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Policy Drivers for Improving Electricity End-Use Efficiency in the U.S.: An Economic-Engineering Analysis

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ABSTRACT

This paper estimates the economically achievable potential for improving electricity end-use efficiency in the U.S. The approach involves identifying a series of energy-efficiency policies aimed at tackling market failures, and then examining their impacts and cost-effectiveness using Georgia Tech's version of the National Energy Modeling System (GT-NEMS). By estimating the policy-driven electricity savings and the associated levelized costs, a policy supply curve for electricity efficiency is produced. Each policy is evaluated individually and in an Integrated Policy scenario to examine policy dynamics. The Integrated Policy scenario demonstrates significant achievable potential: 261 TWh (6.5%) of electricity savings in 2020, and 457 TWh (10.2%) in 2035. All eleven policies examined were estimated to have lower levelized costs than average electricity retail prices. Levelized costs range from 0.5 – 8.0 cent/kWh, with the regulatory and information policies tending to be most cost-effective. Policy impacts on the power sector, carbon dioxide emissions, and energy intensity are also estimated to be significant.

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Any remaining errors are the sole responsibility of the authors.

1. INTRODUCTION

The potential for improved electric end-use efficiency has invoked great interest over the past several decades because the cheapest megawatt hour of electricity is often the one that is not produced (Croucher, 2011). In addition, reducing electricity consumption through energy efficiency also helps conserve fossil fuels, reduce carbon dioxide emissions, improve air quality, and strengthen grid stability.

Comprehensive and integrated resource planning should consider the potential for increases in energy efficiency to reduce the requirements for new generation and transmission investments. Electricity planners have many options at their disposal: supply-side options, such as central power plants, distributed generation, and energy storage; as well as demand-side options, such as demand response and energy efficiency. What combination of these resources can deliver the most reliable, affordable, and clean electricity? Improvements to the knowledge base and modeling capabilities surrounding energy-efficiency resources are critical to the integrity of transmission expansion planning and the optimization of state and regional energy policies.

The unexploited economic potential for energy efficiency, usually referred to as the “energy-efficiency gap”, emphasizes the technically feasible energy-efficient technologies and practices that are cost-effective but are not being deployed. The energy-efficiency gap has attracted wide attention among policy analysts, since society has forgone many cost-effective investments in energy efficiency. This term was first "coined" by Hirst and Brown (1990) in a paper titled "Closing the Efficiency Gap: Barriers to the Efficient Use of Energy." Many other studies have used similar definitions, such as the International Energy Agency (2007) and Jaffe and Stavins (1994). The energy-efficiency gap exists in many sectors, including households, small businesses, corporations, and governments (Dietz, 2010).

Numerous obstacles – including market failures and barriers – contribute to the energy efficiency gap. Market failures are conditions of a market that violate one or more neoclassical economic assumptions defining a competitive market. Traditionally, market failures were attributed to (1) misplaced incentives; (2) distortionary fiscal and regulatory policies; (3) unpriced costs such as air pollution; (4) unpriced goods such as education, training, and technological advances; and (5) monopoly power. More recent literature focuses on information-based market failures including a general lack of information, information asymmetries, and price signaling. This literature draws upon advances in behavioral economics that focus on incentives provided by distributions of information that are less than perfect, but which are arguably commonplace (Jaffe and Stavins, 1994). Government or policy failures have also been enumerated in recent reviews, emphasizing that markets can fail and energy efficiency opportunities can go untapped because of distortions imposed by existing policies and regulations (Brown & Chandler, 2008)

“Market barriers” include other obstacles that contribute to the slow diffusion and adoption of energy-efficient innovations (Hirst & Brown, 1990; Jaffe & Stavins, 1994; Levine, et al., 1995). To the extent that it is in society’s best interest to use its energy more efficiently, improve grid reliability, and reduce emissions from fossil fuel combustion, it is important to understand the full range of obstacles to energy-efficient technologies. These barriers include: (1) the low priority of energy issues among consumers, (2) capital market imperfections, (3) incomplete markets for energy-efficient features and products, and (4) prolonged infrastructure longevity routed in the behavioral economics of sunken costs.

Apart from barriers, estimates of the energy efficiency potential and the design of effective policies must also consider economic and social/institutional drivers of energy efficiency. The business case for energy efficiency varies across market sectors, types of households, firm size, and region of the country, and it reflects a variety of motivations for using energy more wisely. Nevertheless, common motivations emerge from the literature, as summarized in the report on "Strategies for the Commercialization and Deployment of Greenhouse Gas Intensity-Reducing Technologies and Practices" (CCCSTI, 2009): (1) volatile and rising energy prices; (2) environmental concerns and regulations; (3) demand charges and demand response incentives; (4) collateral benefits such as increased productivity, improved product quality, reduced labor costs, and enhanced reliability; (5) international competition; (6)corporate sustainability; (7) consumer and shareholder activism, good corporate governance, and reputation management; and (8) insurance access and costs, legal compliance, and concerns regarding fiduciary duty**.** Most of these drivers for energy efficiency were highlighted in the study of *Real Prospects for Energy Efficiency in the United States* (National Academies, 2009).

Numerous policy levers are available to address traditional market failures and barriers and to leverage drivers for energy efficiency (Brown & Sovacool, 2011; Geller, 2002). One succinct typology of policies identifies three ways of exploiting the achievable potential for energy efficiency: (1) financial assistance, including subsidies, bulk procurements, and loan guarantees; (2) regulatory requirements, such as codes, standards, and cap and trade programs; and (3) information programs including labeling, education, R&D support, and workforce training (Brown et al., 2011). This study follows this typology to classify energy efficiency policies.

The principal objective of this paper is to accurately estimate the economically achievable potential for improving the energy-efficiency of homes, commercial buildings, and industrial plants. The approach of this paper involves identifying a series of energy-efficiency policies and examining their impacts and cost-effectiveness. We emphasize the impacts on electricity consumption and the levelized cost of policy-driven electricity savings. By constructing a policy supply curve, we characterize policies as opportunities to promote energy efficiency from the societal perspective. We also consider the impacts of these policies on the U.S. energy market, CO_2 emissions and the whole economy.

2. ENERGY EFFICIENCY: POTENTIAL ASSESSMENTS AND COST ESTIMATIONS

This study focuses on estimating the achievable potential for improved energy efficiency in the U.S., defined as the portion of the energy-efficiency gap that can be narrowed by the implementation of policies and programs. Other common definitions of energy efficiency potential include the technical potential, usually engineering estimates from all technically feasible measures without considering costs, and the economic potential, which is generally a subset of technical potential that must pass a cost test. The achievable potential is distinguished from technical and economic potentials by considering a policy effort in estimating the achievable potential (NYSERDA, 2003; Rufo & Coito, 2002).

A large body of literature has focused on the economic potential for energy-efficiency measures, as summarized in Table 1. These assessments are derived from theory, simulation, and real-world practices, and they have been conducted at various geographic scales, covering different time frames.

Scenarios for a Clean Energy Future (Brown, et al., 2001a) and a study by McKinsey & Co. (Granade et al., 2009) are national in scope and focus on the 2020 time frame. Brown et al. (2001) used a technology-based accounting approach and concluded that removing obstacles to energy efficiency through policy interventions initiated in the year 2000 could have reduced the forecasted U.S. energy consumption in 2020 by 19% and U.S. electricity consumption by 24%. The McKinsey and Company study estimates the NPV-positive potential for energy efficiency savings in non-transportation uses of energy. It finds that energy efficiency programs can save the nation 9.1 quadrillion Btu (23%) in end-use energy and 18.4 quadrillion Btu in primary energy by 2020. The American Council for an Energy-Efficient Economy (ACEEE) completed a meta-review of energy efficiency potential assessments in the U.S. (Nadel et al., 2004). This review concluded that, across the U.S., the median technical potential is 33%, the median economic potential is 20%, and the median achievable potential is 24%. The overall median achievable potential is an annual energy savings of 1.2%, with similar savings from each end-use sector. A more recent ACEEE study investigates the long-term efficiency potential associated with technology advances and policy improvements (Laitner, et al., 2012). By comparing their policy scenarios with EIA's projection – the Annual Energy Outlook 2010 – the overall potential of energy efficiency is estimated to be 42-59% by 2050. The timeframe and the type of estimated potential vary widely from study to study, making the median numbers relatively unreliable estimations.

Table 1. Assessments of Energy-Efficiency Potential

Publication	Application			Potential Assessment		Cost Estimate	Policy Relevance
	Area	End-use sector	Fuel	Type	Estimation		
Brown et al (2001)	U.S.	Residential	Total energy	Achievable	9-20% by 2020	Total net saving: 62-108 Billion 1997$ in 2020	Estimation based on moderate and advanced policy scenarios examining about 50 policy options
		Commercial			9-18% by 2020		
		Industrial			8-17% by 2020		
Tonn & Peretz (2007)	U.S.	Residential and Industry	Total energy	Achievable	20-30% over a 20-year period	B/C ratio greater than 3:1	Potential achieved by standard energy efficiency programs
Scott, et al (2008)	U.S.	Residential and Commercial	Total energy	Achievable	27% by 2030		Impacts of the 2005 Building Technology program
Granade et al. (2009)	U.S.	Building and Industry	Total energy	Economic	23% by 2020	Average annualized cost: $4.4/MMBtu (	
Brown, et al. (2010)	U.S. southeast states	Residential, Commercial and Industry	Total energy	Achievable	9-12% in 2020; 13-18% in 2035	Levelized cost of electricity: 0.9-15 cent/kWh	Explores 8 policy options promoting efficiency
Kneifel (2010)	16 cities in the U.S.	Commercial	Total energy	Economic	20-30% for new buildings		
Saygin, et al (2011)	U.S.	Chemical and petrochemical industry	Total energy	Economic	24% with top-down approach; 10.9% with bottom-up approach		
Sadineni,et al (2011)	U.S.	Residential	Total energy	Economic	42.5%		
Laitner, et al. (2012)	U.S.	All Sectors	Total energy	Economic	42-59% by 2050		Technology advances and policy improvements modeled
McKane and Hasanbeigi (2011)	Global	Industrial motor systems	Total energy	Technical	27-57%		
				Economic	14-49%		
Fleiter, et al (2012)	Germany	Pulp and paper industry	Total energy	Economic	21% by 2035		
			Electricity	Economic	16% by 2035		

Many studies produce potential estimates at the state level. One of these, by Tonn and Peretz (2007), estimated that standard residential and industrial energy-efficiency programs have energy-efficiency potentials of 20-30% over a 20-year period. The programs studied in that review are generally cost-effective, with benefit-to-cost ratios exceeding 3:1. Neuhoff, et al. (2012) conclude that the most aggressive Energy Efficiency Resource Standards (requiring utilities or program administrators to reach specific goals for energy savings) target energy-efficiency savings of about 2% per year, or electricity savings of about 20% in total between 2010 and 2020. Nadel et al. (2004) summarizes the electricity savings actually achieved by utilities in some of the leading states based on historical data. The leading utilities were estimated to achieve annual electricity savings of 0.5-2.0%. Policy instruments, such as subsidies, income taxes, and carbon taxes can make efficiency investments more profitable(Amstalden, et al., 2007), and energy labeling can improve efficiency in household energy use (Feng, et al, 2010). Recent modeling assessments of energy-efficiency potential have documented a significant achievable potential in the South (Brown et al., 2010), in Appalachia (Brown et al., 2009), and in industry (Brown, et al., 2011).

Some of the energy efficiency potential assessments are coupled with cost estimates with widely varying results due to the variable cost accounting methods applied in different studies. A review by Gellings, Wikler, & Ghosh (2006) found that the full life-cycle cost of energy saved ranges from 0.8 -22.9 cents/kWh (in 2002$) for demand-side management (DSM) programs. Many studies use modeling tools to forecast and estimate potential energy savings and the cost of energy saved. For example, the McKinsey report estimates the average annualized cost for energy efficiency measures to range from $0.4-16 /MMBtu, averaging at $4.4 per MMBtu end-use energy saved (Granade et al., 2009). An assessment of energy efficiency potential conducted by the Electric Power Research Institute (EPRI) forecasts the potential energy saving that would be achieved by utility DSM programs in the U.S. to be 398-566 billion kWh (8-11%) in 2030, with estimated levelized costs between $0.022 and 0.032/kWh (Electric Power Research Institute, 2009).

