Calculating the Nation's Annual Energy Efficiency Investments

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Executive Summary

This report undertakes a rather ambitious task—that of documenting the ongoing annual contribution of the nation's many energy efficiency resources as they drive the economy forward. The effort is ambitious for one very good reason. That is because the United States does not have the means to collect and track data on the energy we don't use. But that is precisely what energy efficiency turns out to be. As broadly used in this study, energy efficiency is defined as "the cost-effective investment in the energy we don't use to produce our nation's goods and services."

For this study, we examined available data for 2010 (the last year for which reasonably complete data is available) on utility energy efficiency program expenditures, sales of ENERGY STAR products, annual investments in building improvements, repairs and new construction, trends in manufacturing energy use and investments, and sales of cars and light trucks. Based on these data, we estimated total expenditures on energy-efficient goods and services as well as the portion of these total expenditures that is the extra cost for efficient goods and services relative to the average goods and services. We then extrapolated this data to the economy as a whole, including equipment that is more efficient than average but not quite at ENERGY STAR levels, and including additional sectors of the economy. Based on this analysis, we estimate that in 2010, from $479-670 billion was spent in the U.S. on energy-efficient goods and services (midpoint estimate of $574 billion). More critically, the incremental cost of the efficiency upgrades themselves (for example, going from an average refrigerator to an ENERGY STAR model) is just $72-101 billion in 2010 (midpoint estimate of $90 billion). Our results are summarized in the table below.

Range of U.S. Energy Efficiency Investments (in real 2010 dollars)

	Energy Star Equivalent		Full Efficiency Upgrade	
Sector Coverage	Full Technology Cost	Energy Efficiency Premium	Full Technology Cost	Energy Efficiency Premium
The Core Analysis	341	56	479	72
Economy-Wide Analysis	478	78	670	101
Average Impact	n/a	n/a	574	90

Source: Author assessment as described in the report narrative

We also compared these results with the results of several other studies and found these new estimates generally consistent with prior work. Also, relative to a prior ACEEE study that looked at energy efficiency expenditures in 2004, energy efficiency spending appears to have increased by about 80% since 2004, excluding the effects of inflation. Furthermore, we found that the larger set of investments in energy efficiency (the $574 billion) is about three times the investments we made in conventional energy supply in 2010. That is, if we contrast the average $574 billion of annual investments in energy efficiency-related technologies, the overall cost of efficiency-related investments is about 3.4 times the $170 billion of annual investments in conventional energy supply—the latter including things like transmission lines, drilling equipment, oil wells, and power plants, and other investments associated with the conventional energy supply industry. The $90 billion premium for the higher levels of energy efficiency is a bit more than one-half of the annual investment in energy supply. Since 1970 this energy efficiency premium has delivered about three times the level of new energy services as conventional energy supply.

Looked at another way, the approximately $574 billion investment in efficiency technologies, and the resulting energy bill savings, supported a net gain of about 300,000 more jobs for the American economy, after accounting for the fact that the energy efficiency investments reduced the need for investments in energy supply. In other words, the productivity of our economy may be more directly tied to greater levels of energy efficiency rather than to continued resource extraction and the building of power plants and other energy facilities.

I. Introduction

This report undertakes a rather ambitious task—that of documenting the ongoing annual contribution of the nation's many energy efficiency resources as they drive the economy forward. The effort is ambitious for one very good reason. That is because the United States does not have the means to collect and track data on the energy we don't use. But that is precisely what energy efficiency turns out to be. As broadly used in this study, energy efficiency is defined as: "the cost-effective investment in the energy we don't use to produce our nation's goods and services." And those efficiency investments have generated an enormously positive impact within the U.S. economy. The energy we don't use saves households and businesses money even as lower energy use also eases environmental impacts by reducing the amount of pollution dumped each year into our nation's air and waterways.

Data from the Bureau of Economic Analysis (BEA 2012) shows that in 2010, the United States spent $3.2 trillion on routine investments to upgrade and expand our nation's roads, bridges, structures, equipment, and appliances within the built environment. Those expenditures represented about 22 percent of our Gross Domestic Product (GDP). The analysis described in this report shows that, as part of those ongoing annual investments, we also spent an estimated $341 to $670 billion for the many different technologies that directly improve our efficient use of energy. The expenditures include more fuel-efficient cars, air conditioners, water heaters, refrigerators, and many other individual devices and appliances that depend on energy to animate their use. Of that $341 billion to $670 billion, an estimated $56 to $101 billion was used to actually improve the larger efficiency of those technology and equipment upgrades.[1] A further assessment highlights a very large energy bill savings for business and consumers as a result of those technology upgrades—even as the more productive use of energy also supported a net gain of about 300,000 more jobs for the American economy.[2]

One of the defining characteristics of energy efficiency is that it is very widely dispersed—across the many energy-using technologies that are so much a part of our everyday lives. Indeed, energy efficiency is such an invisible energy resource that we hardly think about the aggregate impact of these many different productivity upgrades. It turns out that efficiency is everywhere. Perhaps a good way to think about it is that energy efficiency is hidden in plain sight. It's in our buildings, our appliances,

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1. As discussed later in this study, the purchase of equipment and appliances has two sets of costs associated with their energy performance and use. The first is the full technology cost (FTC). This refers to the entire cost of a new car or air conditioner, for example. The second is the incremental cost or the energy efficiency premium (EEP) necessary to upgrade the performance of that technology to a higher level of efficiency.
2. For those not familiar with the many studies on the net positive jobs impacts of energy efficiency compared to conventional energy supply, it turns out that, on average, energy expenditures tend to be capital-intensive but not at all labor-intensive. The purchase of other goods and services within our economy, however, tend to be much more labor-intensive. Hence, any cost-effective energy efficiency upgrade that generates energy bill savings and redirects spending away from normal energy purchases toward other goods and services will tend to generate a small but net positive gain in the nation's overall employment. This assessment is drawn from the 2010 IMPLAN data set for the United States (IMPLAN 2012). See Laitner and McKinney (2008) for a meta-review of some four dozen studies that underpin this insight.

our vehicles, and our manufacturing processes. But we can't observe efficiency in an obvious way such as we can see power plants, oil pipelines, and transmission lines. We can see and recognize a large electric generating station, but when we look at the furnace in our home or the air conditioner in our office, the energy efficiency of those devices is not immediately obvious. We only know that we're getting the heat we need, or the cooling.

As the data indicate, the larger set of investments in energy efficiency is about three times the investments we made in conventional energy supply in 2010 (the last year for which reasonably complete data is available). That is, if we contrast the average $574 billion of annual investments in energy efficiency-related technologies (see Table 1 that follows), the overall cost of efficiency-related investments is about 3.4 times the $170 billion of annual investments in conventional energy supply—the latter including things like transmission lines, drilling equipment, oil wells, power plants, and other investments associated with the conventional energy supply industry (BEA 2012). More critically, the incremental cost of the efficiency upgrades themselves (for example, going from an average 23.5 miles per gallon to 27 miles per gallon or higher) is just $90 billion in 2010. This is a bit more than one-half of the annual investment in energy supply. Yet, as we shall read in the background section that follows, since 1970 this energy efficiency premium has delivered about three times the level of new energy services as conventional energy supply. Hence, the one immediate conclusion from this assessment is that the productivity of our economy may be more directly tied to greater levels of energy efficiency rather than a continued mining and drilling for new energy resources.

The description of the analysis that underpins these results begins with a review of the critical trends involving the delivery of energy services as they impact the nation's overall use of energy. With much of the detail provided in the Appendix, the analysis then lays out the key assumptions and methodologies necessary to provide a reasonable working estimate of the annual energy efficiency improvement in our nation's economy. All values are reported in real 2010 dollars. The analysis then looks at previous studies that have generated comparable insights into the costs associated with routine or ongoing improvements in the nation's energy efficiency. Finally it provides a brief discussion of the opportunity to extend energy efficiency benefits by expanding the magnitude of efficiency investments in the years ahead.

II. Background

Economist William Baumol and his colleagues (1989) once observed: "for real economic miracles one must look to productivity growth." And while we always look for ways to improve the productivity of our investments and our labor force, a large number of studies published by the American Council for an Energy-Efficient Economy (see, for example, Gold et al. 2009; Laitner 2009a, 2009b; and Laitner et al. 2010, 2012) and many others (for example, AEF 2010; Harvey 2010; McKinsey 2009; APS 2008; InterAcademy Council 2007; and Interlaboratory Working Group 2000) suggests we can also prime "the productivity pump" with enhanced or expanded energy efficiency investments.

The compound benefits of energy efficiency investments add up quickly. If we look back in time at efficiency gains since 1970, for example, what we find is that while our demand for travel, heating, lighting, and other energy services grew dramatically, 74 percent of that growth in energy-related demand was met through new efficiency improvements, while new energy supplies provided just 26 percent of the new growth in demand. Another way to think about this is to note that since 1970 the amount of energy consumed to produce one dollar of economic output has been cut in half, from about 15.9 thousand Btus per dollar of economic activity to about 7.3 thousand Btus per dollar by last year. We are clearly doing more with less—and that's the good news. Yet the question remains, how might we put this into the larger perspective of the U.S. economy? Has this trend toward greater efficiency been cost-effective? What might we learn about the typical cost of these efficiency upgrades? Figures 1 and 2 provide an opening perspective into the magnitude and the cost-effectiveness of the ongoing efficiency upgrades.

