.

Geographic Variation. The effects of carbon taxes on commercial building energy efficiencies are geographically broad, based on estimates of their impacts across the nine U.S. Census divisions. Table 13 presents several key characteristics of the nine census divisions in 2010. The impact of the carbon tax on electricity rate, energy use in the commercial sector and its associated CO_2 emissions are shown in Figure 9. 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 the same year, reductions in CO_2 emissions range from 8 to 23%, In 2035, energy savings range from -1.0% in the Pacific division to 20.2% in the Mountain division, while reductions in CO_2 emissions range from 16 to 48%. As a general rule, the percentage energy savings is lower than the percentage reduction in CO_2 emissions, consistent with the shift to low-carbon energy resources that would be precipitated by a carbon tax. The amount of change varies over time and by region, but the direction is consistent, and the gap between energy savings and CO_2 grows over time (Figure 9).

Table 13. Key Regional Statistics (in 2010)*

Division	Population (Millions)	GDP (2009-$)	Energy Use (Quads)		Electricity Rate (Cent/kWh)	CO_2 Emissions (MMT)		Carbon Intensity (MMT/Quad)	
			Total	Commercial Sector	Commercial Sector	Total	Commercial Sector	Commercial Sector	Power Sector
New England	14.4 (4.7)	766 (5.5)	3.1 (3.2)	0.65 (3.6)	9.71	160 (2.8)	27.6 (2.6)	42.5	33.6
Middle Atlantic	40.9 (13.2)	2,120 (15.2)	10.4 (10.6)	2.64 (14.4)	13.4	570 (10.1)	127 (12.3)	48.1	43.8
East North Central	46.4 (15.0)	1,950 (14.0)	15.9 (16.2)	3.14 (17.1)	13.1	990 (17.6)	203 (19.5)	64.6	67.1
West North Central	20.5 (6.6)	904 (6.5)	8.3 (8.5)	1.54 (8.4)	9.6	515 (9.1)	105 (10.1)	68.2	70.6
South Atlantic	59.8 (19.4)	2,570 (18.5)	15.8 (16.2)	3.34 (18.2)	7.4	943 (16.7)	202 (19.4)	60.5	59.9
East South Central	18.4 (6.0)	656 (4.7)	7.4 (7.5)	1.11 (6.1)	9.0	440 (7.8)	69.4 (6.7)	62.5	61.9
West South Central	36.3 (11.8)	1,600 (11.5)	18.0 (18.4)	2.28 (12.4)	7.9	988 (17.5)	141 (13.5)	61.8	61.5
Mountain	20.0 (6.5)	916 (6.6)	7.5 (7.7)	1.60 (8.7)	8.0	488 (8.6)	108 (10.3)	67.5	69.0
Pacific	49.9 (16.2)	2,410 (17.4)	11.3 (11.5)	1.95 (10.6)	7.8	548 (9.7)	58 (5.6)	29.7	21.5