These studies generally suggest high cost-effectiveness for energy efficiency while many ex post assessments tend to estimate higher costs than ex ante studies. An ex poste study estimate the cost of saved energy to be $0.016-0.033/kWh, with an average of $0.025/kWh, based on utility and state evaluations and reports for electricity programs in 14 states (Friedrich, et al., 2009). Other ex post estimations have reported higher levelized costs for energy efficiency. For example, Arimura, et al. (2011) estimate that utility-operated demand-side management programs between 1992 and 2006 saved electricity at a program cost averaging $0.05/kWh using a 5% discount rate, with a 90% confidence interval ranging from $0.03 to $0.98/kWh. Auffhammer, Blumstein and Fowlie (2008) use utility panel data to construct weighted average cost estimates for demand-side management programs. Their findings suggest low cost-effectiveness for DSM programs, with costs ranging from \$0.053 to \$0.151/kWh.

With cost estimates, many studies are able to draw an energy conservation supply curve, also called energy efficiency supply curve, to identify the most cost-effective efficiency options or the lowest hanging fruit (Gellings et al., 2006; Koopmans & te Velde, 2001). Supply curves for energy-efficient equipment have been evaluated since the early 1980's (Brown, et al., 1998; Meier, et al., 1982), culminating with the well-known study by McKinsey & Co. (Granade et al., 2009). Supply curves for energy-efficiency policies are a recent extension of this approach. Rather than aligning energy-efficient technologies by cost and impact, policy supply curves portray the cost and impact of policies, a focus which should be appealing to policy analysts and energy program managers.

3. METHODOLOGY

It is difficult to quantify the exact magnitude of the energy-efficiency gap. One approach to characterizing its size is through modeling. This typically involves enumerating on a technology-by-technology basis the difference between current practice and best practice, where best practice is defined as the utilization of the most cost-effective energy-efficient technologies. Keeping in mind the natural rate of equipment turnover through consumer purchases, one can then estimate the size of the gap that exists and that can be reduced by policy efforts.

In this study, a portfolio of eleven energy-efficiency policies is modeled with the Georgia Institute of Technology's version of National Energy Modeling Systems (GT-NEMS) to estimate the long-term achievable potential in the U.S. Supplemental spreadsheet analysis is used to estimate the levelized cost of electricity (LCOE) that could potentially be saved, based on GT-NEMS output for each of the financial, regulatory and information policies. Similarly, estimates of carbon dioxide emissions and reductions in fuel consumption for all end-use sectors can also be extracted from GT-NEMS output.

3.1 National Energy Modeling System

GT-NEMS is the principal modeling tool used in this paper, supplemented by spreadsheet calculations. Specifically, we employ the version of NEMS that generated EIA's *Annual Energy Outlook 2011* (U.S. Energy Information Administration (EIA), 2011), which forecasts energy supply and demand for the nation up to 2035. NEMS models U.S. energy markets and is the principal modeling tool used to forecast 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" 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 use 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 highly suited to projecting how alternative assumptions about resource availability, consumer demand, and policy implementation may impact energy markets over time.

The GT-NEMS "Reference case" projections are based on federal, state, and local laws and regulations in effect at the time of the analysis. The baseline projections developed by the EIA via NEMS are published annually in the *Annual Energy Outlook*, which is regarded as a reliable reference in the field of energy and climate policy. The reference case forecast has incorporated the impacts of current national-level policies on energy consumption. We have used GT-NEMS to perform scenario analysis under a consistent modeling framework in order to compare policy options to the Reference case projections.

GT-NEMS also provides estimates of the carbon intensity of electricity generation based on generation resources over time. The benefit of reduced CO_2 emissions are estimated by subtracting the emissions in the Reference case from the policy scenario and then multiplying by the "social cost of carbon" (SCC). The SCC is an estimate of the monetized damages caused by a metric ton of CO_2 emitted in a given year. The social cost of carbon used in this analysis is the central value of the U.S. Government Interagency Working Group on the Social Cost of Carbon (EPA, 2010), growing from $23/metric ton in 2011 to $47/metric ton in 2050 (all values are in 2008-$ and account for global avoided damages).

3.2 Energy Efficiency Policy Levers

A suite of eleven policies was selected to estimate the achievable potential for energy efficiency: four regulatory policies, four financial policies, and three information policies (Table 2). For residential buildings, five policies are designed to accelerate the adoption of energy-efficient technologies and to promote the installation of energy-efficient building envelopes. For commercial buildings, three policies are designed to expand investments in energy-efficiency improvements. In the industrial sector, the policies target motor systems and other efficiency improvements in various industrial processes, as well as combined heat and power ("CHP") systems to make use of waste heat in industrial processes.

Financial incentives, such as subsidies, on-bill financing and other financing options, are offered to energy-efficient technologies. For residential buildings, 25 energy-efficient home appliances and equipment were selected from the NEMS technology profile. Financial incentives (either a subsidy or zero-interest loan) were then modeled by reducing the capital costs of these selected technologies. Similarly, 110 commercial building technologies were selected and offered flexible financing options. For industries, combined heat and power systems are consider energy-efficient technologies when they utilize waste heat to produce electricity. Incentives are provided for the installation of industrial CHP systems for ten years.

Regulatory policies impose standards and mandates to enhance efficiency improvements. Building energy codes were modeled to represent shell efficiency improvements in buildings. In the residential sector, compliance with new building codes was assumed implicitly when less stringent codes were forced to gradually retire. For commercial buildings, the whole building stock is assumed to progress in shell efficiency gradually to reach the efficiency level equivalent to the most recent code, ASHRAE 90.1-2010, with 100% compliance in 2035. Appliance standards were applied to remove inefficient house technologies from the market. We also model a new 2017 standard that raises the minimum efficiency of industrial motors by 25%.

Table 2 Selected Policies for Electric End-Use Efficiency

Sector	Policy Type	Policy	Scenario Description
Residential	Financial	Appliance Incentives	Providing a 30% subsidy to cut down capital costs for the most efficient technologies
	Financial	On-Bill Financing	Offering zero-interest loans for the most efficient technologies
	Regulatory	Building Codes	Adding four new building codes to improve shell and equipment efficiency
	Regulatory	Aggressive Appliance Policy	Accelerate market penetration for energy efficiency technologies by eliminating the least efficient ones from the market
	Information	Market Priming	Reducing high discount rates (10-50%) to 7% for private investment in efficient technologies
Commercial	Financial	Financing	Offering flexible financing options to lower the up-front costs of highly energy-efficient equipment
	Regulatory	Building Codes	Requiring higher building shell efficiency and more stringent standards on space heating and cooling equipment
	Information	Benchmarking	Requiring utilities to submit whole building energy consumption data to a uniform database accessible by building owners
Industrial	Regulatory	Motor Standard	New motor standard in 2017 requiring efficiency improvement and 25% more savings for motor system
	Financial	CHP Incentives	Offering a 30% investment tax credit (ITC) for industrial CHP systems for 10 years
	Information	Advanced Manufacturing Initiative	Promoting plant utility upgrades by identifying efficiency opportunities with cost assessments and estimations of potential energy savings.

In addition, a broad set of information instruments was explored in the policy scenario. For homes, the Market Priming policy is a combination of several information options, including mandated disclosure of home energy consumption or performance at the point of sale or lease of a residential unit, home rating, green labeling, and other technical assistance features such as home energy audits and assistance with green leases, etc. For commercial buildings, the benchmarking policy requires utilities to submit whole building energy consumption data to a uniform database accessible by building owners. Studies suggest that providing information can reduce discount rates used in investment decisions from 3% to 22% (Coller & Williams, 1999; Goett, 1983). Thus, adjusting discount rate was the NEMS lever used for modeling Market Priming and Benchmarking. For industries, Advanced Manufacturing Initiative is the information-based policy that provides information about efficiency opportunities for plant utility upgrades. The impact of this information is based on the potential efficiency improvements from the Industrial Assessment Centers (IAC) database.

The eleven energy-efficiency policies were firstly modeled in individual policy scenarios, with carefully selected NEMS levers to avoid overlap. These policies were then modeled in a single integrated policy case to examine the synergy effect of energy-efficiency policies. Modeling details of these policies can be found in the appendix.

3.3 Calculation of Levelized Cost of Electricity

The LCOE of each policy was calculated to estimate the cost of achieving the electricity-savings potentials in individual policy scenarios. The calculation of LCOE is based on the total resource cost test, where costs include the incremental private investment in energy-efficiency measures, program costs for providing incentives, information, technical and other assistance, and program administrative costs. Table 3 illustrates the private and public costs calculated for each energy-efficiency policy.

Table 3 Private and Public Costs in LCOE Calculation

Policy	Private Cost	Public/Utility Cost
Appliance Incentives	Incremental cost of equipment expenditure	30% subsidy on equipment expenditure; program administrative cost
On-Bill Financing	Incremental cost of equipment expenditure	Loan seed money; program administrative cost
Residential Building Codes	Incremental cost of equipment expenditure; shell installation cost	Program administrative cost
Aggressive Appliance Policy	Incremental cost of equipment expenditure	Program administrative cost
Market Priming	Incremental cost of equipment expenditure	Program administrative cost
Commercial Financing	Incremental cost of equipment expenditure	Subsidy cost; program administrative cost
Commercial Building Codes	Incremental cost of equipment expenditure; shell improvement cost	Program administrative cost
Benchmarking	Incremental cost of equipment expenditure	Compliance cost
Motor Standard	Incremental cost of equipment expenditure	Program administrative cost
CHP Incentives	Incremental cost CHP equipment	Subsidy cost; program administrative cost
Advanced Manufacturing Initiative	Private investment for plant upgrade	Program administrative cost

We estimate the magnitude of technology investment costs differently for the three end-use sectors. In the residential sector, costs are increased equipment expenditure extracted directly from GT-NEMS model output. Equipment expenditure are calculated separately for new buildings and replacements , as a function of the number of units purchased and purchase costs for a range of technologies. In the commercial sector, investment costs are estimated separately for new purchases, replacements, and retrofits for approximately 350 technologies uniquely defined by technology type, fuel use, purchase price, energy efficiency, and time frame of availability in the marketplace. In each case, the calculation is based on GT-NEMS estimates of service demand for energy (SD), costs per unit of SD, and capacity factors. In industry, costs for CHP investments are based on the installed costs per KW of capacity for eight different types of CHP systems. These revised costs per kW of installed capacity are codified in GT-NEMS. Other costs for plant upgrade are based on multipliers derived from audit information produced by DOE's Industrial Assessment Centers as described in Brown, et al. (2011).

The LCOE is the weighted average cost, calculated by dividing the present value of total costs by total electricity savings, following the methodology described by the Electric Power Research Institute report (Electric Power Research Institute, 2009). In addition to electricity benefits, natural gas savings are also generated for energy users impacted by energy efficiency policies. We singled out the part of the cost needed to achieve electricity savings by proportioning total cost to the value of electricity versus natural gas savings through 2035 present-value calculations for the levelized cost of electricity use a 3% discount rate from a social perspective and 7% discount rate for the private-sector assessment. This is consistent with Office of Management and Budget guidelines (OMB, 2002, 2009), which recommend the use of 3% and 7% discount rates when evaluating regulatory proposals. Our use of a 7% discount rate for evaluating the private perspective is less than the 10% value used in some other energy-efficiency studies such as McKinsey & Co.'s analysis (Granade, et al., 2009). Since the social appropriateness of policies is being examined, a sensitivity was conducted where all costs were discounted at 3% for LCOE calculations.