Figure 1. Trends for Energy Services, Energy Use, and Energy Intensity, 1970-2012

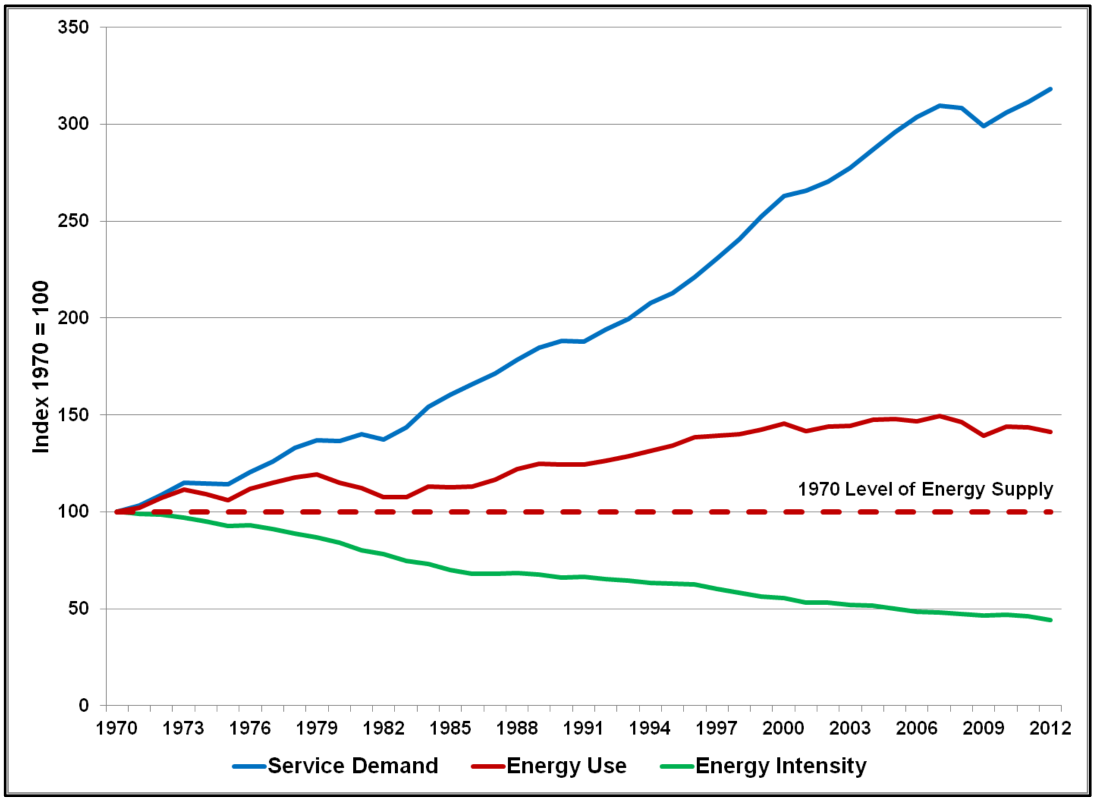
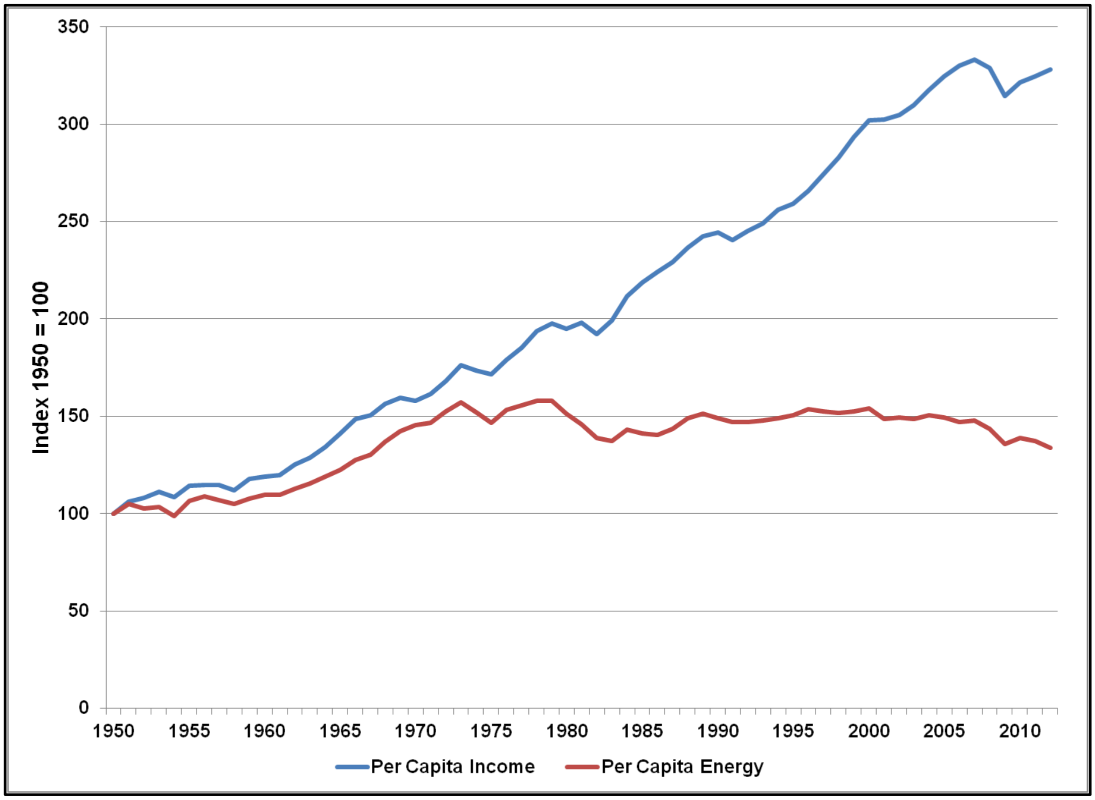


Figure 2. Trends in Per Capita GDP and Per Capita Primary Energy Use, 1950-2012



The data in Figure 1 show three separate trends as they are related to overall energy consumption within the U.S. over the period 1970 through 2010, and preliminarily through 2012. The data are arrayed in an index format where 1970 equals 100. This allows us to examine and compare each of the trends even though the information for each of the trends is expressed in different units. Economic activity, for example, is captured as GDP. We now measure GDP in billions of 2005 chained dollars.[3] Energy consumption, on the other hand, is tracked in quadrillion Btus while energy intensity is a ratio showing how many thousands of Btus the economy requires per real dollar of GDP.[4]

3. Chained dollars are a means to adjust dollar amounts for inflation over time in a way that allows a meaningful comparison of values from different years. The difference between chained dollars and the previously used constant dollars is that the latter is weighted by a constant basket of goods and services while chained dollars are weighted by a basket of goods and services that changes from year to year. This more accurately reflects real spending power. Because the basket of goods and services is averaged for two successive years—in effect, the second number in a pair of successive years becomes the first in the next pair of years, the outcome is a "chain" of real dollars over time.

4. One quadrillion Btus (British Thermal Units) is roughly the amount of heat energy contained in 8 billion gallons of gasoline, or 293 billion kilowatt-hours of electricity. In today's economy, and at current levels of energy productivity, 1 quad is sufficient energy to support about $142 billion of economic activity. In 1970, one quad supported only 57.9 billion dollars of economic activity (with both values expressed in real 2005 dollars). Alternatively, one quad is also sufficient energy to fuel 20 million cars driven an average of 10,000 miles per year—assuming 25 miles per gallon fuel economy.

Looking at Figure 1, the top (blue) line highlights a slow but rising demand in GDP. From another perspective, however, the trend line can also be thought of as reflecting our nation's demand for energy services. Here we must make a distinction between energy and energy services. Energy is the physical animation of people, equipment, and machines. We can also imagine it as a force that transforms matter over time or that moves objects over a distance. The expenditure of energy is a flow that is measured as gallons of gasoline, tons of coal, or kilowatts per hour. While energy flows are at work in all aspects of our physical world, absent some purposeful use as driving a car or playing music, by themselves those flows of energy are likely to do very little in providing desired social value. Generating a social benefit requires that energy be directed in useful ways as it may be enabled by labor and capital working together. In that case, the dynamic wealth of the nation requires some mix of energy, capital, and labor to support a presumably desired level of economic activity. As such, the economy can also be tracked as the equivalent quadrillion Btus of energy necessary to support any physical or economic effort.