* Numbers in parentheses represent the percentage of the national total



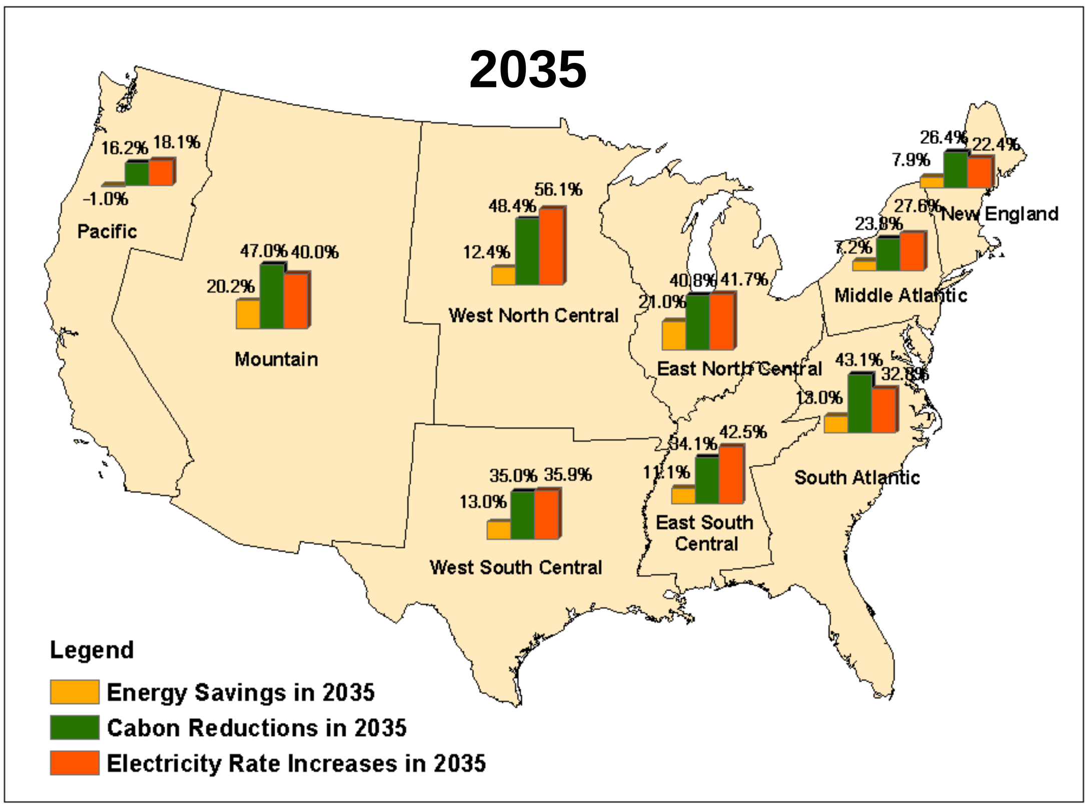


Figure 9. Commercial Energy Consumption, Carbon Emissions and Electricity Rates by Census Division in 2020 and 2035

In the Pacific division, the Carbon Tax + High Tech scenario results in the lowest increase in electricity rates, reflecting the relatively low carbon intensity of energy sources in that region already. The increase in rates reduces carbon emissions but energy consumption is largely unaffected, suggesting that CO_2 emissions and energy consumption have been largely decoupled for this region. This also suggests that a carbon tax is unlikely to motivate much progress in reducing commercial energy consumption in the Pacific Census division.

In 2020, the South Atlantic and New England divisions are the two regions that reduce their CO_2 emissions proportionately more than their electricity prices increase. In 2035, this is also the situation in the Mountain division. These results suggest highly competitive low-carbon substitutes under a carbon tax regime.

The country's four central divisions and the Mountain division are estimated to experience the largest electricity price increases in the Main Tax + High Tech scenario. These are also the five divisions with the highest power sector carbon intensities (Table 13). Thus, these regions appear to have conditions that make it difficult to rapidly move away from carbon-intensive energy sources, even with sizeable increases in electricity prices. At the same time, the carbon reductions increase significantly in these same divisions in 2020 and 2035, suggesting a rapid decarbonization. However, prices are still generally increasing faster than energy savings or carbon reductions.

The projections show that over time, the nine Census divisions generally develop the ability to rely on less carbon-intensive forms of electricity. However, the interactions between all the 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 percent carbon reductions are estimated 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 rate increase and the highest energy savings. 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.

5. Conclusions

Our analysis of a Main Tax + High Tech scenario suggests that a carbon tax would reduce the consumption of energy by commercial buildings by 7% in 2020 and by 12% in 2035, compared with the Reference case. Overall, energy consumption in commercial buildings would continue to grow. CO_2 emissions from the energy used in commercial buildings would decline more significantly: by 18% relative to the Reference case in 2020, and by 38% in 2035. The rapidly declining carbon intensity in the power sector accounts for a majority of the commercial sector's emission reductions. In terms of energy intensity, the Main Tax + High Tech scenario delivers faster and deeper reductions in the commercial sector than in the rest of the economy. Under the Main Tax + High Tech case, energy consumption (and CO_2 emissions) fall in all nine of the end-uses examined here, but especially in lighting.

The effects of carbon taxes on commercial building energy efficiencies would be technologically transformational and geographically broad. While energy expenditures would rise and more capital would be required for energy-efficiency upgrades, the avoided pollution would deliver more than $150 billion in cumulative human health and other benefits through 2035, and the reduced CO_2 emissions would avoid damages worth close to $200 billion over the same period.

While the Main Tax + High Tech scenario would shift commercial buildings toward greater energy efficiency, 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 of 17% below 2005 levels in 2020. 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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Appendix A: Background on Methodology and Analysis Approach

Carbon Tax Schedules

Five carbon tax schedules are examined in this report. Background on each of them is provided below.

