Extreme Energy Efficiency in the U.S.: Industrial, Economic and Environmental Impacts

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ABSTRACT

In this analysis, we simply double total U.S. energy efficiency by 2030 and analyze its industrial, economic and environmental impacts. In this 'Extreme Energy Efficiency' (EEE) case, estimated employment increase nearly 2 percent in the three energy end-use sectors while output declines about ½ percent and CO_2 emissions decline by nearly 2 Gigatonnes (GT)—about 30 percent below today's emissions. Key input data include the type of technologies and their energy savings and cost characteristics as well as how aggressively they penetrate the industrial, buildings or transportation sectors. We constrain the technology penetration to be consistent with the overall goal of doubled efficiency—i.e. instead of using 130 Quadrillion Btus (Q) of primary energy in 2030 as in the Energy Information Administration's 'AEO 2007' Reference Case. (DOEb 2007), our EEE scenario has these sectors using only 65 Q of energy—36.6 Q less than today. For each technology, the "efficiency premium" (additional capital costs) and lower fuel costs are fed into a customized input-output (I-O) model to calculate the cumulative effects on the economy for every five years from 2005 to 2030. Our I-O model already includes considerable technology detail. We have supplemented this with technology data from the references. In particular, in the industry sector modeling, we drew heavily on a new set of 'energy bandwidth' studies by DOE's Industrial Technologies Program. Output includes employment, wage income, and impacts and changes in industry output based on historical relationships between these factors and energy technology penetration. We calculate emissions reductions based on the final mix of primary energy savings by fuel type.

Introduction and Overview

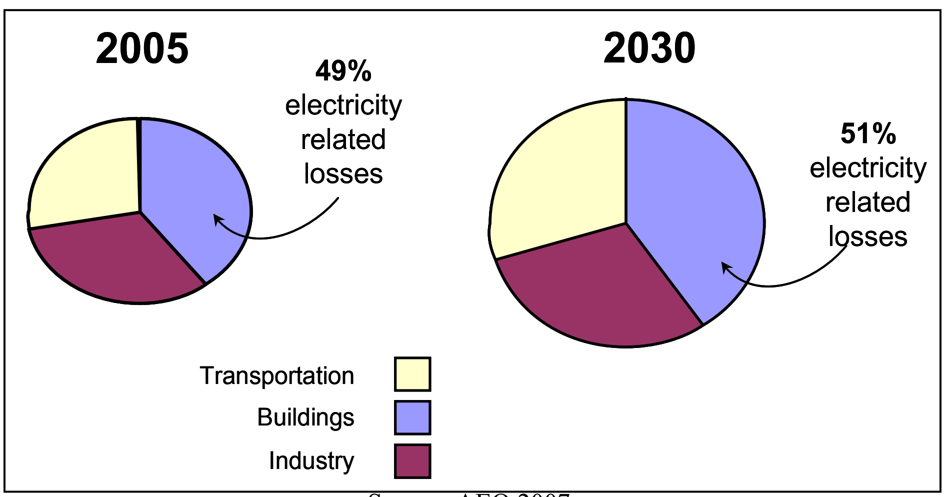
Opportunities to reduce energy use and emissions abound in the US economy. A major opportunity is in electricity-- the majority of which is produced by coal plants that use less than 1/3 of the coal's fuel value. As American industry and buildings steadily increase the electricity fraction of their energy use, so does the opportunity for efficiency gains though electric supply efficiency. Another key opportunity is in vehicles efficiency. the average American drives around in a car that uses less than 20 percent of the energy value of the fuel in the tank. (Rosenfeld et al 2000). But what would happen to our industrial infrastructure, to our economy and to emissions if we doubled US efficiency by switching to Combined Heat and Power (CHP), efficient hybrid cars, and other energy efficient technologies? We first asked this question in 2004 (Kaarsberg et al 2004) and developed a list of a dozen cost-effective, emissions-reducing energy savings technologies to cut US energy use in half by 2015. This analysis builds on our 2004 work with more comprehensive analysis of costs and of detailed impacts—including estimated employment impacts—in 188 different sectors.

Since 2004, Industry has seen more record natural gas prices, drivers have faced unprecedented gas prices and electricity customers in some markets have seen huge increases. At the same time, with more and more dire predictions for climate change, there are more and more calls for increasingly dramatic greenhouse gas (GHG) emissions reductions. For example, in May 2007, a former Energy Secretary and current presidential candidate called for a 90 percent reduction in GHG emissions by 2050 (Richardson 2007). The U.S. Climate Action Partnership which now comprises 20 major companies and six environmental organizations, called for emissions US emissions targets between 70–90 percent of today's levels within fifteen years (USCAP 2007). A group of Architects' organizations called for all new buildings to be zero net energy users by 2030 and their goals have now been endorsed by more than 400 municipal leaders. (A2030, 2007). In light of these proposals, large efficiency increases—such as doubling US efficiency by 2030—that previously seemed a bit extreme, could be considered for policy planning. Since energy use accounts most US GHG emissions—energy efficiency is a key GHG reduction strategy. It turns out that our 2030 efficiency doubling goal is consistent with an 'energy efficiency only' approach to achieving the GHG reduction targets called for by USCAP and others.