Returning to Figure 1, the demand for energy services reached an index value of 318 in 2012, or 3.18 times the 1970 value of 100. The solid middle (red) line in Figure 1 tracks a subset of energy services in the form of the actual flows of energy consumed over that same period of time. In this case, we see that, while the demand for energy services has more than tripled, the demand for energy itself has increased to an index of just over 140, or 40 percent more than in 1970. The difference, of course, is the gain in energy efficiency—or as measured here, the reduction in energy intensity (shown as the bottom green line) with an index that has fallen below 50, or roughly one-half the level of intensity seen in 1970. Interestingly, we can think of the area in the approximate triangle between the top and solid middle lines of Figure 1 as the measure of the new energy we did not consume in order to support the growing level of economic activity. As it turns out, the energy that we did not use over the period 1970 to 2012 was a cumulative 2,198 quads of efficiency equivalent. Or we might say that the energy efficiency gains were equivalent to 379 billion barrels of oil.[5]

On the other hand, the rough triangle formed in Figure 1 between the solid middle line and the dashed line (the latter a measure of the 1970 level of conventional energy that was supplied) is a quantity of the new energy necessary: (a) to maintain the overall level of energy services required to support the economy; and (b) that was not satisfied through the increased use of energy efficiency. The cumulative amount of conventional energy supplies that were consumed in this second triangle is only 785 quads, or the equivalent of 135 billion barrels of oil. Dividing 379 billion barrels of oil of efficiency by the sum of that same 379 billion barrels together with the 135 billion barrels of energy supplied indicates that energy efficiency met 74 percent of the new demands for energy services while energy supply provided only 26 percent of the new demands. Since 1970, then, energy efficiency has delivered about three times the new demand for energy services as has energy supply.

Figure 2 takes us a second step closer to evaluating the cost-effectiveness of the efficiency trend. From a 1950 vantage point, and referencing the solid bottom (red) line in Figure 2, it turns out that the per

5. The conversion of quadrillion Btus into barrels of oil equivalent assumes 5.8 billion Btus per barrel.

capita use of energy grew by about 50 percent through the year 1973. With the emergence of the "oil crisis" in October 1973, a variety of conservation and energy efficiency measures contributed to the stabilization of overall energy use—first hovering around an index of 150 throughout the period 1988 until 2005, and then dropping to 134, or only 34 percent higher by 2012—even as per capita incomes (shown in the top blue line) continued to rise to an index of 184, or 84 percent higher by 1973 and then to an index of 325 (or 225 percent higher by 2012 when expressed as a percentage change). With per capita incomes rising even as per capita energy use has been holding relatively flat, we might easily conclude that, yes, the efficiency gain has more than paid for itself and has remained a cost-effective resource that has been growing over time. We examine the magnitude of energy efficiency investments in the next section that follows. As we shall see, the ongoing energy efficiency outlays that our nation routinely makes each year are shown to be entirely cost-effective—at this modest scale of improvement, with simple paybacks that retired the energy efficiency premiums within a two- to three-year period.[6]

III. Evaluating the Annual Cost of Energy Efficiency Investments

Early in the report we noted that energy efficiency is "the cost-effective investment in the energy we don't use to produce our nation's goods and services." As cited more formally in this section of the analysis, the term "energy efficiency investment" refers to the expenditure of capital necessary to upgrade, modernize, and improve the energy efficiency of any aspect of the nation's built environment. This includes the array of devices, appliances, tools, and other technologies that are deployed throughout the economy. Many businesses, for example, operate equipment and use facilities that are old and energy inefficient. This may be the result of technology advances that have occurred since the initial installation of their current stock of equipment. It also may be the consequence of an inability to finance productivity improvements as the result of a slumping economy. Or it may be the effect of depreciation, or the simple wear and tear on equipment over the years.

Whatever the reason, replacing an older generation of equipment with newer technologies is generally accompanied by improvements in energy efficiency, even if energy efficiency was not the primary goal of the changes that were made. This section of the analysis builds on this idea by describing and characterizing the investment scale of these routine upgrades in energy efficiency for the year 2010.

A. Initial Results and Analytical Considerations

In this analysis, the data very much drives the assessment. Or perhaps more accurately, the lack of data greatly shapes an overall methodology that lays out a surprisingly large $479–670 billion (mid-

6. As the data suggest throughout this study, and especially in the Appendix, the normal rate of energy efficiency improvement is highly cost-effective with a typical efficiency upgrade paying for itself in two years or less. At the same time, however, any push for a greater rate of energy efficiency improvement, beyond what we might term "business as usual," would likely push up the cost of such improvements. Yet, as studies such as Laitner et al. (2012) suggest, the range of efficiency improvement is sufficiently large that we can imagine reducing our nation's total energy needs by 40 to 60 percent even as we continue to save money for consumers and businesses.

point of $574 billion) in 2010 for the full technology cost (FTC) energy efficiency investments. The methodology also reflects $72–101 billion (mid-point of $90 billion) in energy efficiency premiums that are required to upgrade the nation's building stock, vehicle fleet, and manufacturing processes. This section provides the details and the range of estimates that underpin the working assessment as summarized in Table 1 below.

Table 1: Summary of the Range of Energy Efficiency Investments (in real 2010 dollars)

	ENERGY STAR Equivalent		Full Efficiency Upgrade	
Sector Coverage	Full Technology Cost	Energy Efficiency Premium	Full Technology Cost	Energy Efficiency Premium
Core Analysis	341	56	479	72
Economy-Wide Analysis	478	78	670	101
Average Impact	n/a	n/a	574	90

Source: Author assessment as described in the report narrative

There is a lack of detailed data that would otherwise allow a bottom-up assessment of the annual energy efficiency upgrades forces. Instead, a bootstrapping technique using a "two-by-two" analytical framework was used. The first element of the two-by-two, under the category of *Sector Coverage*, distinguishes between what Table 1 refers to as the "Core Analysis" and the "Economy-Wide Analysis." The second element separates what is called the "ENERGY STAR Equivalent" and the "Full Efficiency Upgrade."

We can think of the modest energy efficiency improvements that are made each year as ones which occur along a continuum. It begins with the average efficiency of existing vehicles, appliances, and other equipment that slowly increase in performance until the best (likely also the fewest) technology performers are adopted. As categorized for this analysis (and explained further in Section III.B.5 and Appendix A-4), the ENERGY STAR technologies are generally those that are among the 25 percent most energy-efficient technologies in their class—whether cars with a high fuel economy or air conditioners with a very high efficiency rating. Because ENERGY STAR programs provide a solid cornerstone in moving energy-efficient products into the market, Table 1 allocates energy efficiency performance into those two categories.

At this point we can build the assessment with the Core Analysis for those technologies that are among the ENERGY STAR performers or the ENERGY STAR equivalents (as highlighted in the blue-shaded cells of Table 1). That covers a set of calculations for five different categories of expenditures for which some data are reasonably available, and for which a first estimate of technology costs can be provided. As described in the Appendix Section A-5 below, however, these five categories of investments (see Table 2 that immediately follows this discussion) cover only 71 percent of the economy's total energy end-uses. Thus, it tends by some degree to underestimate the full economy-wide impact of those efficiency improvements. By extending the detailed assessment of the Core Analysis to include the entire economy, we can generate at least a working estimate of the full impact of the ENERGY STAR equivalent technologies. Similarly, we can generate both a core analysis and a full economy-wide assessment of what is shown in Table 1 as the "Full Efficiency Upgrade." In effect, the Core Analysis gives us a floor and the economy-wide, Full Efficiency Upgrade provides an upper bound for the 2010 estimate for energy efficiency improvements. Finally, by averaging the totals for the economy-wide analysis that incorporates both the ENERGY STAR performers as well as the less efficient technologies, we can generate a central estimate of the scale of ongoing energy efficiency improvements.

B. The Core Efficiency Analysis for 2010

Building on the two-by-two framework, we can now take a first step in generating an estimate of the 2010 energy efficiency investment totals. To do that this subsection lays out the major assumptions for each of the five categories of improvements for the business-as-usual efficiency upgrades in the year 2010. Table 2 provides that working summary.

Table 2: Summary of Efficiency Investments by Major Activity (in Billions of 2010 Dollars)

Program or Activity	Full Technology Cost	Energy Efficiency Premium
1. Utility Efficiency Programs	10	6
2. ENERGY STAR Programs	135	18
3. Building Improvements, Repairs, & New Construction	58	17
4. Manufacturing Improvements	28	11
5. New Car Sales Above 27 MPG	110	4
Total Estimated Expenditures	341	56

Source: Author assessment as described in the report narrative

The first of major categories of efficiency upgrades in Table 2 are the various energy efficiency programs sponsored by the nation's natural gas and electric utilities. The second is the set of ENERGY STAR programs that focus on a variety of energy efficiency improvements across the major sectors of the economy. The third is a general category of building upgrades that benefit from both the ENERGY STAR and the utility efficiency programs. Next, drawing on census data comparing 2009 with the year 2010, is a set of efficiency improvements in our nation's manufacturing establishments. The last category is the array of light duty vehicles, including the mix of cars and light duty trucks that, on average, were sold in 2010 with a fuel economy of 27 mpg or greater (see Section III.B.4 for a further discussion of why 27 mpg was selected as the cut-off for the ENERGY STAR equivalent).