Other main assumptions in the LCOE calculation include:

- The consumption reduction in delivered electricity does not include electricity related losses in transmission and distribution. To account for all benefits, avoided transmission and distribution losses are included as part of savings. A multiplier of 1.07 (EIA, 2012) was applied to electricity savings to account for the benefit of avoided electricity related losses.
- Program administrative costs are estimated to be \$0.13 per MMBtu energy saved, unless specified otherwise (see Brown, et al., 2009, for details on these estimates).
- We assume the eleven policies start from 2012 and end at 2035. Any costs stimulated from the policies occur through 2035.
- These energy-efficiency policies are assumed have residual benefits after the policies end. Specifically, electricity savings are modeled to degrade at a rate of 5% after 2035, such that benefits from the policy have ended by 2055.

In addition to examining each of the eleven energy-efficiency policies individually, all eleven energy-efficiency options are modeled in the Integrated Policy scenario to explore the combined effects of these policies. By comparing the Integrated Policy scenario and the reference case we estimate the achievable potential in electricity efficiency and its economic effects.

4. RESULTS

4.1 The Achievable Potential of Electricity Savings

In the reference case, electricity consumption is forecasted to grow at an average rate of 0.8% per year and to rise to 4,481 TWh in 2035. Energy efficiency policies are estimated to drive growth of electricity consumption down to 0.4% per year. The U.S. ratepayers could benefit from these policies, saving 261 TWh of electricity in 2020, and 457 TWh 2035 (Figure 1).

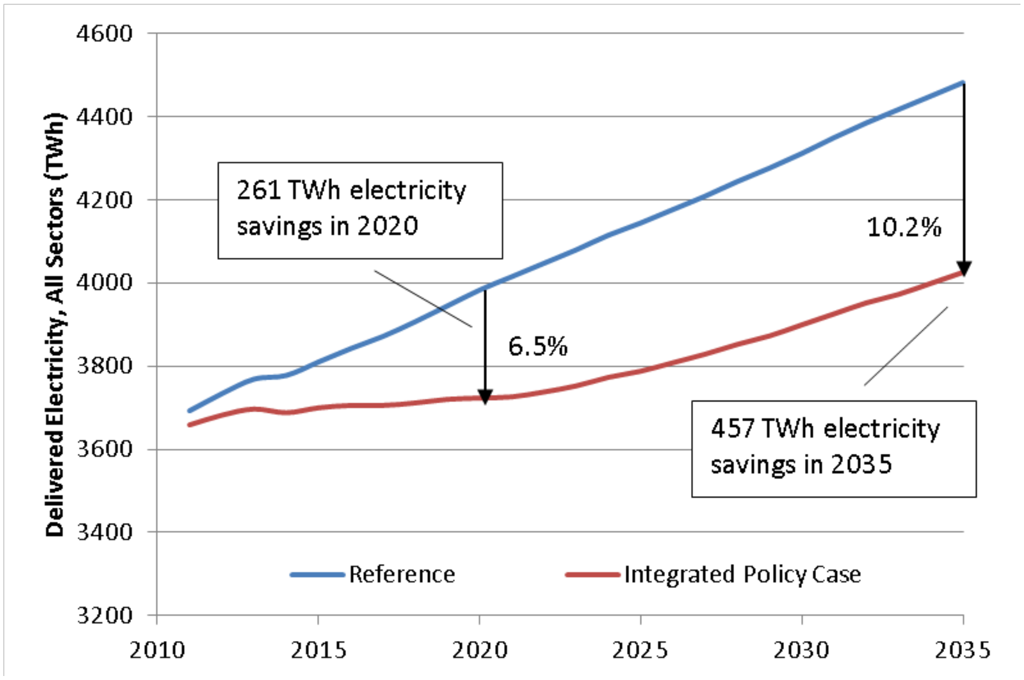

Figure 1 Electricity Savings from the Energy-Efficiency Policy Case

The electricity savings potential is forecasted to come largely from the residential sector. In 2020, electricity savings are projected to be 140 TWh for residential customers, 65 TWh for commercial customers, and 55 TWh for industrial customers. Cumulatively speaking, electricity savings will be 3,713 TWh for residential users, 2,085 TWh for commercial users, and 1,270 TWh for industrial users up to 2035. In addition, part of the electricity from industrial CHP generation is sold back to the grid. It is estimated that about 322 TWh of electricity are produced by CHP systems, 22% which is sold back to the grid (the rest is consumed at the industrial plant) in 2020.

GT-NEMS predicts high per capita electricity savings due to energy efficiency policies, averaging at 763 kWh/capita in 2020. Table 4 suggests that the Central and Southern regions have higher per capita electricity savings potential than other regions of the nation.

Table 4 Per Capita Electricity Savings in 2020, by Census Division (kWh/capita)

Census Division	Residential Sector	Commercial Sector	Industrial Sector	Total Delivered Electricity
New England	250	112	54	414
Middle Atlantic	232	154	62	446
East North Central	288	204	210	703
West North Central	310	171	186	669
South Atlantic	580	252	142	972
East South Central	531	187	416	1,127
West South Central	691	253	221	1,162
Mountain	393	219	180	794
Pacific	252	103	93	444
U.S. Average	406	191	161	763

4.2 Policy Supply Curve for Electricity End-use Efficiency

Policy impacts on electricity efficiency and levelized costs of electricity saved were examined in eleven stand-alone scenarios constructed for each policy. The results are summarized in Table 5. The estimated electricity savings from individual policies sum up to reach 364 TWh in 2020, which is higher than the estimation from the Integrated Policy case (Figure1). This indicates that part of the policy impacts cancels out when all energy efficiency policies are implemented together. Although modeling levers were chosen purposely to avoid overlap, some of the policies target the same set of technologies. It is quite possible that their ability to promote energy efficiency diminishes when overlapping policies co-exist. A related impact is the rebound effect, where energy usage increases when consumers save more in the Integrated Policy case because of electricity rate reductions.

The estimations of efficiency potential from individual policy scenarios were carefully studied against the estimation from the Integrated Policy case. This approach helps determine whether applying multiple policies at once would enhance or reduce the achievable energy-savings potential. On the one hand, the integrated energy-savings potential could be less than the sum of the individual policy savings potentials because the policies target overlapping technologies, barriers, and energy consumers. If the rebound effect is strong, the reduction of electricity rates resulting from reduced energy consumption could cause consumers to take back some of their potential savings by using their bill savings to buy more energy services. On the other hand, synergistic policy combinations could produce greater energy-savings potential. For example, by providing better energy benchmarking data, consumers might be more responsive to an opportunity to secure low-cost financing to invest in more energy-efficient equipment. Similarly, learning effects stimulated by a financing policy could reduce technology costs, leading to an enhanced response to information programs and accelerating adoption of the efficient equipment. The results from the Integrated Policy scenario can help us understand the dynamics among the selected policies and their interactive effects on the energy-efficiency potential of the U.S.

Table 5 Savings Potential and Levelized Cost of Electric End-Use Efficiency, by Policy

Sector	Policy	Electricity Efficiency Potential (TWh) in 2020	Electricity Efficiency Potential (TWh) in 2035	Levelized Cost of Electric End-Use Efficiency (cent/kWh)
Residential	Appliance Incentives	17.6	35.5	6.7-8.0
	On-Bill Financing	20.2	33.4	6.6-7.4
	Building Codes	27.0	51.0	0.5-0.8
	Aggressive Appliance Policy	23.4	59.2	0.6-0.7
	Market Priming	136.9	164.1	2.7-3.6
Commercial	Financing	22.6	82.6	6.4-6.6
	Building Codes	11.1	46.3	3.5-4.6
	Benchmarking	44.3	107.0	0.7-1.2
Industrial	Motor Standard	8.4	12.3	2.4-3.9
	Advanced Manufacturing Initiative	7.6	21.7	3.0-4.8
	CHP Incentives	33.4	39.3	1.5-2.3

Although the target technologies, barriers, and energy consumers may be common to two or more policies, the modeling of policy integration in GT-NEMS is straightforward since the GT-NEMS levers for each individual policy have no overlap. The supply-side modules, the economics and emission modules, and all three end-use sector modules were used together to incorporate feedback loops between multiple segments of the economy to examine policy impacts. By using the IHS Global Dynamics general equilibrium model, the GT-NEMS analysis optimizes energy prices and quantities across energy fuels and across sectors of end-use demand.

A careful reconciliation of the estimates of potential from individual policies versus the Integrated Policy scenario reveals the dynamics among energy-efficiency policies. Together with the levelized cost estimations, the reconciled electricity-savings potentials produce a policy supply curve (Figure 2).

Currently, the national average electricity price for rate payers is approximately 9.0 cent/kWh. Taking the average price as a benchmark, all eleven policies are cost-effective (i.e., having LCOEs lower than the average electricity price). All financial policies except for the CHP Incentive have levelized costs higher than the national average electricity price. CHP Incentives represent the industrial policy with the largest electricity-savings potential. This policy provides a 10-year ITC to reduce capital costs for CHP systems to utilize waste heat in industrial processes. With the incentives, installed CHP capacity is estimated to increase by 20% in 2020. This policy also drives up natural gas consumption and prices while lowering electricity rates. It is highly cost-effective comparing to the retail price of industrial electricity.

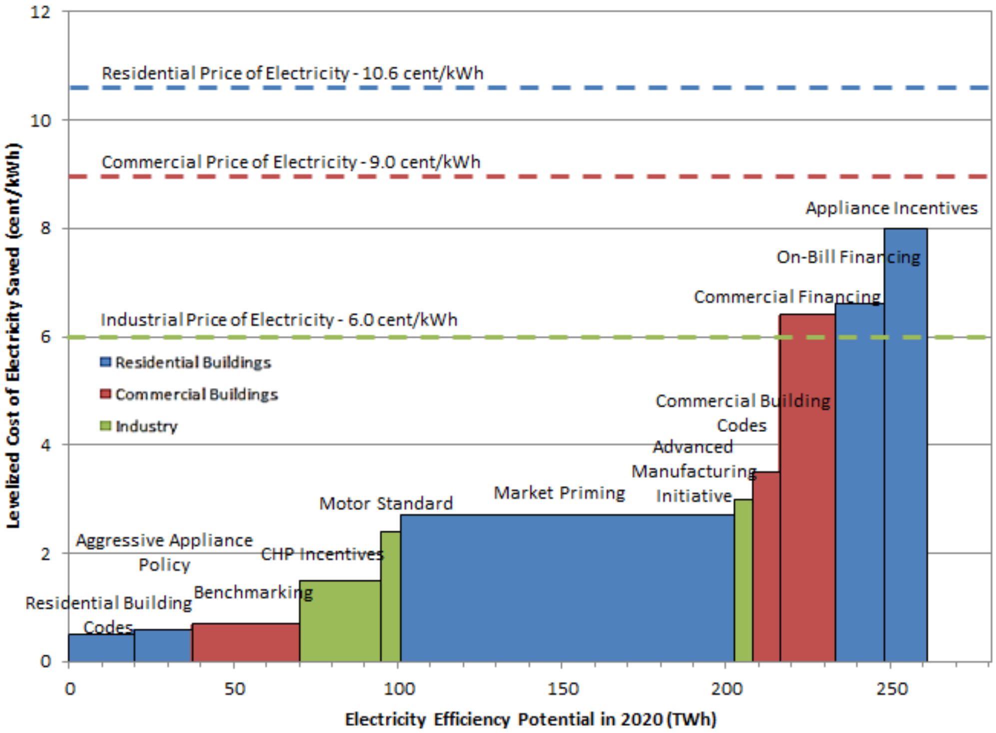

Figure 2. Supply Curve for Electricity Efficiency Resources in 2020

The greatest electricity savings in commercial buildings comes from the benchmarking policy. This policy mandates the provision of energy performance information for U.S. commercial buildings. Utilities are required to submit energy data to a uniform database accessible to building owners and tenants. The compliance effort is estimated to cost utilities about $2.28 million (present value, discounted at 7%) in 2020. Investment in energy-efficient building equipment increases significantly in the policy scenario. Taking the total costs to utilities and consumers into account, the policy is highly cost-effective with a levelized cost ranging from 0.7 to 1.2 cent/kWh.