Overview of Current and 2030 Reference Scenario Energy Use

In 2005, US Industry, Buildings and Transportation sectors used approximately 102 Q of primary energy. In this paper we model reducing this energy use by 37 Q by 2030—half of what the reference forecast projects.

Figure 1. Current and EIA Reference Forecast of Primary Energy Use by Sector



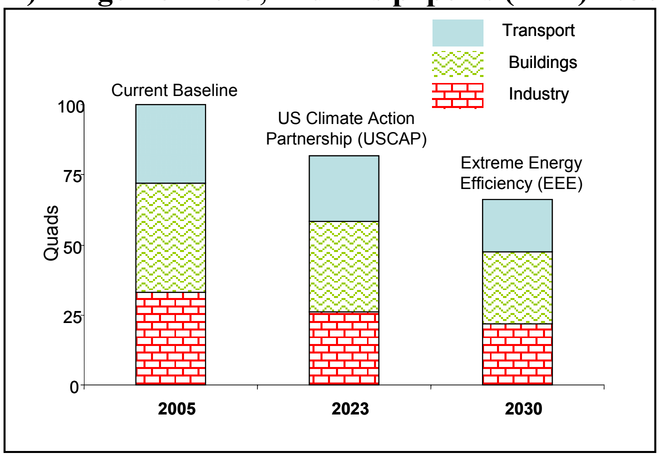
Source: AEO 2007.

Each sector's efficiency doubling target is based on the 2005 sector division of primary energy use not the AEO 2007 forecast for 2030 (see Figure 1). In EIA's reference forecast, the fraction of energy use due to electricity use increases due to both increased electricity use and the relative inefficiency of electricity generation in the base case.

Overview of 2030 Extreme Energy Efficiency (EEE) Scenario Energy Use

The overall goal is to reduce US energy use below 66.5 Quads by 2030. For each sector, we assume the energy use is divided among the sectors at today's ratios rather than by the ratios forecast in the AEO 2007 reference case which has a significant increase in building's energy use share due in part to its increasing fraction of electricity use. For example, in the reference case, the electricity use fraction of building energy use (delivered) jumps from 47 to 54 percent by 2030. Our assumption in the EEE scenario that buildings' share of energy use does not increase is justified by our aggressive penetration of CHP which lowers electricity's contribution to primary energy use in buildings and industry and also by the aggressive building energy savings which includes up to 20 percent of site energy use by onsite photovoltaics (modeled as electricity savings). Figure 2 shows 2005 data and EEE 2030 Sector Energy Use Targets. For comparison, it also shows an interim 2023 target derived by assuming that each sector contributes proportionately to USCAP median goal of 20 percent reduction in GHG emissions in 15 years solely through energy efficiency.

Figure 2. Sector Primary Energy Use (Q) Baseline, U.S. Climate Action Partnership (USCAP) Target for 2023, and this paper's (EEE) 2030 target