Low-Cost Scenario. This low-cost scenario is based on a proposal suggested by Roger Pielke, Jr. to set a global $5-per-ton carbon tax beginning in 2015. As Pielke (2010) explains, the point of a modest carbon tax is not to change people's behavior, to restrict economic activity, or to price fossil fuels at a level higher than alternatives. One purpose of a low-carbon tax is to raise revenues for investments in innovation. If the innovation is successful, leading to the displacement of fossil fuels, it will be more likely that the carbon price could be increased.

Social Cost of Carbon (3% Discount Rate and High Cases). The social cost of carbon (SCC) is defined as an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

The SCC values used in this analysis are based on the central value estimates of the U.S. Government Interagency Working Group on the Social Cost of Carbon (EPA, 2010). In this report, the central value SCC estimates ranged from $23/metric ton of CO_2 in 2011 to $34/metric ton and $47/metric ton in 2030 and 2050, respectively (all values are in $2008).

Three integrated assessment models – FUND, DICE, and PAGE[13] – are used to estimate the SCC in the EPA (2010) report. These models combine climate processes, economic growth, and feedback between the climate and the global economy into a single modeling framework. The general approach to estimating SCC values is to run the three models using the following inputs agreed upon by the interagency group:

- A distribution for the climate sensitivity parameter bounded between 0 and 10 with a median of 3°C and a two-thirds probability of a cumulative probability between 2 and 4.5°C.
- Five sets of GDP, population and carbon emissions trajectories.
- Constant annual discount rates of 2.5, 3, and 5%.

[13] The DICE (Dynamic Integrated Climate and Economy) model by William Nordhaus evolved from a series of energy models (Nordhaus 2008). The PAGE (Policy Analysis of the Greenhouse Effect) model by Chris Hope was developed for use by European decision-makers in assessing the marginal impact of carbon emissions (Hope, 2006). The FUND (Climate Framework for Uncertainty, Negotiation, and Distribution) model by Richard Tol was developed to study international capital transfers in climate policy and more recently to study climate impacts (e.g., Tol, 2002a, and b).

We examine the impact of tax schedules mirroring the SCC damage estimates based on a 2.5% and a 3% discount rate. See EPA (2010) for more details.

EIA GHG Case. The EIA GHG Case is the carbon tax sensitivity "side" case that was published in conjunction with EIA's *Annual Energy Outlook 2011* (EIA, 2011). It assumes an economy-wide carbon tax, starting with moderate values of $25/ton of CO_2 in 2013, but ends with the highest carbon tax rate in 2035 of $75/ton of CO_2.

Main Tax Case. The Main Tax Case essentially tracks the same growth rate as the EIA GHG Case, with implementation of the tax delayed until 2015. The tax is economy-wide, starting at $25/ton in 2015 and increasing at 5% annually, reaching $66.30/ton in 2035.

The Social Cost of Carbon

Our cost-benefit analysis uses estimates of the "social cost of carbon" from the following report:

U.S. Environmental Protection Agency (EPA). 2010. *Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. http://www.epa.gov/otaq/climate/regulations/scc-tsd.pdf

The social cost of carbon (SCC) is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

For each of the three models, the basic computational steps for calculating the SCC in a particular year t are:

1. Input the path of emissions, GDP, and population from the selected EMF-22 scenarios, and the extrapolations based on these scenarios for post-2100 years.
2. Calculate the temperature effects and (consumption-equivalent) damages in each year resulting from the baseline path of emissions.
3. Add an additional unit of carbon emissions in year t. (The exact unit varies by model.)
4. Recalculate the temperature effects and damages expected in all years beyond t resulting from this adjusted path of emissions, as in step 2.
5. Subtract the damages computed in step 2 from those in step 4 in each year. (DICE is run in 10-year time steps, FUND in annual time steps, while the time steps in PAGE vary.)
6. Discount the resulting path of marginal damages back to the year of emissions using the agreed upon fixed discount rates.

7. Calculate the SCC as the net present value of the discounted path of damages computed in step 6, divided by the unit of carbon emissions used to shock the models in step 3.
8. Multiply by 12/44 to convert from dollars per ton of carbon to dollars per ton of CO_2.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three IAMS, at discount rates of 2.5, 3, and 5%. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3% discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

The Hidden Cost of Energy

Our cost-benefit analysis uses estimates of the damage costs of three criteria air pollutants from the following report: *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use* (NRC, 2010).