Market Priming is the energy efficiency policy with most significant savings potential and relatively low levelized cost. Information-based instruments, such as the mandated disclosure of home energy performance with home ratings, green labeling and leasing, home energy audits, etc., are able to promote inclusion of energy efficiency when selling or renting. Efficiency improvements from these policies can generate noticeable home equity premiums (Fuerst & McAllister, 2011; Zheng, et al., 2012). Because of the potential policy impacts on efficiency improvements and equity value, the Federal Office of Management and Budget (OMB) suggests that policies or measures explicitly designed to alleviate asymmetric information should be given preference over other measures, as a general rule-of-thumb (OMB, 2003).

Overall, the policy supply curve suggests that a potential of roughly 217 TWh of electricity savings can be achieved with energy efficiency policies at a cost lower than the delivered cost of operating a zero-capital-cost nuclear power plant (Lovins, 2005). Typical policy instruments include building energy codes, standards, and information policies.

The policy supply curve is created by accumulating individual measures that are applied to specific policy scenarios with savings assessments and cost estimations. It is useful to align options to illustrate opportunities and compare costs for energy efficiency. This policy supply curve does not intend to reflect diminishing returns. Rather, it intends to encourage in-depth analysis of policy options for energy efficiency.

The policy supply curve also indicates that regulatory policies have relatively low levelized costs and financial policies have relatively high LCOEs (Table 6). This is consistent with a previous study of energy efficiency in the U.S. South, which found that the two least cost-effective policies involved financial subsidies (Brown, et al., 2010). The CHP Incentive, as an exception, offers subsidies for industrial CHP systems while having very low levelized cost because of its significant electricity savings and sales to the grid.

Table 6 The Levelized Cost of Electricity Efficiency by Type of Policy (in cents/kWh)

Type of Energy-Efficiency Policy	LCOE in cents/kWh (Lower bound)[a]	LCOE in cents/kWh (Upper bound)[b]
Information	2.1	2.9
Regulation	3.4	4.1
Financing	4.6	4.8
Weighted Average	**3.2**	**3.8**

a. 3% discount rate for public and private costs.
b. 7% discount rate for private costs and 3% discount rate for public costs.

Our estimation of the weighted average LCOE of 3.0 to 3.6 cents/kWh is in the middle range of cost estimates from previous studies. Cost estimations of energy efficiency depend on accurate assessments of energy savings, which can be problematic because of free ridership (Gellings et al., 2006). Alcott and Greenstone (2012) also question ex ante estimates of cost-effectiveness by noting that programs typically reduce electricity demand by only 1-2%, which does not suggest a large energy-efficiency gap. Alternatively, it could be that energy-efficiency programs have simply been underfunded and unable to completely address market failures.

4.3 Policy Impacts on Electricity Rates and the Power Sector

Generally, the energy-efficiency policies are projected to reduce electricity retail rates (Table 7). Although the price decreases are not large, a t-test of differences between the policy and reference cases, using residential, commercial and industrial rates for each of the nine census divisions and the national average in 2020 as observations suggests that the price difference is significant (p-value=0.002).The New England, Middle Atlantic, and Pacific regions exhibit higher rates than the other census divisions. Based on t-tests, the decline in residential electricity rates is significant (p-value = 0.005), with the Mountain division having the biggest decrease. T-tests also suggest that price differences are not significant for commercial (p-value = 0.231) or industrial rates (p-value = 0.114). Nevertheless, New England has notable price decreases in both its commercial and industrial rates.

Table 7 Electricity Rate Changes in 2020, Reference versus Integrated Policy Case

Census Division	Scenario	Residential Retail Rate (cent/kWh)	Commercial Retail Rate (cent/kWh)	Industrial Retail Rate (cent/kWh)
New England	Integrated Policy Case	17.7	11.5	7.3
	Change from Reference	0.1	-0.6	-0.5
Middle Atlantic	Integrated Policy Case	14.5	11.1	6.1
	Change from Reference	-0.1	-0.1	-0.1
West North Central	Integrated Policy Case	9.6	8.3	5.9
	Change from Reference	-0.3	0.0	-0.1
East North Central	Integrated Policy Case	7.9	7.1	5.2
	Change from Reference	-0.5	0.0	-0.1
West South Central	Integrated Policy Case	10.6	9.1	6.5
	Change from Reference	-0.2	0.1	0.1
South Atlantic	Integrated Policy Case	8.0	7.9	5.2
	Change from Reference	-0.3	0.0	0.0
East South Central	Integrated Policy Case	9.2	7.0	5.2
	Change from Reference	-0.5	-0.2	-0.2
Mountain	Integrated Policy Case	8.6	7.9	5.7
	Change from Reference	-0.9	0.3	0.2
Pacific	Integrated Policy Case	11.1	10.9	8.0
	Change from Reference	0.1	0.0	0.1
U.S. Average	Integrated Policy Case	10.3	9.0	5.9
	Change from Reference	-0.3	0.0	-0.1
T-statistic		0.005**	0.231	0.114

**Significant at the 0.5% level.

Although the degree of rate decrease is small for most of the census divisions, savings in energy expenditure is estimated to very significant for customers. With the energy-efficiency policies, residential customers are estimated to save about $26.2 billion (2009$) in 2020. Similarly, commercial customers will save $9.3 billion (2009$) and industrial customers will save $4.8 billion (2009$) in 2020.

Interestingly, the regions with large rate declines do not correspond to the regions with high electricity savings potentials. In 2020, the East North Central and the South divisions are estimated to have the largest electricity savings potential, while electricity price changes are moderate and negligible in these areas. On the other hand, New England has the biggest drop in commercial and industrial prices, and the Mountain division has the biggest drop in residential electricity prices. But savings in these two divisions are rather modest compared with other divisions.

Moreover, the regions with high electricity prices do not correspond to the regions with high savings. This suggests that electricity savings dynamics, including the rebound effect, may play an important role in this rate change – consumers tend to demand more electricity services when rates are low.

Electricity rates drop across the board in the Integrated Policy case in comparison with the Reference case after 2025 A principal driver of the electricity rate decreases is the decline in consumption from improved end-use efficiencies. The electricity market can be treated as a partially competitive market. Consistent with economic theory, energy-efficiency policies drive down demand, which results in a new equilibrium with lower prices.

Table 8 Electricity Generation by Source in the U.S. (in TWh)
Reference Forecast versus Integrated Policy Case

Fuel Type	2010	2020			2035		
	Reference Forecast	Reference Forecast	Integrated Policy Case	% Change	Reference Forecast	Integrated Policy Case	% Change
Coal	1,812	1,879	1,744	-7.2%	2,082	1,914	-8.1%
Petroleum	39	39	37	-5.8%	41	40	-4.1%
Natural Gas	779	696	635	-8.8%	914	688	-24.7%
Nuclear	803	877	828	-5.6%	874	826	-5.5%
Renewables	371	519	497	-4.4%	567	510	-10.1%
Total	3,804	4,013	3,741	-6.8%	4,483	3,981	-11.2%
Energy-Efficiency Potential			**272**			**502**	

In the Integrated Policy case, low consumption levels and low electricity retail rates impacts the power sector's future supply investments. Table 8 suggests that fewer power plants (6.8% fewer in 2020 and 11.2% fewer in 2035) would be built as a result of the energy-efficiency policies in the Integrated Policy case. Natural gas power plants experience the greatest generation losses relative to the reference case (8.8% less generation in 2020, and 24.7% less generation in 2035). In the Integrated Policy case, electricity generated from renewable sources does not decrease as much as generation from other sources in 2020. By 2035, however renewables are reduced proportionately more than coal or nuclear (10.1% versus 8.1% and 5.5%), but natural gas generation is offset most dramatically – by more than 200 TWh, when compared with the reference case. If natural gas hydrofracking continues to produce low-cost gas in the U.S., coal, nuclear and renewables might be further reduced while combined cycle natural gas plants would likely retain more of their market share.

Figure 3 also illustrates the policy impacts on the power sector. In the Reference case, the share of power generated from natural gas grows from 17% in 2020 to 20% in 2035. But this growth is estimated to be largely eliminated by energy-efficiency policies in the Integrated Policy case. Although the share of electricity from coal goes up to 48% in the Integrated Policy case, electricity generation from coal grows only slightly. This suggests that most of the new coal power plants with relatively lower carbon technologies will not be built in the policy case.

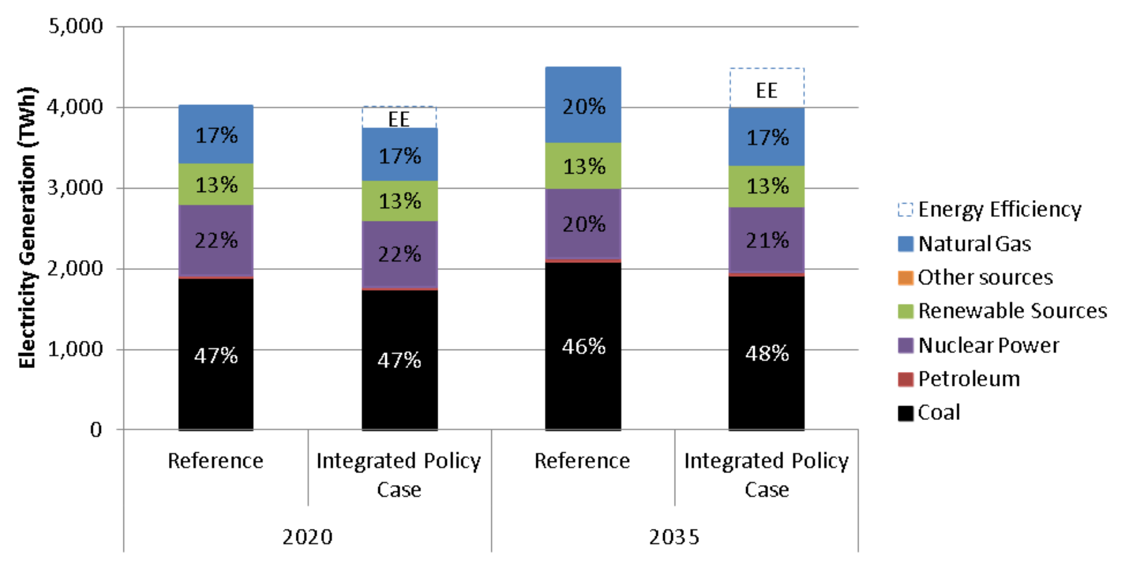

Figure 3 Power Generation by Source in the U.S., in TWh

4.4 Policy Impacts on Other Fuels and Carbon Emissions

Although aiming to shrink electricity efficiency gap, most of the eleven energy-efficiency policies have spillover benefits that may also cause significant savings in natural gas and other energy sources. In 2020, the U.S. could save 0.9 quadrillion Btus of natural gas due to energy-efficiency policies. The natural gas savings could grow to 2.3 quads in 2035, accounting for 40% of the total energy-savings potential.

Figure 4 illustrates the forecast of total energy consumption the reference case and the Integrated Policy case. In 2020, energy efficiency policies are estimated to save 3.4quads (3%) of energy, which is about four times the energy savings in electricity for that year. In 2035, the potential of savings in total energy will grow to 5.7 quads (5%), which is 3.6 times the energy savings in electricity for that year.