Before continuing the discussion, we might offer one further reminder of the analytical context prior to describing the key assumptions of these five elements of the Core Assessment. Yes, there are indeed a large number of efficiency improvements in other areas of our nation's economy. There are improvements to be tracked in our nation's movement of freight, or the large number of passengers to be moved by our air, rail, and transit systems. There are productivity improvements within the agricultural, mining, and construction industries that are being made as well. As summarized in Appendix A.5, the five elements of the core analysis cover 71.5 percent of the total energy delivered to end-uses. This implies these missing elements are likely to increase the assessment of potential efficiency by about 40 percent above what is otherwise shown in the Table 2 Core Analysis. And again, there are improvements that might be tracked that bridge the difference between the average performance of the existing installed base of technologies and what is termed here as the ENERGY STAR equivalent. With these elements, as well as the larger caveats explained in the Appendix to this report, the next set of program reviews explains the five categories of efficiency upgrades, in the order in which they appear in Table 2.

1. Utility Efficiency Programs

In 2010, the nation's natural gas and electric utilities spent $942 and $4,596 million, respectively (Sciortino et al. 2011). These expenditures certainly achieved a level of success, if only because the program expenditures increased by another 40 percent in 2011 (Foster et al. 2012). According to Friedrich et al. (2009), utilities appear to be picking up 55 percent of total costs. This is generally thought to reflect a combination of the program and administrative costs to run the programs as well as providing incentives that are designed to offset the incremental cost of improving the efficiency of the installed technologies. The efficiency premium is estimated to be $6 billion of investment.[7] At the same time, however, the utility programs tend to build on the ENERGY STAR programs supported by the U.S. Environmental Protection Agency (EPA) as described next (CPPD 2011a). Hence there is some overlap between the two program efforts, a factor we adjust for as noted in Footnote 7.

2. ENERGY STAR Programs

The U.S. Environmental Protection Agency's successful ENERGY STAR program uses a variety of approaches to promote energy efficiency improvements through all sectors of the economy. In 2010, the aggregation of these programs saved businesses and consumers more than $20 billion on their energy bills (CPPD 2011a). While the program data are not available for individual years, we can reverse engineer information from the annual report released by EPA's Climate Protection

7. The full technology cost of efficiency improvement in rounded billions of 2010 dollars is 0.9 + 4.6 with both values divided by 0.55, or $10 billion. Program marketing and administrative costs are approximately $1.65 billion (30 percent of the utility costs of $5.5 billion), leaving $8.35 billion as energy efficiency premium costs. We round down to $6 billion in order to eliminate overlap with ENERGY STAR and other categories that we analyzed separately. This is an "educated guess" of the amount of overlap.

Partnerships Division (CPPD) to arrive at a working estimate of program impacts for 2010. The present value of energy bill savings is $402 billion cumulative over the period 1993–2020. EPA reports the cumulative investments in that same period at just over $96 billion. Drawing from various data points within the annual report suggests a total marginal spending of $18 billion in 2010 alone. This was generally confirmed in conversation with EPA personnel.

The ENERGY STAR data generally reflect the incremental cost of purchasing an ENERGY STAR-qualified product compared to a standard product or technology. We draw the total efficiency spending from EPA's report of product shipments (CPPD 2011b). The information provided only reports actual shipments for which working estimates of retail prices are applied. With that in mind, the sum of these products suggests that consumer expenditures (for both households and businesses) are on the order of $135 billion for qualified ENERGY STAR products. Again both data points are reflected in Table 2. There are other expenditures for building improvements and industrial operations before the products shipped. For the moment those values are reflected in the broader mix of services described in the following two sections on building improvements and repairs and manufacturing improvements.

3. Building Improvements, Repairs, and New Construction

Drawing from the Department of Energy's (DOE) *2011 Buildings Energy Data Book* (DRI 2012), the national economic accounts report that the value of building improvements and repairs (including both residential and commercial buildings for both private and governmental purposes) ran about $416 billion in 2010. This becomes one of our starting points for assessing the investment in efficiency upgrades. The other major component is the 447,000 new homes built in 2010, and the addition of an estimated 1.8 billion square feet of commercial office space, also constructed in 2010. Yet, this segment of the accounting may be the most difficult for which to generate a precise estimate since there are so many data sources, all reflecting different slices of information, at different moments of time, and intersecting with other programs including both ENERGY STAR and the utilities' energy efficiency programs.

The building improvements and repairs include consumer appliance upgrades, insulation, and space conditioning (commonly referred to as heating, ventilation, and air conditioning, or HVAC). This totals to about $30 billion in 2010. Since the main purpose of insulation is to maintain a comfortable thermal condition within all buildings, this analysis includes the entire cost of insulation as the efficiency premium—about $3 billion. On the other hand, the analysis suggests that the mere replacement or the addition or upgrade of rooms and space may take 75 percent of the equipment and HVAC cost, leaving 25 percent attributable to efficiency gains in existing buildings. As suggested in the footnote below, this suggests an efficiency premium of about $11 billion in 2010.[8]

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8. The calculation here would be $30 billion times 0.25 plus $3 billion, which equals $10.5 billion, or $11 billion in rounded terms.

The 447,000 new homes built in 2010 and the 1.8 billion square feet of new commercial space are assumed to have an efficiency premium of $5000 per home and $2.25 per square foot of commercial building (IMT 2011). Maintaining the assumption that the efficiency premium is 25 percent of the full technology cost, total new construction might have an efficiency-related cost of $25 billion with an efficiency premium of $6 billion in 2010.

As shown in Table 1, the sum of the products from the two paragraphs above point to a full technology cost of $58 billion with an energy efficiency premium of $17 billion. Other categories (such as upgrades installed by energy services companies, significant upgrades in K-12 schools, completion of about 500,000 square feet of green roofs together with $207 million in state appliance rebates) add further complexity. For the moment, however, the working assumption is that these are among the drivers that contribute to the net $17 billion energy efficiency premium.

4. Manufacturing Improvements

Notwithstanding the lagging improvement in the larger economy in 2010—the nation's energy intensity as a whole actually increased by 0.3 percent in that year,[9] the manufacturing sector appears to have generated some net efficiency gains based on data from the *Annual Survey of Manufactures* (Census 2012). In this regard, the analysis compares the total cost of purchased energy (including both electricity and other fuels) for 2009 and 2010 as a share of the value of shipments, using 2010 constant dollars for both years. Had the nation's manufacturing sector remained at 2009 energy intensity but expanded sales at their 2010 level of shipments, they would have spent $5.66 billion more dollars in 2010 than the $90.8 billion that was actually recorded. The question then becomes—how to convert that savings into an estimated capital cost? The insights from Table 3 provide at least one useful benchmark. The data in Table 3 summarizes 3,412 recommendations for energy efficiency improvements made available to small and medium manufacturing plants by a network of university engineering departments within the United States.

9. See the discussion in the Appendix Section A.3 for background on how efficiency gains might appear even as the economy as a whole increases its overall energy intensity.

Table 3: Average Energy Efficiency Payback Period (Years) from IAC Database

#	Recommendation	Cost	Savings	Payback
297	Eliminate Leaks in Inert Gas and Compressed Air Lines/Valves	$608,399	$2,273,872	0.3
288	Utilize Higher Efficiency Lamps and/or Ballasts	$7,829,240	$3,362,338	2.3
180	Reduce the Pressure of Compressed Air to the Minimum Required	$189,701	$1,184,348	0.2
173	Install Occupancy Sensors	$1,168,758	$739,002	1.6
158	Use More Efficient Light Source	$22,436,738	$4,448,634	5.0
108	Install Compressor Air Intakes in Coolest Locations	$177,869	$363,707	0.5
88	Use Multiple Speed AFD Motors for Pump, Blower, Compressor Loads	$2,286,257	$1,636,760	1.4
74	Insulate Bare Equipment	$555,689	$663,401	0.8
66	Utilize Energy-Efficient Belts and Other Improved Mechanisms	$59,289	$149,492	0.4
63	Reduce Compressed Air for Cooling, Agitating Liquids, Moving Product, Drying	$161,412	$331,810	0.5
1917	All Other Recommendations	$97,641,128	$59,080,725	1.7
3412	Total Combined Recommendations	$133,114,480	$74,234,089	1.8
n/a	Average Per Recommendation	$39,014	$21,757	1.8

Source: Integrated Assessment Centers Database, Rutgers University (2012)

Table 3 draws on the extensive database of the Department of Energy's Integrated Assessment Center maintained by Rutgers University. The dataset contains the results of over 14,000 assessments conducted over the past 32 years with more than 100,000 recommendations from a network of university engineering departments across the nation (Muller 2011). In effect, Table 3 examines the last full year and provides a record that summarizes the costs and energy bill savings for the top 10 recommendations made to manufacturing plants and an aggregate of all other recommendations made in the last year. The average cost of a specific recommendation was $39,014 with a suggested savings of $21,757, which implies a simple payback of 1.8 years per measure. [10] These insights are consistent with other findings as well (see, for example, Russell et al. 2012).