The Hidden Costs of Energy defines and evaluates key external costs and benefits that are associated with the production, distribution, and use of energy, but are not reflected in market prices. The damage estimates reflect damages from air pollution associated with electricity generation, motor vehicle transportation, and heat generation. The report also considers other effects not quantified in dollar amounts, such as damages from climate change, effects of some air pollutants such as mercury, and risks to national security.

The report estimates that pollution damages totaled $120 billion in 2005, excluding damages from climate change, effects of mercury, impacts on ecosystems, and other difficult-to-monetize damages. The total costs are dominated by human health damages from air pollution associated with electricity generation and vehicle transportation. Also included in the estimates are damages sustained by grain crops and timber yields, buildings, and recreation. Altogether, non-climate damages from coal power plants are estimated to exceed $62 billion annually. These damages average 3.3 ¢/kWh in $2008.

Coal. The NRC used the APEEP model developed by Muller and Mendelsohn (2006) for each of the 406 coal fired plants in 2005. Only SO_2, NO_x, $PM_{2.5}$, and PM_{10} were analyzed. Since other pollutants are not estimated, the full "social" cost of pollution is underestimated. CAMR and CAIR both attempted to address additional pollutants, but both were vacated or remanded by the court system.

The calculation involves translating the emissions into changes in air quality, using concentration-response functions to calculate health and environmental impacts, and valuing the health and environmental impacts. APEEP accounts for the spatial component of emissions and the dilution effects in a county-by-county basis. It cannot, however, model episodic events because it uses annual and seasonal averages.

The PM numbers are obtained from Pope et al. (2002), which might be lower than recent EPA estimates.

Ecosystem damages are listed as a limitation. Acid rain damage to fish and tree canopies were not monetized. Likewise, eutrophication from nitrogen deposition was also not monetized.

$PM_{2.5}$ plays a central role in the Value of a Statistical Life (VSL) discussion – they used $6M US$2000 as the VSL.

$PM_{2.5}$ is associated with premature death and visibility impairments. Both $PM_{2.5}$ and PM_{10} are associated with chronic bronchitis and respiratory or cardiovascular hospital admissions. Ozone impacts crop and timber yields, and SO_2 emissions damage building materials.

The NRC approach compares currently installed technologies to the damages and does not include potential installations of scrubbers or fuel switching that could eliminate most of the impact. This implies that the damages calculated at each plant are an upper bound to the benefits from additional pollution controls.

APEEP also calculates ammonia and ozone damages, but NRC does not include these in the analysis due to missing emissions data for roughly 25% of coal plants. With regard to dropping ammonia damages, NRC reports that for 95% of plants, ammonia emissions represent less than 1% of damages. In the remaining plants, it accounts for up to 14% of damages per kWh. Since higher emissions of ammonia only occur in a small fraction of plants, NRC purports that including ammonia would change the reported damages very little. No explanation is given for dropping ozone.

Direct emissions of $PM_{2.5}$ do have high damages, but the vast majority of this comes from natural sources or construction, and not power production (NRC, 2010 p. 88).

The map below (Figure A.1) shows the distribution of monetized impacts across all power plants. Large damages are concentrated along the Ohio River valley, in the middle Atlantic, and the South.

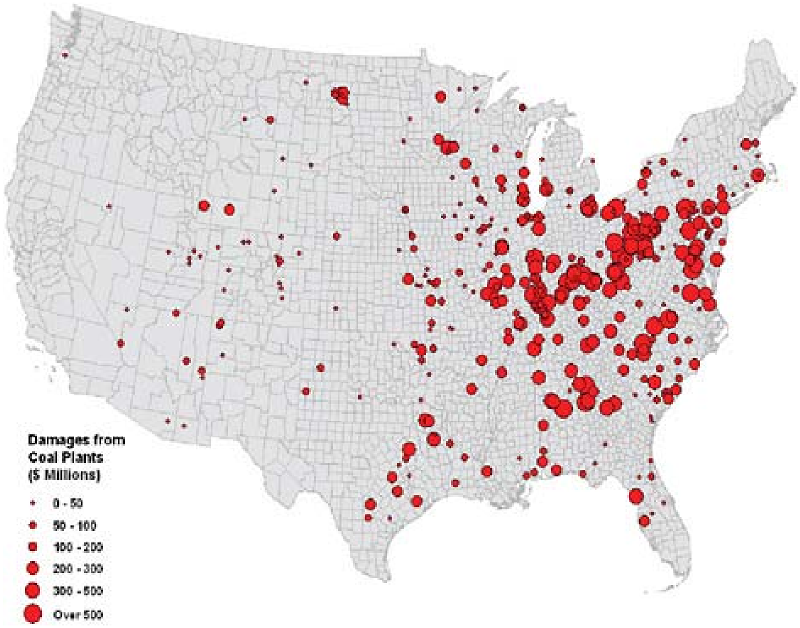

Figure A.1. Air-pollution damages from coal generation for 406 plants, 2005
(U.S. 2007-$) (NRC, 2010, Figure 2-6, p. 90)

Interestingly, distribution is less important for SO_2 damages than the raw emissions, suggesting the dilution factor is not very strong.