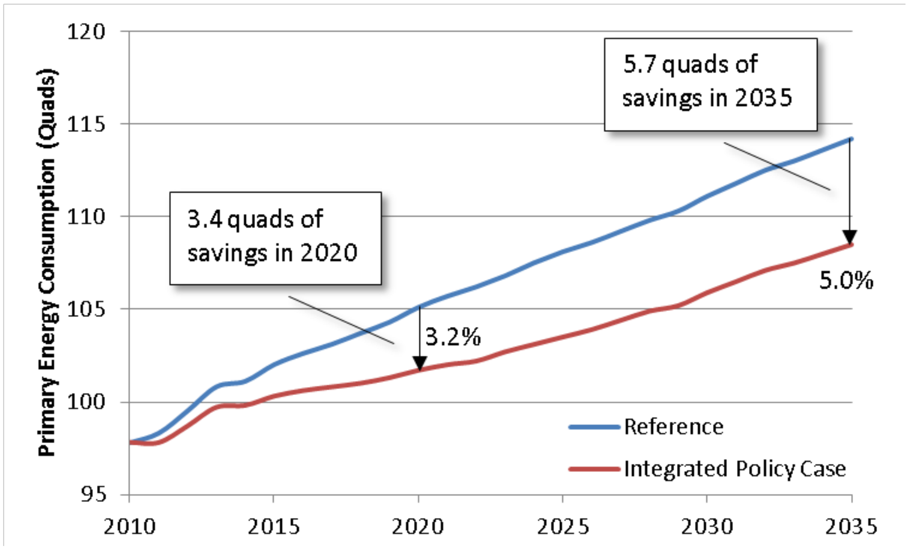

Figure 4 Savings Potential in Primary Energy

These sizable reductions in energy consumption are associated with reductions in carbon dioxide emissions. Figure 5 suggests that the energy-efficiency policies could reduce carbon emissions by 218 million tonnes of CO_2 (3.8%) in 2020, while the potential for emission reductions increases to 326 million tonnes of CO_2 (5.2%) in 2035. Based on the social cost of carbon, we estimate the benefit of reduced carbon emissions to be \$6.0 Billion (in 2009\$) in 2020 and \$12.2 Billion (in 2009\$) in 2035.

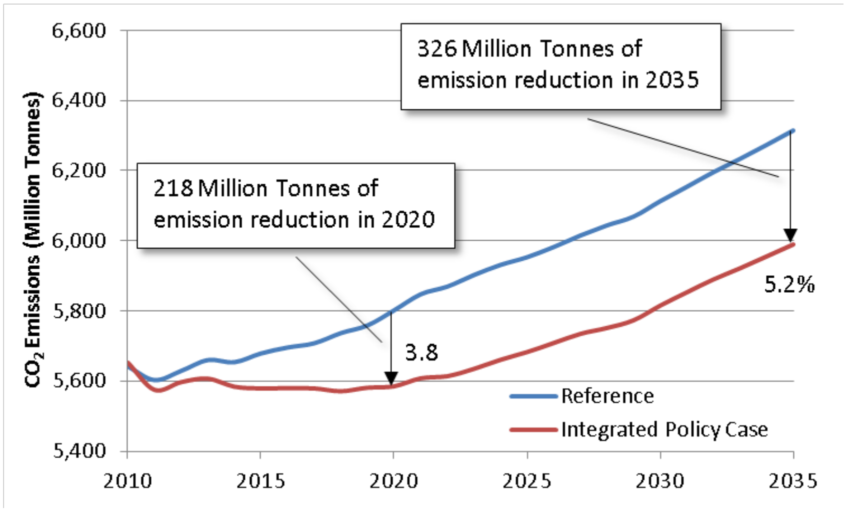

Figure 5 Projected CO_2 Emissions, Reference versus Policy Case

Energy efficiency policies not only reduce carbon emissions, but also decrease carbon intensity of the economy. GT-NEMS output of per capita CO_2 emission suggests that energy efficiency policies drive emission down from 17.0 to 16.3 $mmtCO_2$/capita in 2020. With regard to economic activities, carbon intensity decreases from 333$mmtCO_2$/million \$GDP in the reference case to 321 $mmtCO_2$/million \$GDP in the Integrated Policy case in 2020. This suggests that these policies are efficient in cutting down energy consumption in the carbon intensive part of the economy.

4.5 Policy Impacts on Energy Intensity and GDP

The impact of energy-efficiency policies on different sectors of the economy can be compared through energy intensity metrics. Residential building energy intensity is measured by primary energy per household, while commercial building energy intensity is measured by primary energy use per square footage. The energy intensity of the whole economy is represented by primary energy use per GDP.

An electricity intensity measures was constructed for the industrial sector. The eleven energy efficiency policies target only the electricity savings potentials in the industrial sector, while electricity represents merely one third of industrial energy consumption. The commonly used industrial energy intensity, energy per dollar of shipment, is much less influenced by these policies. Thus, we developed an electricity intensity factor, constructed as electricity per dollar of shipment, to reflect policy impacts on industries.

Figure 6 suggests that energy efficiency policies and programs would reduce household energy intensity more than the energy intensity of other end-use sectors. For example, in 2020, energy use per household decreases by 10.6%, while energy use per square footage of commercial building decreases by 4.8%, and electricity per dollar of shipment decreases by 5.3%. For the economy as a whole, energy use per GDP declines by only 3.2% in the same year.

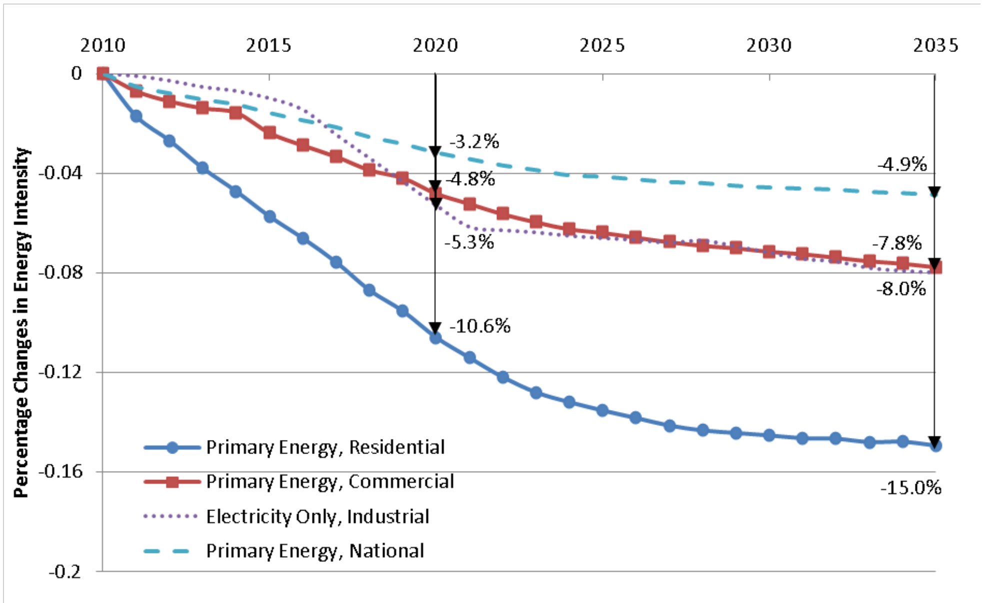

Figure 6 Forecasted Changes in Energy Intensity by Economic Sectors

GT-NEMS has predictions about national economic activities. Table 9 suggests that our energy-efficiency policies have a negligible negative impact on GDP. The national GDP is estimated by NEMS to grow $18 Billion (0.09%) less in the policy case in 2020, which is equivalent to only 9 hours of delay in GDP growth. In 2035, the GDP is estimated to drop by $52 Billion (0.18%), which is equivalent to about 30 hours of delay in GDP growth.

Table 9 GDP Impact

Scenario	GDP (Billion 2009$)	2020	2025	2030	2035
Reference	GDP	19,168	22,021	25,000	28,260
Integrated Policy Case	GDP	19,150	22,008	24,970	28,208
	Change [a]	0.09%	0.06%	0.12%	0.18%
	Delay (hour)[b]	9	9	19	30

a. Numbers are percentage change relative to the Reference case
b. "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 Integrated Policy scenario.

The higher equipment investments prompted by the eleven policies would divert the capital that could have been invested in other economic activities. Results from GT-NEMS suggest that this reallocation of capital resources would affect the national GDP, albeit to a small extent. In addition, the policies would reduce energy consumption and production, which also has GDP consequences. As an energy-economic model, GT-NEMS is capable of modeling the macroeconomic impact of any energy policy by incorporating Global Insight's model of the U.S. economy in its Macroeconomic Activity Module (MAM). Both energy demand and supply sides interact with MAM through a Cobb-Douglas production function to calculate the national GDP. However, the IHS Global Insights model assumes the U.S. economy has a 0.07 energy elasticity, which means that a 1% decrease in energy supply decreases potential GDP by 0.07% (EIA, 2012), but unlike input-output models such as IMPLAN, the reduction in energy expenditures is not recycled back into the economy to reflect re-spending of the energy savings. As a result, NEMS tends to produce estimates of decreased GDP when energy-efficiency investments increase (Laitner, 2013).

5. DISCUSSION AND CONCLUSION

With well-designed policies, we estimate that the U.S. could cost-effectively achieve significant electricity savings. By 2035, the demand for 457 TWh (or 10.2% of the reference case forecast by EIA) could be eliminated by investments in more efficient technologies. Driven by policy, this achievable potential for greater end-use efficiency is relatively low compared with some prior assessments of the technical and economic potential. Our review of the literature, however, indicates that this estimated potential for the U.S. is comparable to many estimates of the achievable potential for increased electric end-use efficiency at various scales of analysis, ranging from the metropolitan to the national.

The policy supply curve illustrates that each of the eleven policies evaluated here are cost-effective with levelized costs lower than sectorial retail prices for electricity. Information and regulatory policies are particularly cost-effectiveness, while financing policies tend to have higher LCOES, although there are exceptions to this pattern.

The electricity savings benefit of energy-efficiency policies is accompanied by other benefits, including natural gas savings, savings of other fuel types, and reduced carbon emissions. In addition, the eleven energy-efficiency policies are able to drive electricity retail prices down in many regions and produce large energy bill savings for consumers. The electric power sector is also affected by these policies, in that generation growth is slowed in the Integrated Policy case, reducing the need for capital-intensive new generation. Overall, these policies are able to decrease the energy and carbon intensity of the U.S. with no significant impact on GDP growth.

In sum, this paper offers a reliable assessment of achievable potential and an in-depth analysis of the impacts of energy-efficiency policies in the U.S. The policy supply curve can serve as a powerful tool for decision makers seeking for policy solutions to energy efficiency. However, generalization of our findings to specific markets within the U.S. will require prudence and deliberation.

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Appendix A: GT-NEMS Modeling and Cost Estimations of Energy Efficiency Policies

A portfolio of eleven policies was modeled with GT-NEMS to explore the achievable potential of electricity efficiency. NEMS outputs from individual policy scenarios were used in supplemental spreadsheet analysis to calculate the levelized cost of electricity. This appendix provides information about modeling details and cost estimations policy by policy.

(1) **Appliance Incentives** offer a 30% subsidy to reduce the capital cost for the most efficient technologies in residential buildings based on the technology inventory of GT-NEMS. A list of 25 selected technologies from the major end-uses eligible for incentives can be found in Table A.1. Capital costs of these technologies (from the rtekty input file) were reduced by 30% in the Appliance Incentives policy scenario.

Table A.1 Most Efficient Home Appliances and Equipment [a]

End-Use	Equipment Type	Average Cost [b] ($2007)	Average Efficiency	Available Years
Space Heating	Fuel Oil Furnace 3	4,983	0.95	2009-2023
	Fuel Oil Radiator 3	4,513	0.95	2012-2022
	Electric Heat Pump 4	3,567	3.14	2014-2021
	Geothermal Heat Pump 2	6,414	5	2010-2018
	Kerosene Furnace 3	4,983	0.95	2009-2023
	LPG Furnace 5	2,470	0.96	2009-2019
	Natural Gas Furnace 5	2,470	0.96	2009-2020
	Natural Gas Radiator 3	4,513	0.95	2012-2022
Space Cooling	Central Air Conditioner 4	5,290	6.504	2011-2019
	Electric Heat Pump 4	3,567	5.325	2014-2021
	Geothermal Heat Pump 2	5,749	30	2011-2021
	Room Air Conditioner 3	900	3.52	2012-2026
Clothes Washing	Clothes Washer 3	958	0.114	2008-2022
Dishwashing	Dishwasher 3	1,181	1.1	2010-2020
Water Heating	Fuel Oil Water Heater 3	2,400	0.68	2012-2026
	Electric Water Heater 5	1,430	2.4	2009-2023
	LPG Water Heater 4	852	0.746	2014-2022
	Natural Gas Water Heater 4	852	0.746	2014-2023
Cooking	Electric Stove 2	400	601	2006-2050
	LPG Stove 2	500	0.42	2006-2050
	Natural Gas Stove 2	500	0.42	2006-2050
Clothes Drying	Electric Clothes Dryer 2	500	3.74	2009-2023
	Natural Gas Clothes Dryer 2	515	0.931	2007-2028
Refrigeration	Refrigerator 4	1,107	399	2009-2023
Freezing	Freezer 3	626	290	2010-2032

a. The cost, efficiency and available years for each equipment type vary by region. The efficiency for different equipment types are measured by different metrics.

b. Cost before subsidy.