Given that backdrop, this analysis assumes the net energy savings in 2010 required an investment that likely paid for itself in two years. Based on an assessment using the Long-Term Industrial Energy Forecast Model (Ross et al. 1993), the assumption was that the upgrades had an energy efficiency premium of about 18 percent.[11] Because manufacturing tends to be more focused on larger

10. There is, in fact, not a lot of discrete data on actual energy efficiency investments within the manufacturing sector, and the IAC database (Muller 2011) may be somewhat problematic because it focuses on equipment measures for small to medium manufactures that may rely on somewhat more costly improvements than what we see for larger firms that integrate retooling and process improvements in addition to discrete equipment upgrades. As a result, this may overstate the costs over the longer time horizon but for year-to-year short-term changes, a two-year payback may be a useful rule of thumb for this type of thought experiment.

11. LIEF is an 18-sector industrial model that was designed for the study of future industrial energy consumption. Among other features it provides conservation or energy efficiency supply curves given assumed energy prices, elasticities, the

productivity improvements in which the non-energy benefits of efficiency upgrades tend to be at least as big as the energy efficiency benefits, the assumption for this analysis of the manufacturing sector was that the energy efficiency premium would be about 40 percent of total investment.[12]

With those parameters established, and as shown in Table 2, manufacturing would therefore have devoted $28 billion to efficiency upgrades with an associated energy efficiency premium of $11 billion in 2010.[13] By way of comparison, the *Annual Survey of Manufactures* (Census 2012) suggests manufacturing had a total capital expenditure of $128 billion in 2010. If the efficiency investments described here continue to hold, then manufacturing would be expending about 22 percent of its 2010 investment to upgrade the energy performance of its operations.

5. Sales of Light Duty Vehicles

According to the National Automobile Dealers Association (NADA 2011), the U.S. sold about 12 million cars and light trucks in 2010 for an average dealer cost $29,783. However, their annual reports do not track the fuel economy (miles per gallon) of vehicles that are sold. For some rough insights into the sale-weighted MPG of our nation's cars we turn to WardsAuto.com (2012) for the purchase of a dataset, which recorded 276 models of cars and light trucks together with their individual and total sales as well as their suggested fuel economy. Table 4 below summarizes the breakout of that data.

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differences between the average and the best energy practices within an industry, and desired financial returns. In this case, the model assumed an efficiency gap of 0.25, a short-run price elasticity of -0.18, and a 12 percent return on investment. For various examples of studies using LIEF, see Cleetus et al. (2003) and Laitner et al. (2010).

12. These added savings or productivity gains range from reduced maintenance costs and lower waste of both water and chemicals to increased product yield and greater product quality. In one study of 52 industrial efficiency upgrades, all undertaken in separate industrial facilities, for instance, Worrell et al. (2003) found that these non-energy benefits were sufficiently large that they lowered the aggregate simple payback for energy efficiency projects from 4.2 years to 1.9 years. Several other studies have quantified non-energy benefits from energy efficiency measures and numerous others have reported linkages from non-energy benefits and completed energy efficiency projects. In one, the simple payback from energy savings alone for 81 separate industrial energy efficiency projects was less than 2 years, indicating annual returns higher than 50 percent. When non-energy benefits were factored into the analysis, the simple payback fell to just under one year (Lung et al. 2005).

13. In this case, the single-year energy savings is estimated to be $5.66 billion. If we assume a two-year payback, the implied investment for that one-year upgrade is $11 billion (rounded). The 40 percent efficiency premium implies a total investment of $28 billion as shown in Table 2.

Table 4: U.S. Vehicle Sales by Fuel Economy (November 2011-October 2012)

Performance	Vehicle Sales	Weighted MPG
Less than 23.5 MPG	7,821,663	19.3
Between 23.5 and 26.9 MPG	2,803,901	25.2
Greater than 27.0 MPG	3,547,473	32.3
Total Vehicle Sales	14,173,037	23.7

Source: Author calculations from WardsAuto (2012)

Looking at the EIA data for 2010 (EIA 2012b), it appears the average fuel economy of cars and light trucks, with the aggregate often referred to light duty vehicles, was 23.5 mpg. The suggestion then is that any car sold with a fuel economy higher than 23.5 mpg would be contributing to an improvement in the nation's energy intensity. At the same time, the analysis highlights what can we refer to as an improvement that is *ENERGY STAR equivalent*. For this purpose, and consistent with the general criteria of the ENERGY STAR program, the database was sorted through the top 25 percent of total vehicle sales, which identified those that might be termed ENERGY STAR equivalent—that is, among the top 25 percent of cars and light trucks as ranked by their fuel economy. The results indicated that vehicles sold with a performance of 27 miles per gallon or better might be listed in the top 25 percent ENERGY STAR tier for this purpose.

Table 4 then shows those results based on the recent sales of 14.2 million cars. The 7.8 million cars that were listed below 23.5 mpg had an aggregate fuel economy of 19.3 mpg. The 2.8 million sold with a fuel economy between 23.5 and 26.9 mpg shown an aggregate 25.2 mpg. The 3.5 million cars in the ENERGY STAR cohort showed an average fuel economy of 32.3 mpg. In the aggregate, the sales-weighted performance of all cars sold was listed at 23.7 mpg. In short, because the fuel economy of the entire fleet for that year was 23.7 mpg, the performance of the vehicle stock improved. And this might be even more the case as some of these new vehicles are likely to replace older clunkers that tend to drag down the performance of the entire vehicle stock.

The next question is to ask—at what cost? Neither the Wards data nor the NADA report provided this information. Hence the need to construct a simplified cost curve. The good news here is that the EIA supplementary transportation tables (EIA 2012b) provides some useful information in that regard. As part of the *Annual Energy Outlook 2012*, EIA generated a set of data comparing various light duty vehicles with equivalent information in two different worksheets that were merged to provide a single dataset comparing the cost of different vehicle categories (for example, comparing compact cars with gasoline engines with light duty trucks with both diesel and gasoline engines). The bad news is that however the analysis is done, the tradeoff of cost versus performance generates an exceedingly low R-squared, which suggests that there are many other factors that impact vehicle prices. This is certainly supported by the discussion found around Appendix Table A-4, which indicates that consumers could actually obtain greater fuel economy even as they pay lower prices for their choice of cars.

A review of costs across the range of light duty vehicles (EIA 2012b) suggested that a reasonable value of incremental vehicle cost might be $125 for each mile per gallon increase in fuel economy above the 23.5 standard. The average new light duty vehicle in 2010 was $29,783 (NADA 2011). This means that a car that might have a fuel economy of 32.3 mpg (as suggested in Table 4 above) might have an incremental cost of $1,100 relative to a less-efficient car of similar size and features. The average sales of those cars might be about $110 billion. The incremental increase might push close to $4 billion. These are the values reported in Table 2.

C. From the Core Analysis to A More Complete Assessment

With the set of five programs or economic activities now reasonably quantified for their combined energy efficiency investments, the core of the two-by-two framework is set. The remaining three elements of the two-by-two assessment shown in Table 1 (copied below for ease of review) can be approximated using a series of straightforward calculations.

Two key assumptions help build out the next set of estimates. The first is that the "full efficiency upgrade" for the core analysis will be limited to building and light duty efficiency improvements. Two of the other three elements—the utility efficiency and ENERGY STAR programs—for the most part have already carved out the high-end of the building improvements. This implies a need to estimate the non-ENERGY STAR improvements within residential and commercial buildings as they might be approximated by the building improvement and repair category in Table 2. At the same time the manufacturing improvements in Table 2, largely by assumption, already include both ENERGY STAR and non-ENERGY STAR upgrades. By this logic we need some basis to estimate the non-ENERGY STAR advances for buildings and light duty vehicles.

Table 1: Summary of the Range of Energy Efficiency Investments (in real 2010 dollars)

	ENERGY STAR Equivalent		Full Efficiency Upgrade	
Sector Coverage	Full Technology Cost	Energy Efficiency Premium	Full Technology Cost	Energy Efficiency Premium
The Core Analysis	341	56	479	72
Economy-Wide Analysis	478	78	670	101
Average Impact	n/a	n/a	574	90

Source: Author assessment as described in the report narrative

Earlier in Section III.B.3 we noted the total value of all improvements and repairs for all residential and commercial buildings ran about $416 billion in 2010. If we back out the so-called ENERGY STAR program improvements from the first three elements in Table 2, that implies a remaining $213 billion of improvements that remain. And if we assume one-fourth of those improvements were energy-related upgrades, this suggests an additional investment of about $53 billion to upgrade the nation's building stock in 2010.[14] Recalling the previous assumption that the energy efficiency premium was about 15 percent of the total technology cost means the marginal cost of the efficiency upgrade would be $16 billion.