Premature mortality represents 94% of the reported damages. Approximately 59.5% of coal fired power plants are not subject to NSPS, which represents 66% of NO_x emissions and 76% of SO_2 emissions. This impedes some of the regulatory power (NRC, 2010, Table 2-10, pp 95-95).

The EPA modeling of CAIR (CMAQ) shows higher benefits than the NRC report because of differences in the air quality model, which estimates nearly twice as much premature mortality and predicts a greater impact than the APEEP model. NRC acknowledges the CMAQ model is more detailed than the APEEP model they employ, but they also criticize that it has an upwards-estimation bias when compared to sample locations. However, this does not fully represent the difference between the two model outputs. APEEP does better with spatial representations than CMAQ, but there is still uncertainty – a model with better spatial resolution may find different results.

2030. NRC made an estimate of damages in 2030 using *AEO 2009* (EIA, 2009). EIA forecasts SO_2 and NO_x emissions, and PM emissions were imputed from the *AEO 2009* estimates. Using the National Electricity Reliability Council (NERC) region outputs, regional multipliers were created and the siting of plants was assumed to not change. Thus, NRC assumptions are consistent with *AEO 2009*, and were deliberate since their charge was meant to ignore policy changes.

AEO 2009 reports that SO_2/MWh would decrease from 10.1 lbs in 2005 to 3.65 in 2030 and NO_x would decrease from 3.42 to 1.90. The NRC used APEEP to model these changes. No adjustment for an older population in the VSL calculation was conducted, though an adjustment for a larger population from census estimates was included. The NRC report assumed VSL increases by 27% due to higher incomes and VSL elasticity. This leads to an increase in damages per pollutant of about 50% per ton, but this varies greatly by county.

All of this leads to monetized air pollution damages of about $38B in 2030, even though net generation is 20% higher. This is because lbs/MWh of SO_2 falls 64% and NO_x and PM emissions fall 50%, counteracting the increase in damages per ton. In the end, NRC projects from this methodology that the externality per ton of electricity will be 1.7¢/kWh by 2030, about half of what is currently the case (3.2¢/kWh). Neither a complete tracking of costs nor a complete set of pollutants is provided by NRC.

Natural Gas. A comparable analysis is conducted for the nearly 500 natural gas plants in the U.S. Results are similar, although the distributional impacts are of greater importance for gas than for coal (dilution factors are more important). PM is also higher, due to distributional emissions.

It appears the NRC analysis was conducted before the increase in shale gas, since the NRC report assumes that the prospects of shale gas might be limited and that liquid natural gas (LNG) and synthetic natural gas (SNG) are more likely to be supplies for natural gas.

Based on the *AEO 2009* (EIA, 2009), EIA projected a 9% increase in natural gas usage by 2030, a 19% decrease in NO_x, a 32% decrease in PM, and a 51% decrease in SO_2. The projected damages per ton increase like the case of coal. Overall, damages fall from $0.74B in 2005 to $0.65B in 2030 (from 0.16 ¢/kWh to 0.11¢/kWh).

Calculation of Technology Investment Costs

We estimate the magnitude of technology investment costs in the commercial sector separately for new purchase, replacements, and retrofits, as follows.