The Appliance Incentives policy would incur two types of costs: the, private investment which is the expenditure spent by residential consumers to purchase equipment, and the public costs that include the cost of subsidizing the most efficient technologies and program administrative costs. The total cost of the policy is the sum of both the private and public costs, and it is estimated to be $2.9 billion in 2035. By weighting the cost with electricity savings, the levelized cost of electricity (LCOE) in this policy case is estimated at 6.7-8.0 cent/kWh (Table A.2).

Table A.2 Cost Estimations from Appliance Incentives

Cost (Billion $2009) [a]	2020	2025	2030	2035
Private Cost	-1.37	-1.01	-0.73	-0.53
Subsidy Cost	4.51	4.25	3.83	3.42
Administration Cost	0.01	0.01	0.01	0.01
Total	3.15	3.25	3.11	2.90
LCOE (cent/kWh)	6.7 [b] -8.0			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(2) In the **Building Energy Codes** policy case, four new codes were added to the residential building codes profile (in the rtektyc input file) to force shell efficiency and equipment improvements. These codes were modeled with relatively high heating and cooling shell efficiency, and relatively high shell installation costs, trying to mimic the periodic code updates.

In the Reference case, new residential buildings are built in compliance with five different levels of codes: no code, IECC 2006 code, Energy Star code, forty-percent above IECC 2006 code, and the most efficient code: PATH code. In this study, the Building Code scenario were set up based on EIA's Expanded Standards and Codes side case, where three new codes were added to the code profile: 'IECC 2006+', 'IECC 2006++', and 'IECC 2006+++' to reflect code improvements. We added one more code, the 'New Code' to push further shell efficiency improvement. Table A.3 shows the details about the residential building codes in our policy case.

Table A.3 Building Energy Codes Profile for Residential Buildings [a]

Building Codes	Average Shell Installation Cost	Average Heating Shell Efficiency Factor	Average Cooling Shell Efficiency Factor
'No IECC'	7	1.21	1.15
'IECC 2006'	5,251	0.81	1.06
'Energy Star'	5,508	0.79	1.03
'FORTY%'	6,797	0.68	0.97
'PATH'	7,868	0.51	0.93
'IECC 2006+'	5,580	0.69	0.90
'IECC 2006++'	6,018	0.65	0.85
'IECC 2006+++'	6,128	0.61	0.80
'NEW CODE'	7,392	0.56	0.85

a. The cost and efficiency factors for each building shell type vary by region.

The policy case also forces early retirement of less stringent codes. For example, Energy Star, Forty and IECC 2006+ retire in the same year, which is five years later than IECC 2006's retirement; IECC 2006++ retires at 2023 for all regions; IECC 2006+++ retires at 2028 for all regions; New Code and PATH, which are the two most efficiency codes, are available for all years for all regions. This policy recognizes the regional differences in code adoption based on historic patterns (Figure A.1).

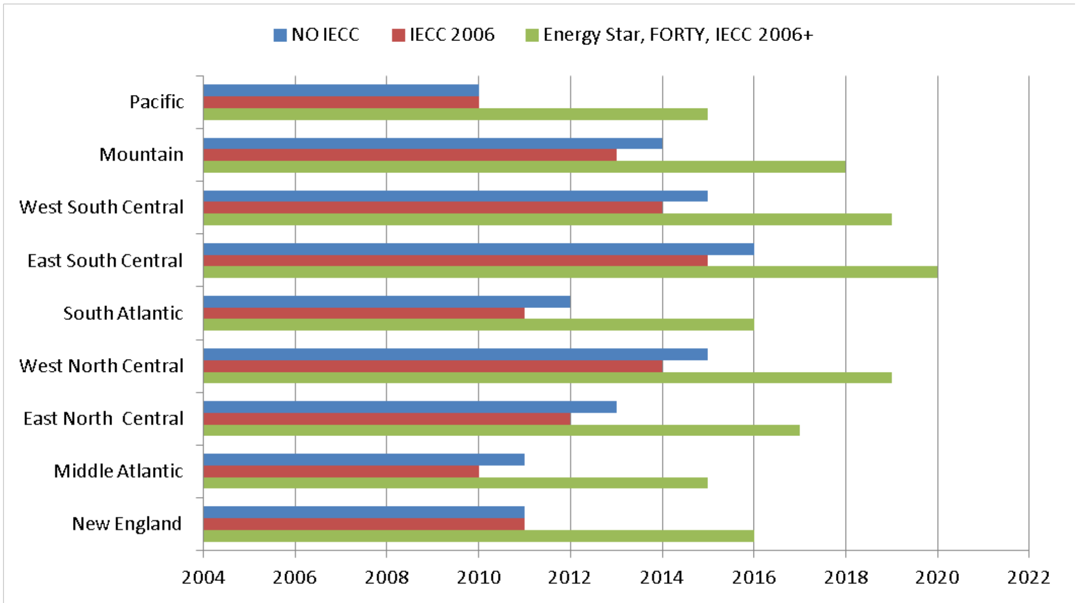

Figure A.1 Building Energy Code Retirement Years by Census Division

New houses built in compliance with new codes save energy from more efficient equipment and better insulation and building design. They eventually gain market share, although new codes have higher shell installation costs than existing codes (Figure A.2).

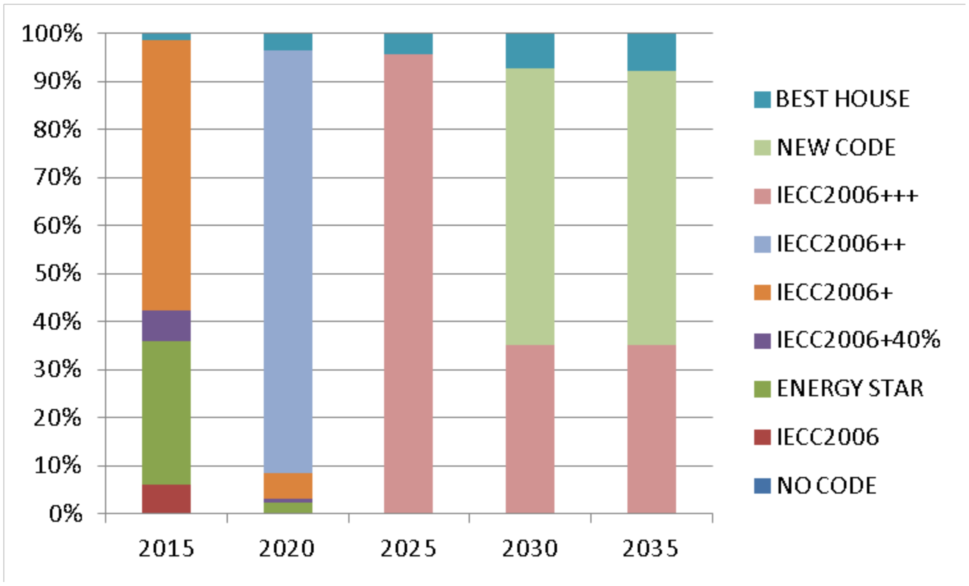

Figure A.2 Share of New Houses Built in the Policy Case

In the policy case of Building Energy Codes, the private investment is the incremental cost of equipment plus the installation cost for improvements to the building shell. By promoting investments in more thermally efficient envelopes, HVAC equipment can be down-sized, resulting in lower equipment expenditures relative to the Reference case. There is no public cost except for the program administrative costs. This policy assumes cost associated with building code enforcement would be represented by the budget of each state hiring their building code officials and inspectors. The administrative costs are based on each state adding one administrative office run at $150,000 per annum budget and one code official at $75,000 salary per annum. It also includes two additional building code inspectors for the verification of every 100 million square feet in the state at $75,000 per year (Brown, et al., 2009). The levelized cost is estimated to be 0.5-0.8 cent/kWh (Table A.4).

Table A.4 Cost Estimations from Residential Building Energy Codes

Cost (Billion $2009) [a]	2020	2025	2030	2035
Equipment Expenditure	-0.02	-0.02	-0.01	-0.01
Shell Installation Cost	0.33	0.28	0.39	0.25
Administration Cost	0.02	0.02	0.02	0.02
Total	0.33	0.29	0.40	0.26
LCOE (cent/kWh)	0.5-0.8[b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(3) The **On-bill Financing** program offers zero-interest loans to the most efficient home appliances and equipment. The technologies eligible for zero-interest loans are the same technologies that are eligible for appliance subsidies as listed in Table A.1. In GT-NEMS modeling, two new parameters for residential technologies were added to the rtekty input file: CAPDIST assigns interest rate (or discount rate for non-eligible technologies), and CAPHOR assigns payback time (or time horizon for non-eligible technologies) for residential technologies.

To realize the input file changes, cost calculation equations in the residential module source code were also modified. In the reference case, the life-cycle costs for residential technologies are calculated as following:

$$LFCY_{y,es,b,r,v} = CAPITAL_{es} + OPCOST_{y,es,b,r,v} * \left(\frac{1-(1+DIST)^{-HORIZON}}{DIST}\right)$$

With interest rate option, we changed the life-cost equation to:

$$LFCY_{y,es,b,r,v} = (ANNUALPAY_{es} + OPCOST_{y,es,b,r,v}) * \left(\frac{1-(1+DIST)^{-HORIZON}}{DIST}\right)$$

When interest rate is 0%, we have,

$$ANNUALPAY = \frac{CAPITAL}{CAPHOR}$$

When interest rate is greater than 0%, we have,

$$ANNUALPAY = CAPITAL * \frac{CAPDISRT}{1-(1+CAPDISRT)^{-CAPHOR}}$$

Where, LFCYCLE is the lifecycle costs for appliances;

CAPITAL: the capital costs for appliances;

OPCOST: the operational costs for appliances;

DIST: the discount rate for the operational cost during the life time of the appliances

HORIZON: the appliance life time

ANNUALPAY: the annual payment for on-bill financing equipment

CAPHOR: the payback time

CAPDIST: the interest rate

In the rtekty input file, the selected technologies with high efficiencies were assigned a 0% interest rate and 10-year payback time, indicating that the life-cycle costs for these technologies were calculated with the revised equation. Other technologies were assigned the default setting, and their life-cycle costs were calculated with the original equation.

With on-bill financing, increased private investment is the increased expenditure for purchasing home appliances and equipment. Loan cost is the initial seed money put into the program for zero-interest loans. Program administrative cost is estimated as \$0.13/MMBtu energy saved. The LCOE associated with On-bill Financing is estimated to be 6.6-7.4 cent/kWh (Table A.5)

Table A.5 Cost Estimations from On-Bill Financing

Cost (Billion \$2009) [a]	2020	2025	2030	2035
Private cost	0.95	0.64	0.40	0.25
Loan Cost	1.48	0.02	-0.09	0.01
Administrative Cost	0.01	0.01	0.01	0.01
Total	2.44	0.67	0.32	0.27
LCOE (cent/kWh)	6.6-7.4 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(4) The **Market Priming** policy also targets the same set of technologies as shown in Table A.1, but was modeled with hurdle rate changes. Providing information is assumed to lower discount rate when consumers make investment decisions. GT-NEMS modeling of this policy changed the hurdle rates of the efficient technologies to 7% by modifying the beta 2 parameter for the logit model of technology choice in the rtehty input file.