One task remains to build out the full efficiency upgrade of our core analysis. Here we want to map the cost of the so-called non-ENERGY STAR light duty vehicles. In effect, we are looking for the cost of the 2.8 million vehicles in Table 4 that were sold with a fuel economy between 23.5 and 26.9 mpg. This was done by multiplying 2.8 million by the average $29,793 cost of light duty vehicles sold in 2010 plus the estimated $125 for each mile per gallon of increased fuel economy above 23.5 mpg. The result suggests the aggregate cost of $84 billion with an associated energy efficiency premium of about $1 billion. With these totals now in place we can add the $53 billion in building upgrades and the $84 in car sales to the existing $341 billion full technology cost in ENERGY STAR equivalent to generate a new total of $479 billion shown in the full technology cost in the full efficiency upgrade column of Table 1. Similarly, we can add the energy efficiency premiums of the $16 billion of building improvements and the $1 billion of marginally improved light duty vehicles to find the new estimate of the efficiency premium of $72 billion (with a rounding to the nearest unit that accounts for the apparent difference of $1 billion).

With the core analysis now completed for the five elements previously estimated, representing about 71.5 percent of total delivered energy (see the discussion in Appendix Section A-5), we can now determine the economy-wide analysis. In effect, we can make a simplifying assumption that the remaining energy uses have a parallel level of cost-effectiveness as the sum of the five elements of the core analysis. Hence, we divide each of the four totals in the core analysis by 0.715 to generate a working estimate of the economy-wide impacts, which gives us both a lower and an upper bound. Taking the average of the full technology costs and the energy efficiency premiums then provides us with the working totals of $479-670 billion (midpoint of $574 billion) for the full technology costs and the $72-101 billion (midpoint of $90 billion) for the energy efficiency premiums.

D. ADDING IT ALL UP

As suggested in the introduction of this report, the immediate insight that follows these working estimates of annual investments is how big of a player energy efficiency already is within the economic arena. We can get a sense of that by again recalling three data points. The first is that energy efficiency historically has provided about three-fourths of the new demand for energy-related goods and services, while energy supply only one-fourth. The second is that efficiency has delivered its energy services at a substantially lower cost. The $90 billion energy efficiency premium expended in 2010 is one about one-half the cost of the $170 billion cost for conventional energy supply. Yet it delivers a much bigger energy punch. Finally, without much fanfare or recognition, energy efficiency

14. The calculation here would be $413 billion previously cited less the $10 billion cited in Table 2 for utility programs, the $135 billion for ENERGY STAR productions, and the $58 billion for other building improvements. Multiplying that remaining sum by 0.25 leaves the suggested $53 billion.

has enabled per capita consumption of energy to remain relatively flat since 1970 even as per capita income has roughly doubled.

IV. In Contrast with Previous Assessments

While energy efficiency has been a powerful but largely invisible resource, other analysts have tried to highlight its contribution to our economic well-being in a small number of previous studies. Table 5 summarizes their findings as their data are reported in billions of 2010 dollars. The studies are listed by organization, major authors, and year of publication.

Table 5: Summary of Previous Assessing the Efficiency Magnitude (in Billions of 2010 Dollars)

Source	Year of Analysis	Full Technology Cost	Energy Efficiency Premium
ACEEE—Ehrhardt-Martinez and Laitner (2008)	2004	334	48
Brookings—Muro et al. (2011)	2010	n/a	62-125
ACEEE—Laitner (1995)	1970 to 1991	n/a	39
ACEEE—The Present Study	2010	574	90
BEA (2012)—Investments in Energy Supply	2010	170	n/a

Source: Author assessment as described in the report narrative

ACEEE—Ehrhardt-Martinez and Laitner (2008). In the first–of-its-kind bottom-up assessment (very similar to that used in this study—indeed, the present analysis draws heavily from this earlier effort), the authors determined that in 2004 the U.S. economy invested a total of $300 billion in energy efficiency technologies and infrastructure in the United States. Narrowing the focus to include solely the premium associated with improvements in energy efficiency technologies, they estimated a market activity at roughly $43 billion in 2004. Converting these totals to 2010 dollars indicates a full technology cost of $334 billion and an energy efficiency premium of $48 billion, as reported in Table 5. There are two items of note in comparing the 2008 study with the current effort. First, the earlier assessment provided perhaps more analytical rigor than was possible with this current analysis. In effect, the focus in 2008 was deeper but narrower in scope. In this regard, the estimate of $48 billion might more appropriately parallel the $56 billion energy efficiency premium shown as part of the core analysis of Table 1. Second, the amount of energy efficiency investments is likely increasing in real terms rather than holding steady.

Brookings—Muro et al. (2011). In a detailed econometric assessment, Mark Muro and his colleagues at the Brookings Metropolitan Policy Program generated a county-level database of establishment-level employment statistics as they pertained to a survey of clean economy industries in the United States over the years 2003 through 2010. They determined that the clean economy employed some 2.7 million workers across a diverse number of industries in 2010. Of the total clean economy jobs, Brookings found that about 830,000 people were supported in a category called energy and resource efficiency. Paring the list to sectors more directly related to energy efficiency improvements—including appliances, energy-saving building materials, architectural and construction services, lighting, and building controls, the data suggest a total of about 400,000 jobs now currently supported.

Muro et al. (2011) did not estimate the amount of investment associated with this jobs, so we used their data to make a first-order estimate. Using data from the IMPLAN data for the U.S. economy in 2010, we can generate a set of labor coefficients to determine the sector revenue generated for each category of job. Economy-wide, each job requires an average spending of about $155,000 per job. This suggests revenue of $62 billion is required to support all 400,000 jobs. Using a sector-based estimate for each of those 400,000 jobs suggests an annual spending of about $125 billion is necessary to support those same jobs. Assuming these reflect an equivalent of the energy efficiency premium, the range in Table 5 would be the suggested $62-125 billion. This is similar to the $72-101 billion range estimated in this study.

ACEEE—Laitner (1995). This paper reviewed a set of 14 different energy-related indicators of economic, social, and environmental progress. Among those indicators was a supplemental benchmark to generate perhaps the first-of-its-kind top-down estimate of the energy efficiency investment trend over the period 1970-1991. The starting point was a seven-sector decomposition analysis used to separate changes in the nation's energy intensity from efficiency improvements versus structural changes within the economy. The average marginal investment over a 21-year period was estimated at $25 billion per year in 1987 dollars. Updating that value to 2010 dollars provides a working estimate of $39 billion as reported in Table 5.

BEA—Investments in Energy Supply (2012). In contrast to the efficiency investments, a useful comparison is provided by examining the annual 2010 investments in both power supply and petroleum and natural gas production. This supply-side data is tracked through the annual surveys that form the National Income and Product Accounts maintained by the Bureau of Economic Analysis (BEA 2012). Table 5.4.5 of those accounts provides records on private investments while Table 5.8.5B provides statistics on government investments. For the year 2010, federal, state, and local governments spent $11 billion for power supplies while private investments in the power, petroleum, and natural gas sectors totaled $159 billion. The combined private and government investments in the energy supply sectors added up to $170 billion as reported in Table 5.

V. Building on the Efficiency Resource

The data in Table 5 and elsewhere indicates that, as a nation, we are clearly making positive strides toward increasing our energy productivity and reducing our carbon footprint. Yet other studies suggest that we are underperforming in the development of our energy efficiency resources. For example, the November release of the International Energy Agency's (IEA) *World Energy Outlook 2012* attests to the growing awareness of energy efficiency. Indeed, though a reasonably modest goal noting that energy efficiency can save an equivalent to 18 percent of the year 2010's global energy consumption by 2035, global GDP would be 0.4 percent higher in 2035.

In an ACEEE study released in early 2012 (Laitner et al. 2012), the evidence suggested an economic potential to reduce the nation's energy consumption in the year 2050 from a projected 122 quads all the way down to 50 quads. This roughly 60 percent reduction—as the report documents, all done through highly cost-effective efficiency investments in a wide variety of energy efficiency improvements on both the demand-side and the supply-side—could generate up to 2 million jobs while saving all residential and business consumers a net $400 billion per year, or the equivalent of about $2,600 per household annually. As noted in a subsequent analysis, the level of energy savings would be the equivalent to roughly 250 billion barrels of oil.[15] Yet, this magnitude doesn't happen without purposeful effort—or in this case, investments in energy efficiency improvements.

Based on the DEEPER Modeling System, the ACEEE assessment found that an investment of $5.3 trillion would be needed to drive that level of energy efficiency improvements. Looking over the period 2012 through 2050 implies an average annual investment of $142 billion (in 2010 dollars). From an investment standpoint, therefore, we are currently driving energy efficiency investments at about 60 percent of what we might think of as economically optimal.

15. Taking the cumulative savings of energy in quads, over the period 2013 through 2050 the efficiency gains total 1,447 quads of energy savings. Each barrel of oil is equivalent to 5.8 billion Btus. Dividing the former by the latter suggests 249.48 billion barrels of efficiency equivalent, or rounded to 250 billion barrels.

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Appendix: Some Methodological Considerations

How does one assess the scale of on-going energy efficiency investments in a given year for which there is no meaningfully complete set of data? One of the first and perhaps classic approaches to generating an answer was shown by physicist Enrico Fermi. His curiosity prompted the use of a thought experiment that allowed him to estimate the strength of the atomic bomb that was detonated in 1945 at the Trinity test site. Using known data, he generated an estimate based on the distance traveled by pieces of paper dropped from his hand during the blast. Fermi's resulting thought experiment and calculations indicated the blast was equivalent of 10 kilotons of TNT. As later documented, this was remarkably close to the now-accepted value of around 20 kilotons.