- New Purchases
  - SD_{new} x (Cost/8760) x 1/CF = Investment Cost
    - SD_{new} is a KSDOUT output, as are $SD_{replacement}$ and $SD_{surviving}$
- Replacements
  - $SD_{replacement}$ x (Cost/8760) x 1/CF = Investment Cost
- Retrofits
  - $SD_{surviving}$ x (Cost/8760) x 1/CF x 0.022/($SD_{surviving}$/SD_{total})
    - Where SD_{total} = SD_{new} + $SD_{replacement}$ + $SD_{surviving}$ and 0.022 is the average amount of commercial floorspace undergoing a retrofit
    - This proportions the surviving service demand to the commercial sector retrofit average

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Appendix B. Technology Shifts by Commercial Energy End-Uses

Table B.1. Technology Shifts in Electric Space Heating: Main Tax Scenario vs Reference Case

Winner Technologies	Change in Service Demand (TBtu)*		COP	Cost (2007$/1000 Btu Out/hour)
	2020	2035		
Rooftop ASHP-heat 2030 high	0	8.612	3.8	96.67
Commercial GSHP-heat 2011 typical	2.384	4.343	3.5	120
Commercial GSHP-heat 2020-30 typical	0.123	1.422	4	120
Commercial GSHP-heat 2011 typical 10% ITC w MACRS	2.846	1.045	3.5	87
Commercial GSHP-heat 2011 high 10% ITC w MACRS	1.449	0.543	4.9	108
Commercial GSHP-heat 2011 high	0.29	0.391	4.9	150
Rooftop ASHP-heat 2007 high	0	0.001	3.4	96.67
Loser Technologies	**2020**	**2035**	**COP**	**Cost**
Rooftop ASHP-heat 2010 typical	-14.955	-28.82	3.3	76.67
Other electric packaged space heat	-2.618	-9.576	0.93	16.87
Commercial GSHP-heat 2007 typical	-2.193	-4.26	3.5	140
Electric boiler 2003 installed base	-0.409	-1.136	0.94	17.53
Commercial GSHP-heat 2007 typical 10% ITC w MACRS	-2.21	-0.807	3.5	101
Commercial GSHP-heat 2007 high 10% ITC w MACRS	-1.64	-0.61	4.9	118
Other electric packaged spc heat	-0.21	-0.246	0.93	22.36
Commercial GSHP-heat 2007 high	-0.153	-0.157	4.9	170
Rooftop ASHP-heat 2007 typical	-0.002	-0.004	3.2	72.78
Rooftop ASHP-heat 2003 installed base	-0.003	-0.002	3.1	63.89
Commercial GSHP-heat 2003 installed base	-0.002	-0.001	3.4	140
Grand Totals (Changes in Service Demand) & Weighted Averages of COP and Cost (based on 2035 service demand)	**-17.303**	**-29.262**	**1.67**	**55.9**

Notes:
Technologies in red are new technologies added to the High Tech case.
*The change in service demand is the difference between the service demand in the Main Tax+High Tech case and the Reference Case. Positive numbers mean more service demand for that technology in the Main Tax+High Tech Case relative to the Reference case. Technologies are ranked based on their change in 2035 service demand.

Table B.2. Technology Shifts in: Natural Gas Space Heating Main Tax Scenario vs Reference Case

Winner Technologies	**Change in Service Demand (TBtu)***		**COP**	**Cost (2007$/1000 Btu Out/hour)**
	2020	**2035**		
Gas furnace 2011 high	603.347	924.016	0.94	9.76
Gas boiler 2011 high	22.623	29.554	0.95	37.08
Residential gas HP-heat 2030 typical	0	1.451	1.50	141.67
Residential type gasHP-heat 2020 typical	0.38	1.433	1.50	150.00
Loser Technologies	**2020**	**2035**	**COP**	**Cost**
Gas furnace 2030 high	0	-258.812	0.94	9.76
Gas furnace 2020 high	-45.765	-240.976	0.94	9.76
Gas furnace 2030 typical	0	-117.477	0.80	9.12
Gas furnace 2020 typical	-22.268	0112,358	0.79	9.23
Gas furnace 2007-2010 high	-293.066	-80.046	0.80	9.90
Gas furnace 2007 current standard/typ	-169.136	-56.11	0.78	9.35
Gas boiler 2007-2010 high	-31.757	-30.181	0.95	38.28
Gas furnace 2003 installed base	-38.572	-11.994	0.71	10.20
Gas boiler 2012 standard	-2.705	-11.241	0.80	21.02
Gas boiler 2003 installed base	-6.582	-5.016	0.73	20.78
Residential gas HP-heat 2007 typical	-0.396	-2.805	1.40	158.33
Gas boiler 2007 mid-range	-1.28	-0.879	0.84	24.35
Gas boiler 2007 current standard/typical	-0.26	-0.612	0.78	21.56
Grand Totals (Changes in Service Demand) & Weighted Averages of COP and Cost (based on 2035 service demand)	**14.563**	**27.946**	**0.89**	**12.7**

Notes:
Technologies in red are new technologies added to the High Tech case.
*The change in service demand is the difference between the service demand in the Main Tax+High Tech case and the Reference Case. Positive numbers mean more service demand for that technology in the Main Tax+High Tech Case relative to the Reference case. Technologies are ranked based on their change in 2035 service demand.