With Market Priming, private investment increases when consumers purchase more of the efficient appliances and equipment. Public cost is represented by program administrative cost, estimated as \$0.13/MM Btu energy saved. The levelized cost is estimated to be 2.7-3.6 cent/kWh for Market Priming (Table A.6).

Table A.6 Cost Estimations from Market Priming

Cost (Billion $2009) [a]	2020	2025	2030	2035
Private cost	6.91	3.76	2.90	1.44
Administration Cost	0.03	0.03	0.02	0.02
Total	6.94	3.79	2.92	1.46
LCOE (cent/kWh)	2.7-3.6 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(5) The **Aggressive Appliance Policy** forces retiring the least efficient technologies from the market place at 2012. In GT-NEMS, the selected technologies were made either unavailable after 2012, or assigned a hurdle rate equals to 100% in the rtehty input file. A list of forced retired technologies is shown in Table A.7.

Table A.7 Residential Technologies Forced Early Retirement [a]

End-Use	Equipment Type	Average Efficiency	Available Years
Space Heating	Fuel Oil Furnace 1	0.82	2010 - 2032
	Fuel Oil Radiator 1	0.825	2010 - 2031
	Electric Heat Pump 1	2.35	2014 - 2028
	Kerosene Furnace 1	0.82	2010 - 2032
	LPG Furnace 1	0.818	2010 - 2032
	Natural Gas Furnace 1	0.818	2010 - 2032
	Natural Gas Radiator 1	0.815	2010 - 2031
Space Cooling	Central Air Conditioner1	3.899	2009 - 2039
	Electric Heat Pump 1	4.003	2014 - 2028
	Room Air Conditioner 1	3.103	2013 - 2027
Clothes Washing	Clothes Washer 1	0.160	2012 - 2022
Dish Washing	Dishwasher 1	0.587	2010 - 2024
Water Heating	Fuel Oil Water Heater 1	0.585	2011 - 2032
	Electric Water Heater 1	0.925	2011 - 2032
	LPG Water Heater 1	0.59	2006 - 2050
	Natural Gas Water Heater 1	0.605	2011 - 2032
Refrigeration	Refrigerator 1	428. 7	2013 - 2027
Freezing	Freezer 1	347.5	2010 - 2032

a. The efficiency and available years for each equipment type vary by region. The efficiency for different equipment types are measured by different metrics.

Similar to the Market Priming policy, the cost estimation for the Aggressive Appliance Policy has private cost from the expenditure for purchasing equipment, and public cost from program administrative costs. The levelized cost is estimated to be 0.6-0.7 cent/kWh (Table A.8).

Table A.8 Cost Estimations from Aggressive Appliance Policy

Cost (Billion \$2009) [a]	2020	2025	2030	2035
Private cost	0.25	0.16	0.11	0.08
Administration Cost	0.01	0.01	0.01	0.01
Total	0.26	0.18	0.13	0.09
LCOE (cent/kWh)	0.6-0.7 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

We estimate the magnitude of technology investment costs in the commercial sector separately for new purchases, replacements, and retrofits. In each case, the calculation is based on GT-NEMS estimates of service demand (SD) for energy.

- New Purchases
    - SD_{new} x (Cost/8760) x 1/CF = Investment Cost
        - SD_{new} is a KSDOUT output, as are $SD_{replacement}$ and $SD_{surviving}$
        - CF is the equipment-specific capacity factor
- 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

(6) In the **Benchmarking** policy case, GT-NEMS uses a combination of discount rates and the rate for U.S. government ten-year Treasury notes to calculate consumer hurdle rates used in making equipment-purchasing decisions. While the macroeconomic module of GT-NEMS determines the rate for ten-year Treasury notes endogenously, the discount rates are inputs to the model. Modifying these inputs is the primary means of estimating the impact of benchmarking for the commercial sector in this analysis. This is done in two steps: first, by updating the discount rates to reflect a broader selection of the literature; and second, by adjusting the updated discount rates to account for the effects of a national benchmarking policy.

To illustrate, Table A.9 presents the 2015 hurdle rates used in GT-NEMS across scenarios for two major end-uses in the commercial sector, space heating and lighting (these values represent the sum of the Treasury bill rates and the discount rates).

Table A.9 Discount Rates Across Scenarios for Space Heating and Lighting in 2015

% of Population		Discount Rate [a]	
Reference	Bench-marking	Reference	Bench-marking
Space Heating			
27	14.2	1005.75	40.4
23	14.3	**105.75**	19.6
19	14.3	50.75	15.4
18.6	14.3	30.75	**12.4**
10.7	14.3	20.75	9.8
1.5	14.3	12.25	7.4
0.2	14.3	5.75	4.8
Lighting			
27	14.2	1005.75	57.3
23	14.3	**105.75**	40.8
18.6	14.3	50.75	36.5
18.6	14.3	30.75	**33**
8.8	14.3	20.75	30.4
1.5	14.3	12.25	26.9
2.5	14.3	5.75	21.7

a. Discount rates presented include the projected Treasury bill rate for 2015. **Bold** numbers represent the median estimate for the specific scenario.

The Benchmarking policy provides energy performance information on commercial buildings. Equipment expenditure increases with this policy. Program administrative cost was estimated as \$0.13/MMBtu energy saved. The levelized cost of electricity is estimated to be 0.7-1.2 cent/kWh (Table A.10).

Table A.10 Cost Estimations from Benchmarking

Cost (Billion \$2009) [a]	2020	2025	2030	2035
Private Cost	0.93	0.85	0.85	0.82
Compliance Cost	-0.001	-0.001	-0.001	-0.001
Total	0.92	0.85	0.84	0.82
LCOE (cent/kWh)	0.7-1.2 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(7) The **National Building Code** is modeled, in part, by assuming a more rapid rate of commercial shell efficiency improvement, as shown in Table A.11.

Table A.11 Commercial Building Shell Efficiency Improvement [a]

	New Construction	Existing Buildings
EIA Reference case	14%	6%
EIA High Tech Case	17.4%	7.5%
Building Code Scenario	30%	19%

a. Improvement of 2035 efficiency over 2003 efficiency

In this policy scenario, private investment is the incremental cost of equipment and building envelope expenditures to meet new building codes. There is no public cost except for program administration. This policy assumes costs associated with building code enforcement carried out by state building code officials and inspectors. The administrative cost was calculated using the same assumption as in the residential building codes policy. The levelized cost is estimated to be 3.5-4.6 cent/kWh (Table A.12).

Table A.12 Cost Estimations from Building Codes

Cost (Billion $2009) [a]	2020	2025	2030	2035
Private Cost	1.08	-1.91	0.39	0.25
Shell Improvement Cost	0.07	-0.15	0.05	0.03
Administration Cost	0.04	-0.10	0.04	0.03
Total	1.19	-2.16	0.48	0.31
LCOE (cent/kWh)	3.5-4.6 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(8) In the **Commercial Financing** policy case, a 30% subsidy was provided to 107 technologies, based on a prior analysis of the impact of implementing a carbon tax (Brown, Cox, & Sun, 2012). The subsidized technologies are listed in Table A.13.

Table A.13 Incentivized Technologies in Financing Policy Case

Fuel type	Technology	Average efficiency	Average cost [a] ($/Btu out)	First available year	Last available year
Space Heating					
Electricity	comm_GSHP-heat 2011 high	4.90	150.00	2011	2052
	comm_GSHP-heat 2011 high 10% ITC w MACRS	4.90	108.00	2011	2016
	comm_GSHP-heat 2011 typ	3.50	120.00	2011	2052
	comm_GSHP-heat 2011 typ 10% ITC w MACRS	3.50	87.00	2011	2016
	comm_GSHP-heat 2020-30 typical	4.00	120.00	2020	2052
	rooftop_ASHP-heat 2007 high	3.40	96.67	2003	2052
	rooftop_ASHP-heat 2030 high	3.80	96.67	2030	2052
Natural Gas	gas_boiler 2011 high	0.95	37.08	2011	2052
	gas_furnace 2011 high	0.94	9.76	2011	2052
	res_type_gasHP-heat 2020 typical	1.50	150.00	2020	2052
	res_type_gasHP-heat 2030 typical	1.50	141.67	2030	2052

Space Cooling					
	centrifugal_chiller 2007 high	7.30	43.33	2003	2052
	centrifugal_chiller 2007 mid range	6.90	40.83	2003	2052
	centrifugal_chiller 2010 typical	6.40	36.67	2010	2052
	centrifugal_chiller 2020 typical	7.00	36.67	2020	2052
	centrifugal_chiller ASHRAE 90.1-2004	6.10	35.42	2003	2052
	comm_GSHP-cool 2011 high	8.15	150.00	2011	2052
	comm_GSHP-cool 2011 high 10% ITC w MACRS	8.15	108.00	2011	2016
	comm_GSHP-cool 2011 typ	4.10	120.00	2011	2052
	comm_GSHP-cool 2011 typ 10% ITC w MACRS	4.10	87.00	2011	2016
	comm_GSHP-cool 2020-30 typical	4.10	120.00	2020	2052
	reciprocating_chiller 2007 high	3.52	47.08	2003	2052
	reciprocating_chiller 2020 high	3.63	42.08	2020	2052
	reciprocating_chiller 2020 typical	3.20	38.75	2020	2052
	reciprocating_chiller 2030 high	3.78	42.08	2030	2052
	res_type_central_AC 2003 installed base	2.84	47.84	2003	2003
	res_type_central_AC 2030 typical	4.40	80.95	2030	2052
	res_type_central_AC NAECA standard-pre-2006	2.93	49.13	2003	2005
	rooftop_AC 2003 installed base	2.70	58.33	2003	2003
	rooftop_AC 2007 typical	2.96	65.56	2003	2009
	rooftop_AC 2010 high	3.52	80.56	2011	2052
	rooftop_AC 2011 typical	3.28	66.67	2011	2052
	rooftop_AC 2030 high	3.81	80.56	2030	2040
	rooftop_ASHP-cool 2030 high	3.81	96.67	2030	2040
	screw_chiller 2020 high	3.63	42.08	2020	2052
	screw_chiller 2030 high	3.91	42.08	2030	2052
	scroll_chiller 2007 typical	2.93	36.25	2003	2052
	wall-window_room_AC 2011 typical	3.05	33.81	2011	2052
Electricity	wall-window_room_AC 2020 typical	3.22	33.81	2020	2052
Water Heating					
Natural Gas	gas_water_heater 2020 high	0.95	26.40	2020	2052
	HP water heater 2011 typical	2.30	225.00	2011	2052
	HP water heater 2020 typical	2.30	210.71	2020	2052
	Solar water heater 2010 typ south	2.50	249.12	2010	2052
	Solar water heater 2011 typ 30 pct ITC south	2.50	193.76	2011	2016
	Solar water heater 2020 typ south	2.50	205.16	2020	2052
Electricity	Solar water heater 2030 typ south	2.50	175.85	2030	2052
Ventilation					
	CAV_Vent 2008 high	1.10	8833.35	2004	2050
	CAV_Vent 2020 typical	0.63	8326.82	2020	2050
	CAV_Vent 2030 typical	0.73	8326.82	2030	2050
	VAV_Vent 2008 high	1.63	8790.87	2004	2050
Electricity	VAV_Vent 2020 typical	0.73	8398.71	2020	2050
Cooking					