Sources: AEO 2007, USCAP 2007

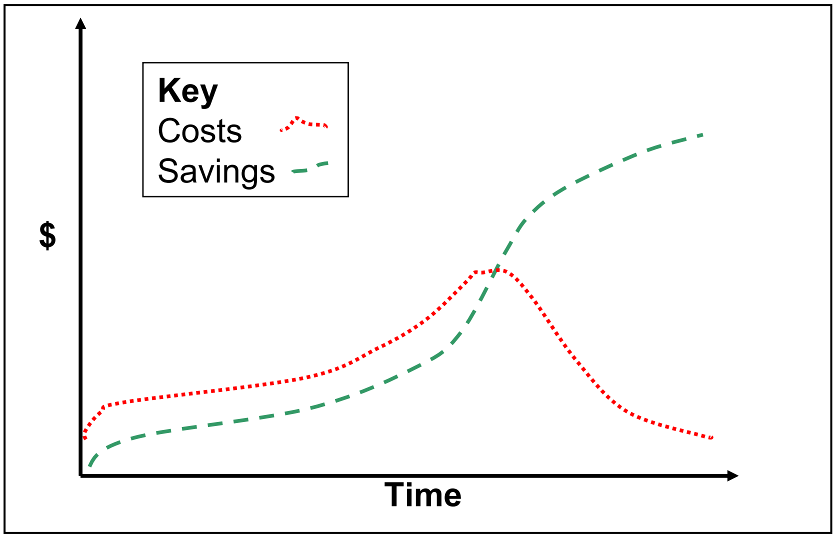
Model Description and Approach

Previous efforts to determine the potential for energy efficiency across all U.S. energy sectors (5-Lab, 1997) have begun with policies and then determined how much energy savings could be achieved. In this paper, we take the opposite approach. We start with the desired energy savings and then determine what it would take to achieve it and what the impacts would be. Such an approach may be what is needed to analyze climate policy proposals to achieve a specific amount of reductions.

Given this, within each sector, we searched for technologies that together could cut energy use more than 50 percent by 2030. To model the impact of accelerated penetration of these EEE technologies, we first estimate penetration curves from 2005 to 2030. All of these curves are some version of an 'S-curve.' More capital intensive technologies tend to have a more gradual slope. Relatively mature technologies reach the plateau of the S during the study period. Where capacity or market share goals exist (e.g. DOE's CHP Challenge Goal (DOEc 1997), and Architecture 2030 Goals (A2030, 2007) they are used to constrain the technology penetration curve. In order to estimate the capital cost premiums and lower (or switched) fuel costs we use data from EE programs supplemented with technology detail from several new reports (DOEd, DOEf, DOEg, DOEh, 2006), (DOEe 2007) (LBNL 2005).

Figure 3 shows a schematic of the typical financial data input for each technology. Generally, the capital cost is equal to or higher than the savings and initially increases with penetration. But economies of scale and learning by doing start to have a countervailing impact and slow the rate of increase: As initial capital costs are paid off, the curve flattens and drops and non-O&M savings from avoided pollution increase. Over time, therefore, net costs (dotted) peak and decline while savings (dashed) continue to increase.

Figure 3. Typical EEE Technology Cost (dotted) and Energy Savings (dashed)



Source: Clay *et al*, 2005

Cost and energy savings data for each technology—generally similar to the generic technology illustrated in Figure 3, are the input to our customized input-output (I-O) model "ImSET" (Impacts of Sectoral Energy Technologies). ImSET is based on the benchmark national I-O table published for 1997, (Lawson, *et al.*, 2002). It was originally developed by one of the authors (Roop, *et al.*, 2005) to estimate the employment and income effects of energy-saving technologies for DOE's Building Technologies Program. We use ImSET to introduce the technical characteristics of the penetrating technology into the input-output structure of the economy by modifying the Use Matrix annually from 2005 to 2030. As each technology penetrates into markets, it changes to the inter-industry structure of the economy which is the model solves for industry output. These outputs are then multiplied by employment and wage income coefficients for the 188 sectors. The output of the model includes cumulative and annual employment, wage income, and changes in industry output that result from the technologies' expanded use from 2005 to 2030.

Electricity Sector

Because of the extreme, and in the base case, growing significance of electricity related losses in US Energy use, the first technology to be considered is combined heat and power (CHP). Ironically, the biggest single source of EEE Scenario Savings is in the sector not usually modeled in energy efficiency studies—the electricity sector. This sector's history of stagnation in energy efficiency (Gorte *et al* 1999)—due mainly to institutional not technical barriers—makes it one of the best opportunities for efficiency improvements. We model efficiency improvements in this sector through increased penetration of CHP in buildings, industry, and even in transport (with increased use of plug-in hybrids). Table 1 summarizes the CHP contribution to primary energy savings in each sector by 2030.

Table 1. CHP Savings by Sector Compared with AEO 2030 Forecast.

Sector	2030 CHP Savings (Q)
Industry	8.0
Buildings	5.7
Transport	0.05
Total	**13.8**

Sources: Kaarsberg & Roop, 1999; Kaarsberg et al 1998, Kaarsberg et al 2000, updated.

As shown in Figure 4 and as detailed in the next section, when this CHP replaces Separate Heat and Power (SHP), 'Electricity Related Losses' which account for 27 percent of total energy use in the 2030 base case, are cut in half and the difference between delivered and primary electricity use drops accordingly. As shown in Table 1, across the three sectors, CHP saves 13.8 Q of Primary Energy (avoided electricity) compared with the reference case.

Site vs. Source Energy by Sector

Using the ratios from Figure 2, we can now calculate the site energy targets for each sector. Table 2 shows that the Buildings has the greatest primary/site difference with a 2030 site target 10.8 Q lower than its 2030 primary energy target (25.7Q shown in Fig. 2). The effect is less dramatic for Industry (Industry site energy is only 3.8Q lower than primary electricity use since grid electricity is only 13 percent of industry site energy use now) and transport (though the 0.8 Q difference is not completely negligible due to the some increased use of plug-in hybrids).