Table B.3. Technology Shifts in: Electric Space Cooling
Main Tax Scenario vs Reference Case

Winner Technologies	Change in Service Demand (TBtu)*		COP	Cost (2007$/1000 Btu Out/hour)
	2020	2035		
Rooftop AC 2011 typical	330.51	492.292	3.28	66.67
Centrifugal chiller 2020 typical	2.426	34.857	7.00	36.67
Reciprocating chiller 2020 typical	3.21	26.509	3.20	38.75
Wall-window room AC 2020 typical	1.81	18.298	3.22	33.81
Reciprocating chiller 2030 high	0	8.652	3.78	42.08
Rooftop AC 2030 high	0	8.231	3.81	80.56
Screw chiller 2030 high	0	3.245	3.91	42.08
Screw chiller 2020 high	0.343	2.983	3.63	42.08
Reciprocating chiller 2007 high	5.601	2.348	3.52	47.08
Centrifugal chiller 2010 typical	5.328	2.155	6.40	36.67
Loser Technologies	**2020**	**2035**	**COP**	**Cost**
Rooftop AC 2007 mid range	-326.233	-490.385	3.28	72.22
Wall-window room AC 2007current standard	-7.469	-42.572	2.87	26.67
Reciprocating chiller 2003 installed base	-7.359	-37.148	2.34	33.75
Centrifugal chiller 2003 installed base	-4.945	-13.022	4.69	29.17
Rooftop ASHP-cool 2010 typical	-4.829	-8.171	3.22	76.67
Scroll chiller 2020 typical	-0.605	-7.857	3.08	36.25
Residential central AC 2007 E-star	-1.827	-5.019	4.10	73.81
Residential central AC 2006 standard/2007 typical	-2.221	-4.48	3.81	67.86
Commercial GSHP-cool 2007-2010 typical	-0.606	-1.329	4.1	140
Wall-window room AC 2030 typical	0	-0.66	3.22	33.81
Scroll chiller 2010 typical	-1.634	-0.586	2.99	36.25
Grand Totals (Changes in Service Demand) & Weighted Averages of COP and Cost (based on 2035 service demand)	**-5.215**	**-5.755**	**3.47**	**46.9**

Notes:
Technologies in red are new technologies added to the High Tech case.
*The change in service demand is the difference between the service demand in the Main Tax+High Tech case and the Reference Case. Positive numbers mean more service demand for that technology in the Main Tax+High Tech Case relative to the Reference case. Technologies are ranked based on their change in 2035 service demand.

Table B.4. Technology Shifts in: Electric Water Heating
Main Tax Scenario vs Reference Case

Winner Technologies	Change in Service Demand (TBtu)* 2020	2035	COP	Cost (2007$/1000 Btu Out/hour)
Solar water heater 2030 typical south	0	4.199	2.50	175.85
Solar water heater 2020 typical south	0.305	2.259	2.50	205.16
Solar water heater 2011 typical 30 pct ITC south	2.72	1.044	2.50	193.76
HP water heater 2020 typical	0.069	0.689	2.30	210.71
HP water heater 2011 typical	1.452	0.396	2.30	225.0
Solar water heater 2010 typical south	0.332	0.127	2.50	249.12
Loser Technologies	**2020**	**2035**	**COP**	**Cost**
Electric water heater 2007 current standard/typical	-1.847	-8.771	0.97	21.82
Solar water heater 2010 typical 30 pct ITC south	-2.272	-0.882	2.50	205.16
Electric water heater 2003 installed base	-0.218	-0.323	0.96	16.96
HP water heater 2003 typical	-0.865	-0.24	2.00	232.14
HP water heater 2007-10 typical	-0.282	-0.075	2.30	253.57
Grand Totals (Changes in Service Demand) & Weighted Averages of COP and Cost (based on 2035 service demand)	**-0.606**	**-1.577**	**1.10**	**63.5**

Notes:
Technologies in red are new technologies added to the High Tech case.
*The change in service demand is the difference between the service demand in the Main Tax+High Tech case and the Reference Case. Positive numbers mean more service demand for that technology in the Main Tax+High Tech Case relative to the Reference case. Technologies are ranked based on their change in 2035 service demand.