In a very similar way this analysis provides a working estimate of the scale of annual energy efficiency investments that arise from normal progress as households and businesses make routine improvements in their homes, offices, factories, automobile purchases—even as there is an admitted shortfall of meaningful data. In much the same spirit, we take what is known and then implement what might be called the Fermi problem (Von Baeyer 1993). A Fermi calculation, is a thought experiment that involves the interaction of several estimated factors (e.g., sales of different models of cars, each with different levels of fuel economy), will probably be more accurate than might be first supposed (assuming there is no consistent bias in the known data or the estimated factors).[16] This is because there will likely be some factors that are estimated too high and other factors that are estimated too low. Such errors will partially, if not more completely, cancel each other out. The analysis here builds on this idea—that is, we take known factors or data and integrate them with reasonable, if incomplete, information to generate a series of estimates about the annual contribution of energy efficiency investments.

Before moving into the further discussion, however, there are several housekeeping chores which are necessary to resolve to provide an appropriate context for the analysis described in the main report. More specifically, there are five critical issues and a cautionary note that provide a structure for this analysis. The first issue is to understand the conceptual framework in which energy efficiency investments are characterized and estimated. The second is to ensure an appropriate understanding the difference between efficiency gains and the overall energy intensity of the economy. As we will learn, the reduction in energy intensity is not necessarily the same as improvements in energy efficiency.

16. In addition to Von Baeyer (1993), a further background on the value of thought experiments in scientific inquiry can be found in a variety of historical assessments. See, for example, Mach (1897, 1973) and Damper (2001). While Mach and Damper, among many others, suggest that thought experiments are a necessary part of the process of theory formation and scientific discovery. Damper also notes if the theoretical underpinnings are uncertain, thought experiments can be misleading or even harmful. In this case the evidence suggests a very strong theoretical perspective for the large-scale contribution of energy efficiency. But what makes this thought experiment necessary is the lack of a systematic and tracking of energy efficiency improvements that necessitates such an approach to help policy makers better understand the scale and magnitude of might be seen as an otherwise routine contribution to the economic well-being of the economy.

The third issue, building on the previous notion, is the insight that even when the energy intensity of the economy may increase in some irregular years there likely continues to be meaningful gains in efficiency improvements. The fourth is the very real possibility that in some cases, efficiency improvements may actually have negative costs. The fifth examines the larger efficiency gains estimated from a subset of investments. A final discussion provides a cautionary note on the results presented here.

A.1. The Conceptual Framework

The analytical effort begins with the appropriate accounting of the energy efficiency upgrades. A first step in this regard is to define what is meant by investment from a functional perspective. This involves an accounting identity which says that the Full Technology Cost (FTC) of any upgrade or investment equals the Base Cost at Average Performance (BCAP) plus an Energy Efficiency Premium. This might be more easily explained by using the purchase of a new car.

As we shall see later this in this discussion, the average new car sold in 2010 had a fuel economy of 23.7 miles per gallon and sold for $29,793 (NADA 2011). On the other hand, a light duty vehicle with a fuel economy of 32.3 mpg (also discussed below) might have sold for an average of $31,073. In other words, the base cost of a car with average performance in 2010 was $29,793 while the greater 32.3 mpg fuel economy might require an energy efficiency premium of $1,075. In effect, while we have to buy the entire vehicle, the cost of the added fuel economy would be $1,075 in this comparison.[17] A similar logic follows for the purchase of other technologies, whether a central air conditioner or a personal computer.

We might also note that different investments—say, the purchase of a new car compared to the purchase of a new central air conditioner, or an upgrade in one aspect of a specific industrial operation—are likely to have different marginal costs associated with the improvement. For instance, a routine two or three percent improvement might have a simple payback of two years or less while a more significant 15-20 percent upgrade might show a payback of four or five years. For the most part, this analysis focuses on the smaller routine improvement that we might normally expect to be made in the business-as-usual case. Hence, they are likely to have a much smaller marginal cost or energy efficiency premium if only because the efficiency gains are likely to be much smaller compared to a policy-driven scenario looking to the future which might drive a greater annual rate of improvement.

17. Readers might note the apparent false precision of such a precise number as an incremental cost of $1,075 per vehicle. Indeed, there are so many different variables that impact the actual sale price of any car or light truck that, with the data now routinely collected on such costs, it is impossible to say whether the more fuel-efficient car might have an incremental cost of $1,600 or just $400; or even the possibility that some efficiency gains may have negative costs as suggested in subsection A.4 of this Appendix. Yet the incremental cost per vehicle provided here (as a function of fuel economy improvements) draws on the author's judgment and calculations as they are shaped by the Energy Information Administration data on light duty vehicle cost and performance (EIA 2012b).

A.2. Energy Efficiency vs. Reduced Energy Intensity

The data will show that for any given year there is some amount of energy consumed per dollar of economic activity. Assuming that we are talking about cost-effective changes in the way we use energy, reducing the level of energy necessary to support each dollar of economic activity—in effect, reducing the overall energy intensity of an economy—is generally a good thing. Yet, there are a number of different ways to achieve a lower level of energy intensity. Improving end-use energy efficiency may be the most productive investment strategy, but it is only one of several influences that might drop our current levels of energy intensity.

One big driver of past changes in energy intensity has been the move away from more energy-intensive manufacturing as a source of jobs and income toward a less-intensive service economy. Moreover, we can also reduce energy intensity by changing the way we supply energy. For example, if industrial users pull their electricity directly from the grid, that are relying on a system that is only 32 percent energy-efficient. On the other hand, if they invest in an onsite combined heat and power facility—in effect, obtaining both process steam and electricity from a single technology, overall system efficiency is likely to be improved. This supply-side efficiency, in turn, helps to lower overall energy intensity. Finally, as we import various goods and services, we can further reduce our energy intensity as we rely on other nations to burn their energy rather than using up our own resources in the production of the products we import. For purposes of this assessment, we are looking for estimates of costs that will improve end-use energy efficiency in our homes, schools, offices and industrial facilities.

A.3. Efficiency Gains despite a Lagging Improvement

There is an irony reflected in our 2010 assessment. Notwithstanding the large efficiency investments described later in this section, the year 2010 proved to be an anomaly compared to recent trends as the average energy intensity. On average, the economy increased its energy intensity by about 0.3 percent in that year. This compares to the long-term trend of a 1.4 percent decrease over the last 60 years. Despite this single year loss of overall improvement, the sales of energy-efficient technologies continued in significant ways, even as their combined impact on the economy was offset in that single year by the purchase and use underperforming technologies. Table A-1 below is an illustration that highlights this circumstance. Here we can again use automobile sales to help us imagine and understand how normal efficiency improvements might occur even as energy intensity might increase. Even as the average fuel economy started increasing prior to 2010, and with new fuel economy standards in place, gains in overall fuel economy will continue to accelerate.[18] The example

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18. In August 2012 the Department of Transportation and the Environmental Protection Agency today finalized federal car and light truck fuel economy and greenhouse gas emissions standards for model years 2017 to 2025. The standards, together with those previously adopted for model years 2012 to 2016, mean an 80 percent increase in fuel economy for the average model year 2025 vehicle from the 2011 CAFE (Corporate Average Fuel Economy) requirement of 27.6 miles per gallon. For more background on this point, see the discussion by ACEEE's Transportation Program Director Therese Langer, "*New Vehicle Standards to Achieve Major Fuel Savings and Emissions Reductions*."

below, however, highlights the anomalous activity in 2010. Here we might have an existing vehicle stock with an average fuel economy of 23.5 mpg.

Table A-1: Illustration New Care Sales Compared to Existing Vehicle Stock

Car Model	MPG
Current Vehicle Stock	23.5
New Car Sales	
Cadillac Escalade	14.0
Toyota Land Cruiser	15.0
Buick Regal	23.5
Suburu Crosstrek	27.0
Daimler Smart Car	36.0
New Car Average	23.1

Source: Author data from WardsAuto (2012)

Ignoring issues of vehicle scrappage and replacement, let's assume that we previously sold one car with an average 23.5 mpg fuel economy and that we sold another two cars with have a "better-than-average" fuel economy of 27 and 36 mpg, respectively. But then we might also have sold two cars with a much lower fuel economy of 14 and 15 mpg each. All of this means, as shown in the last row of Table A-1, that the average sales in this example will weaken the overall fuel economy of the vehicle stock. So while the new car average for that year might have been worse than current fuel economy, the good news is that we still invested in some vehicles that were more efficient—that is to say, two of the vehicles listed in this example had a greater fuel economy than the current vehicle stock of 23.5 mpg. This helped minimize the cost of both energy and oil imports. Moreover, the sales of those more efficient vehicles become an important part of a future market on which to build a potentially larger energy savings. In this case, then, we are identifying and adding up the total investment in the more energy-efficient technologies to highlight their contribution to the larger economic well-being of our nation.