Electricity	Range, Electric-induction, 4 burner, oven, 11	0.80	46.57	2000	2052
Natural Gas	Range, Gas, 4 powered burners, convect. oven, 11	0.60	38.92	1995	2052
Lighting					
	72W Inc (Halogena Type HIR)	12.21	79.19	2008	2050
	F28T5	71.50	31.98	2003	2050
	F32T8 Super	65.20	21.71	2003	2050
	F96T8 High	95.10	10.96	2003	2050
	F96T8HO LB	76.90	18.81	2003	2050
	LED 2011-2019 Typical for high tech	86.80	196.79	2011	2019
Electricity	LED 2020-2029 Typical	181.00	134.18	2020	2050
Refrigeration					
	Bevrg_Mchndsr 2008 high	1.87	1674.84	2004	2050
	Bevrg_Mchndsr 2008 low	0.88	1102.94	2004	2009
	Bevrg_Mchndsr 2011 typical	1.34	1348.04	2011	2050
	Bevrg_Mchndsr 2020 typical	1.43	1348.04	2020	2050
	Bevrg_Mchndsr 2030 typical	1.54	1348.04	2030	2050
	Bevrg_Mchndsr installed base	0.79	1266.34	2003	2009
	Ice_machine 2010 EPACT standard	0.50	1142.41	2010	2050
	Ice_machine 2011-2020 typical	0.53	1186.34	2011	2050
	Reach-in_fzr 2008 high	2.26	1270.06	2004	2050
	Reach-in_fzr 2020 typical	1.66	1180.93	2020	2050
	Reach-in_fzr 2030 typical	1.77	1180.93	2030	2050
	Reach-in_fzr installed base	1.23	1136.37	2003	2009
	Reach-in_refrig 2008/2010 high	5.13	898.69	2004	2050
	Reach-in_refrig 2011 typical	3.42	866.01	2011	2050
	Reach-in_refrig 2020 typical	3.67	866.01	2020	2050
	Reach-in_refrig 2030 typical	3.85	866.01	2030	2050
	Reach-in_refrig installed base	2.03	931.37	2003	2009
	Supermkt_compressor_rack 2011 high	3.06	130.72	2011	2050
	Supermkt_compressor_rack 2011 typical	2.75	116.71	2011	2050
	Supermkt_compressor_rack 2020 high	3.06	130.72	2020	2050
	Supermkt_compressor_rack 2020 typical	2.81	116.71	2020	2050
	Supermkt_compressor_rack 2030 high	3.06	130.72	2030	2050
	Supermkt_compressor_rack 2030 typical	2.87	116.71	2030	2050
	Supermkt_condenser 2008 high	27.84	32.25	2004	2050
	Supermkt_condenser 2020 typical	22.27	25.80	2020	2050
	Supermkt_condenser installed base	17.82	29.02	2003	2050
	Supermkt_display_case 2008 high-2012 standard	3.02	436.28	2004	2050
	Supermkt_display_case 2011 typical	2.57	303.92	2011	2011
	Supermkt_display_case 2020 high	3.42	436.28	2020	2050
	Supermkt_display_case installed base	2.45	303.92	2003	2011
	Vend_Machine 2008 low	0.53	2201.69	2004	2012
	Vend_Machine 2008-10 high-2013 standard	1.06	2621.85	2004	2050
Electricity	Vend_Machine 2008-10 typical	0.75	2341.74	2004	2012

Vend_Machine 2011 high	1.17	2621.85	2011	2050
Vend_Machine 2011 typical	0.84	2341.74	2011	2012
Vend_Machine 2020 high	1.24	2621.85	2020	2050
Vend_Machine 2030 high	1.32	2621.85	2030	2050
Walk-In_fzr 2008 high	1.21	2148.16	2004	2050
Walk-In_fzr 2009 EISA stnd-2010 typical	1.83	2068.59	2009	2050
Walk-In_fzr 2020 typical	1.86	2068.59	2020	2050
Walk-In_fzr 2030 typical	1.89	2068.59	2030	2050
Walk-In_fzr installed base	0.81	1650.90	2003	2008
Walk-In_refrig 2008 high	6.73	725.11	2004	2050
Walk-In_refrig 2009 EISA stnd-2010 typical	6.24	710.16	2009	2050
Walk-In_refrig 2020 typical	6.54	710.16	2020	2050
Walk-In_refrig 2030 typical	6.94	710.16	2030	2050
Walk-In_refrig installed base	2.73	490.52	2003	2008

a. Costs before subsidy.

In the Financing case, total cost was estimated to be the sum of increased equipment expenditure, the cost of subsidizing the most efficient technologies, and program administrative costs. The levelized cost is estimated to be 6.4-6.6 cent/kWh (Table A.14).

Table A.14 Cost Estimations from Financing

Cost (Billion \$2009) [a]	2020	2025	2030	2035
Private Cost	0.71	0.58	0.49	0.44
Subsidy Cost	9.17	8.07	9.07	8.64
Administration Cost	0.06	0.06	0.07	0.06
Total	9.94	8.71	9.64	9.14
LCOE (cent/kWh)	6.4-6.6 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(9) In various industrial processes, systems using motors are big users of electricity. The **Motor Standard** policy assumes an additional 25% efficiency improvement in 2017 for motor systems used in industry. The modification was made effective from 2017 in the industrial source code, ind.f.

Private costs in the Motor Standard case were estimated based on the cost of rewinding and replacing failed motors. Public cost is only the program administrative cost estimated as \$0.13/MMBtu energy saved. The LCOE in this policy case is estimated to be \$-2.4-3.9cent/kWh (Table A.15)

Table A.15 Cost Estimations from Motor Standard

Cost (Billion \$2009) [a]	2020	2025	2030	2035
Private Cost	0.408	0.224	0.182	0.204
Administration Cost	0.001	0.002	0.002	0.002
Total	0.410	0.226	0.184	0.207
LCOE (cent/kWh)	2.4-3.9 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.

b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(10) In the **CHP Incentives** scenario, subsidies were applied to industrial CHP systems to promote efficient usage of waste heat in various industrial processes. A 10-year subsidy increasing from 15% in 2012 to 30% was applied to the total installed cost parameter in the indcogen.xml input file. We assume that in the CHP market, retailers are able to share the benefits of the subsidy with the consumers at the beginning. All benefits gradually go to the consumers. To reflect this phenomenon, a 15% subsidy was applied for the first three years, rising by 5% every year from 2015 and staying at 30% from 2017 to 2021. GT-NEMS represents CHP as a combination of eight technology systems, including two internal combustion CHP systems (ranging from 1 to 3 MW), five gas turbine CHP systems (3 to 40 MW) and one combined cycle system (with two 40 MW gas turbines and a 20 MW steam turbine).

We account for the increased natural gas consumption and increase equipment expenditure as the private cost associated with the CHP Incentives policy. Subsidy cost was estimated based on the amount of incremental cost in CHP investments, while program administrative cost was estimated as 2% of subsidy cost. The LCOE in this policy case is estimated to be 1.5-2.3 cent/kWh (Table A.16).

Table A.16 Cost Estimations from CHP Incentive

Cost (Billion $2009) [a]	2020	2025	2030	2035
Increased Natural Gas Expenditure	1.55	1.15	0.62	0.54
CHP system	0.25	-0.02	-0.01	0.00
Subsidy cost	0.56	0.00	0.00	0.00
Administration cost	0.01	0.00	0.00	0.00
Total	2.37	1.13	0.62	0.54
LCOE (cent/kWh)	1.5-2.3 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(11) The **Advanced Manufacturing Initiative** policy mimics the voluntary plant upgrades by the private sector. It took the estimated electricity and natural gas savings from efficiency improvements reported from 2010 to 2012 in the Industrial Assessment Center (IAC) database (Table A.17). The percentage savings were applied to change the TPC parameter in the itech.txt input file.

Table A.17 Electricity and Natural Gas Saving Estimations from IAC Reports

Industry	Electricity savings				Natural Gas			
	Northeast	Midwest	South	West	Northeast	Midwest	South	West
311 Food	47.58%	47.98%	37.48%	47.08%	0.58%	25.75%	2.00%	0.00%
322 Paper	29.20%	31.24%	15.06%	11.51%	5.19%	15.98%	11.15%	0.00%
325 Chemicals	62.73%	13.04%	51.98%	35.74%	-32.64%	25.06%	-3.76%	-98.63%
327 Non Metals	9.82%	20.23%	46.18%	37.26%	5.12%	29.45%	0.00%	
331 Iron and Steel	15.14%	57.13%	28.02%	5.03%	13.75%	18.44%	3.44%	2.61%
332 Fabricated Metals	29.27%	46.89%	42.70%	28.74%	-49.03%	16.55%	11.15%	N/A
333 Machinery	19.61%	54.08%	45.88%	40.35%	29.22%	53.70%	27.33%	N/A
334 Computers and Electronics	79.76%	58.39%	15.75%	31.06%	28.54%	22.85%	7.08%	N/A
336 Transportation Equipment	17.42%	40.24%	56.61%	9.93%	16.85%	4.79%	N/A	N/A
335 Electrical	8.88%	12.20%	24.35%	36.22%	21.71%	21.81%	3.55%	N/A
321 Wood	22.94%	38.47%	34.16%	76.18%	23.14%	3.86%	55.09%	
326 Plastics Others	44.69%	26.43%	27.64%	24.39%	15.24%	480.64%	16.78%	10.36%
313 Textile	5.25%		24.03%		4.61%		8.81%	
314 Textile product	89.25%	10.83%	13.15%	13.20%	-11.25%	95.10%	23.81%	29.45%
324 Petroleum and Coal	13.98%	16.05%	6.64%	12.65%	74.27%	16.57%	20.72%	3.57%

The Advanced Manufacturing Initiative is a combination of R&D and demonstration programs, which aim at identifying the most promising opportunities associated with new technologies that can be applied to various industrial processes and sectors. This policy is able to stimulate volunteer upgrades in plants and firms.

Private cost was estimated as the investment for plant upgrades in the private sector. Following the division of industrial plants by Brown et al (2011), this study grouped firms into small, medium and large firms (Figure A.3). It is assumed that the private investment is $14/MMBtu energy saved for large firms and $12.6/MMBtu energy saved for small and medium firms (Brown, Jackson, Cox, et al., 2011).

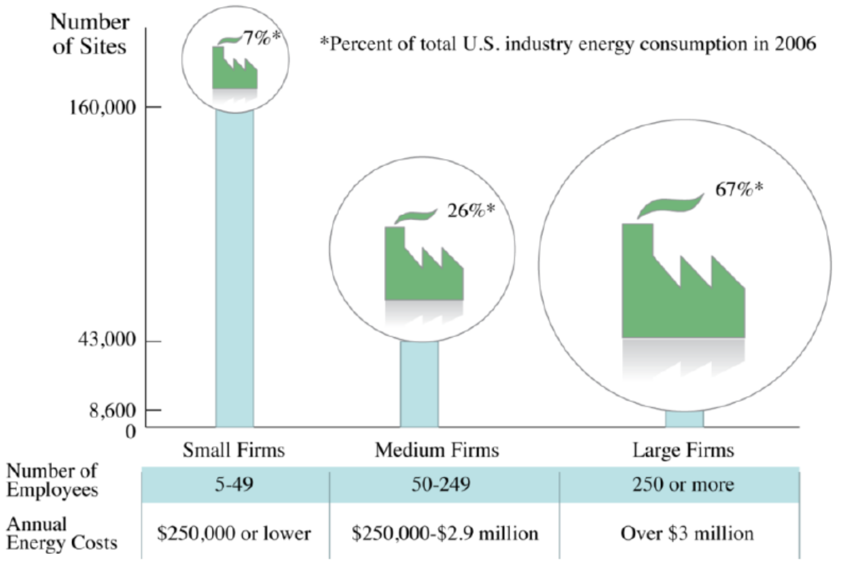

Figure A.3 U.S. Industrial Consumption by Size of Firm

(Source: Brown, et al., 2011)

The levelized cost associated with the **Advanced Manufacturing Initiative** is estimated to be 3.0-4.8 cent/kWh, with investment cost decreasing from $1.34 Billion in 2020 to $2.25 Billion in 2035 (present value, Table A.18).

Table A.18 Cost Estimations from Advanced Manufacturing Initiative

Cost (2009$Billion) [a]	2020	2025	2030	2035
Private Cost	1.34	1.26	0.89	0.94
Public Cost	0.02	0.03	0.03	0.03
Total	1.36	1.29	0.93	0.97
LCOE (cent/kWh)	3.0-4.8 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.

b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.