Table B.5. Technology Shifts in: Natural Gas Water Heating
Main Tax Scenario vs Reference Case

Winner Technologies	Change in Service Demand (TBtu)* 2020	2035	COP	Cost (2007$/1000 Btu Out/hour)
Gas water heater 2020 high	26.838	290.587	0.95	26.40

Loser Technologies	2020	2035	COP	Cost
Gas water heater 2007 high	-16.346	-228.087	0.93	26.97
Gas water heater 2007 current_standard/typical	-10.836	-60.888	0.78	16.03
Gas water heater 2003 installed base	-0.282	-0.723	0.75	13.33
Grand Totals (Changes in Service Demand) & Weighted Averages of COP and Cost (based on 2035 service demand)	**-0.626**	**0.889**	**0.89**	**23.2**

Notes:
Technologies in red are new technologies added to the High Tech case.
*The change in service demand is the difference between the service demand in the Main Tax+High Tech case and the Reference Case. Positive numbers mean more service demand for that technology in the Main Tax+High Tech Case relative to the Reference case. Technologies are ranked based on their change in 2035 service demand.

Table B.6. Technology Shifts in: Lighting
Main Tax Scenario vs Reference Case

Winner Technologies	Change in Service Demand (TBtu)* 2020	2035	Luminous Efficacy (lumens/watt)	Cost ($2007 /thousand lumens)
LED 2020-2029 Typical	1.657	178.84	181	138.89
F32T8 Super	27.695	110.389	56.4	21.71
LED 2020-2029 Typical	0.153	45.299	181	138.89
72W Inc (Halogena Type HIR)	0	38.982	12.2	79.19
LED 2011-2019 Typical for high tech	9.352	4.207	86.8	196.79
F96T8 High	0.885	0.633	73.5	9.56
F96T8HO LB	0.327	0.544	71.8	17.56
LED 2020-2029 Typical	0	0.025	181	138.89
LED 2020-2029 Typical	0	0.007	181	138.89
Loser Technologies	**2020**	**2035**	**Luminous Efficacy**	**Cost**
F96T8 Typical	-0.38	-0.405	73.5	11.70
90W Halogen PAR-38	-0.693	-0.781	13.5	56.59
MH 175	-0.637	-0.818	46.9	39.35
F28T5	2.227	-1.487	71.5	31.98
90W Halogen PAR-38	-1.219	-1.852	13.5	57.15
F32T8	-0.169	-3.041	56.4	20.51
LED 2010-2019 Typical	-7.907	-3.571	86.8	198.19
70W HIR PAR-38	-1.592	-63.857	16.7	59.62
F32T8 HE - standard	-32.777	-152.16	60.6	21.09
26W CFL	-0.569	-152.582	41.1	65.18
Grand Total	**-5.178**	**-2.957**	**62.1**	**39.1**

Notes:
Technologies in red are new technologies added to the High Tech case.
*The change in service demand is the difference between the service demand in the Main Tax+High Tech case and the Reference Case. Positive numbers mean more service demand for that technology in the Main Tax+High Tech Case relative to the Reference case. Technologies are ranked based on their change in 2035 service demand.

Figure B-1. Technology Shifts:
Main Tax + High Tech Scenario vs Reference Case

Technology	2010-2020		2020-2035	
	Ascendant	Declining	Ascendant	Declining
Electric Space Heating	Ground source heat pumps	Air source heat pumps	High efficiency air source heat pumps	Low efficiency air source heat pumps
Natural Gas Space Heating	High efficiency furnaces and boilers	Low efficiency furnaces and boilers	High efficiency gas furnaces and boilers	Low efficiency furnaces and boilers
Electric Cooling	Mid-efficiency rooftop AC	Expensive rooftop AC; wall and window AC	Mid-efficiency rooftop AC	Expensive rooftop AC and low efficiency chillers
Electric Water Heating	Solar and heat pump water heaters	Electric resistance water heaters	High efficiency solar and heat pump water heaters	Electric resistance water heaters
Natural Gas Water Heating	Standard Gas water heaters	High efficiency gas water heaters	High efficiency gas water heater	Older high efficiency gas water heaters
Lighting	Advanced F32T8 and LEDs	Standard F32T8 HE and LEDs	Typical F32T8 and LEDs	26W CFLs, Standard F32T8 HE, 70W HIR-PAR-38