A.4. Efficiency Gains that May Not Cost More

Generally the assumption is that as the percent of savings increases compared to some baseline, the energy efficiency premium will also increase. In the real world, however, this may not always hold—as underscored by the cost and performance data in Table A-2 below (with information made available from a leading vehicle manufacturer). In this case we may have a consumer who is currently thinking about getting a 5-passenger sport sedan with an estimated 29 mpg fuel economy for low-end cost of $27,755. Yet, he or she could also choose to purchase a family sedan that gets an expected 36 mpg at a much lower cost of $21,328. In this case, a difference choice implies a less expensive car that also savings on gasoline purchases.

On the other hand, we might also imagine that the consumer will decide to upgrade their purchase with other amenities (a different interior, a better sound system, etc.). So rather than spending just $21,328, he or she may spend perhaps closer to $30,000 which is more than the original vehicle of interest. In this case the efficiency premium would be negative even as the total cost of the vehicle actually increases compared to what might have been intended.[19]

Table A-2: Typical 5-Passenger Vehicle Costs by Fuel Economy

Car Model	MPG	Vehicle Price 2012 $	
		Low	High
Sport Sedan	29	27,755	36,640
Sport Sedan	31	26,788	36,488
Family Sedan	36	21,328	32,887
Hybrid	44	23,807	26,463

Source: Author derived data from a leading vehicle manufacturer

One can imagine other negative costs for energy efficiency improvements, ranging from breakthroughs in the cost of production or volume savings that reduce the next round of technology purchases. Table A-3 that follows next provides another look at this possibility by examining a total of 39 commercial building upgrades as represented in the Energy Information Administration's technology database used to generate results for its 2012 *Annual Energy Outlook* (EIA 2012c).

Table A-3: Comparing Cost Changes for New Appliances

Change in Costs	Number	Average Change
Reduced	5	-12%
Unchanged	7	0
Increased	27	24%
Total Count	39	15%

Source: Author calculations from EIA (2012c)

In this case 39 different combinations of technology upgrades—including the purchase of more efficient air conditioner, vending machines, hot water heaters and refrigeration systems—revealed a surprising variety of cost reductions among the more efficient technologies. There were a total of five combinations with an average 12 percent reduction in the cost of the new technologies compared to

19. This circumstance reflects one form of the rebound effect as the consumer may think about using some of the fuel savings to allow additional upgrades on the car.

the current or installed base of technologies, a total of seven that improved energy efficiency but with zero incremental cost, and a total of 27 purchases that might increase overall cost by an average 24 percent compared to the existing base of technologies. On average the cost of more-efficient new technologies was about 15 percent above the current base.

Table A-4: Average Energy Efficiency Payback Period (Years) from IAC 2012 Database

Technology	Energy Efficiency Metric	2005 Installed	2010 Typical	2010 ENERGY STAR	2010 High
Res Gas-Fired Water Heaters	Energy Factor	0.60	0.62	0.67	0.85
Res Gas-Fired Furnaces	AFUE (%)	78	80	90	98
Res Room Air Conditioners	EER	8.7	9.8	10.8	11.5
Res Central Air Conditioners	SEER	10.2	13.7	14.5	24.0
Res Air Source Heat Pumps	HSPF (Heating)	6.8	8.0	8.2	10.7
Res Ground Source Heat Pumps	COP (Heating)	3.0	3.1	3.5	4.3
Res Ground Source Heat Pumps	EER (Cooling)	12.0	13.4	16.1	23.0
Res Refrigerator / Freezer	Energy Consumption (kWh/yr)	840	475	408	285
Res Natural Gas Cooktops	Cooking Efficiency (%)	38.0	39.9	n/a	42.0
Res Dishwashers	Efficiency (cycle/kWh)	0.30	0.61	0.66	1.13
Comm Gas-Fired Furnaces	Combustion Efficiency (%)	76	80	80	82
Comm Gas-Fired Boilers	Efficiency (%)	77	80	90	98
Comm Reciprocating Chillers	(kW/ton)	1.15	1.15	0.90	0.80
Comm Rooftop Air Conditioners	EER	10.1	11.2	12.0	13.9

Source: Navigant (2011)

As perhaps one other useful exploration, Table A-4, above, suggests an interesting pattern which reveals, that however small, almost all purchases of new technologies are likely to improve the efficiency of the existing stock of technologies already in place. As one example, the currently installed residential gas-fired water heaters have a typical efficiency of 0.60. But the typical purchase made in 2010—regardless of the availability of programs or policies which might drive greater levels of energy efficiency—is likely to have an efficiency of 0.62. This is admittedly a small difference, but it clearly indicates an ongoing improvement. On the other hand, greater recognitions of the EPA's ENERGY STAR brand might encourage many consumers to buy a water heater with an energy factor of 0.67 while some utility programs may reward consumers who buy water heaters with an efficiency rating of 0.85. A similar pattern is shown for other purchases in Table A-4 as well.

A.5. The Broader Energy Perspective

The usual representation of annual estimates of energy use is to outline consumption by major end-use sector. This generally entails mapping the different energy resources, whether natural gas, oil, or electricity, by the residential, commercial, industrial and transportation sectors. Because the consumption of electricity also carries significant heat losses in the generation, transmission and distribution of electricity, the annual summary also includes information on both the delivered energy and the total primary energy use within an economy. In this assessment, however, we need to generate an estimate of how much the core analysis covers the economy-wide estimate. Table A-5 provides us with a methodology to make that determination.

Table A-5: Delivered Energy Compared to Total Energy Use (in Quads)

Energy Category	2010
Delivered Energy End Uses Covered Here	
Residential Buildings	11.7
Commercial Buildings	8.7
Manufacturing Activities	11.3
Light Duty Vehicles	16.6
Subtotal Delivered Energy Covered Here	**48.3**
Other Delivered Energy End Uses	
Agriculture, Construction, Mining Activities	8.3
Passenger and Freight Transportation	11.0
Subtotal Other Delivered Energy End Uses	**19.3**
Miscellaneous Energy Uses	
Asphalt and Road Oil	0.8
Manufacturing Feedstocks	3.0
Subtotal Miscellaneous Energy Uses	**3.8**
Total Delivered Energy Uses	**71.3**
Electricity Related Losses	**26.8**
Total Primary Energy	**98.2**

Source: Author calculations from EIA (2012a)

Briefly, the first major category in Table A-5 summarizes the total energy that was delivered for use in residential and commercial buildings as well as for manufacturing activities. It also includes energy for the transportation needs provided by light duty vehicles. These data cover the five elements within the core analysis highlighted in Table 2 and sum to 48.3 quads for 2010. Other delivered energy end uses not captured by the core analysis include agriculture, construction, and mining activities as well as passenger and freight transportation. That totals to 19.3 quads of delivered energy. The immediate implication is that the core activities cover an estimated 71.5 percent of total energy delivered to end users.[20] At the time petroleum and natural gas resources that are used as feedstocks

20. The calculation is 48.3 divided by the sum of 48.3 plus 19.3 which is the equivalent of 71.5 percent (in rounded terms).

in various manufacturing activities are omitted from delivered energy categories since they are used as commodities rather than for heat and power. Asphalt and road oil are also backed up of the delivered energy categories for similar reasons. Although they are not included in this assessment, there are also supply-side efficiency improvements. The latter include the capturing of waste heat and converting it into useful energy, and the deployment of combined heat and power (CHP) systems that attain a combined system efficiency of 70 percent or more (which compares to an existing energy efficiency of our nation's electricity grid that is only 32 percent energy-efficient). Adding up the delivered energy uses together with the miscellaneous or commodity use of energy and the electricity losses with the economy provides the 2010 total primary energy consumption of 98.2 quads.

A.6. The Critical Caveat

For understandable reasons, the various government agencies and key players within the private sector have not done an especially good job of characterizing and tracking the improvements of our nation's energy performance. The data used to drive any meaningful estimates of performance and costs are neither centrally organized and stored, nor are they tracked using common metrics which allow an easy assessment. Moreover, baseline assumptions can greatly affect the overall result. For instance, if we assume that anything that improves average performance is a meaningful efficiency benefit—for example, assuming that the purchase of any car that has a fuel economy greater than the average mix of vehicle now on the road, that will drive one estimate of cost and improvement. On the other hand, if we assume meaningful efficiency gains are those made possible by the purchase of technologies that are generally in the top 25 percent of performers (what we might generally call an ENERGY STAR equivalent), that will produce a much different result.

Given the range of uncertainties, the accounting difficulties, and the development of the baseline and the energy efficiency counterfactual, the assessment reported might best be described as developing a working estimate that produces a plausible result rather than an analysis that delivers a precise outcome. Consistent with the philosophy of Stanford University's Energy Modeling Forum (Huntington et al. 1982), we are modeling for insights rather than exact numbers—or in this case, evaluating reasonable assumptions about between efficiency improvements as they might deliver prospective benefits to the U.S. economy. Even as every effort is made to document assumptions and provide a meaningful set of calculations, the final result—in this case, the $90 billion annual investment in energy efficiency upgrades as the report previously indicates—is a reasonable approximation that allows us to compare the normal energy efficiency gains to the more costly outlays for traditional energy supply investments.