Table 2. Sector Site Energy Use Baseline and Targets

Sector/Delivered Energy(Q)	2005	2023 Target	2030 Target
Industry	24.8	22.3	18.0
Buildings	20.6	18.7	14.9
Transport	27.9	23.1	17.7

Note: 2023 target is based on the USCAP goals (USCAP, 2007).

Industry

Industry's share of the efficiency doubling goal is a decline from 33.9 Q in 2005 to 21.7 Q of primary energy use by 2030 rather than an increase to 38.9 Q as in the AEO 2007 reference case. We assumed that the percentage of each fuel type, (.e.g. oil natural gas, and site electric) remains constant between now and 2030. Industrial efficiency gains that comprise this 16.9 Q of primary energy savings fall into three categories: 1) waste heat recovery (including CHP discussed earlier), 2) 'best practices' and advanced technologies, and 3) new technologies. The shrinkage of certain energy intensive industries due to reduced demand from other sectors also contributed significantly to energy reductions in industry. Table 3 summarizes the contributions of each of these to the halving of industrial energy use.

To represent the contributions from each of these areas, we assumed capital and O&M costs for accelerated deployment of a subset of technologies for each type. For example, in 2) best practices, we only considered 4 industries. Even though the industries themselves are capital intensive, many of these 'best practices' efficiency improvements are design- and information technology related and therefore not capital intensive.

Table 3. Different Types of Primary Energy Savings to Industrial Total in 2030

Technology Approach	2030 Primary Quads Saved compared with AEO2007
1a) CHP [1]	8.0
1b) Waste Heat Recovery other than CHP [2]	2.5
2) Best Practices and Advanced Technologies [3]	3.3
3) New Technologies [4]	1.8
4) Reduced Demand [5]	1.3
Industry TOTAL	**16.9**

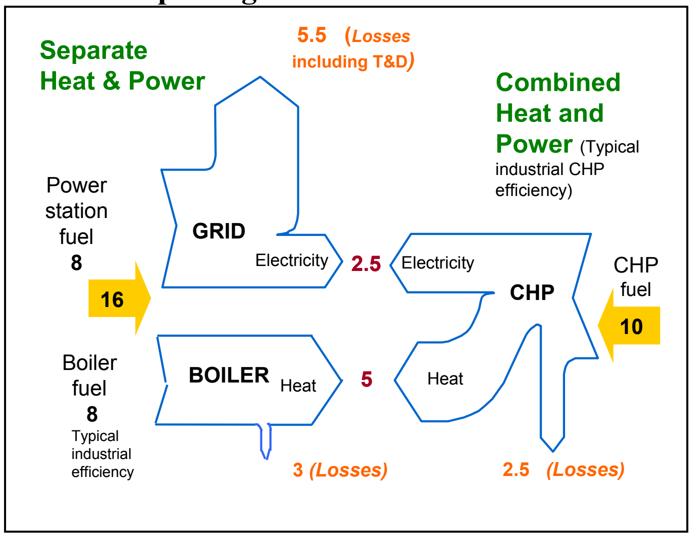
Sources: 1- Kaarsberg & Roop 1999 updated; 2-LBNL 2005, DOEh 2006; 3-Table 4 assuming practical is achieved by 2030; 4-Brown, 2005; 5- Architecture 2030 2007, DOEa MECS 2002

CHP and other waste heat recovery. Figure 4 provides a heuristic example of the technical potential of industrial CHP. If all the steam and electricity used by manufacturers in 2002 had been generated with CHP, it would have required only 10 Q of input fuel. Separate heat and power—which is what manufacturer's mostly used-- requires a total of 16 Q. This is because using boilers to generate all the steam needed in manufacturing ~5 Q requires ~8 Q of input fuel and the 2.5 Q of electricity delivered to manufacturers requires another 8 Q of input fuel. Had we used CHP to provide the steam and power needed by manufacturers in 2002, it would have saved nearly 6 Q of energy.

Our modeling of CHP in the industry sector is a bit more realistic. We replace boilers with CHP gradually over time as they reach retirement age and we also have CHP penetrating industry By 2030 we achieve 8 Q of energy savings in manufacturing and other industry sectors with thermal needs such as waste water treatment. Even higher savings could have been achieved by using the current and future state-of-the-art CHP technologies to satisfy industry heating and cooling needs and then selling the excess "low carbon" electricity.

The technologies for non-CHP waste energy recovery include waste heat recovery, technologies such as those used in CHP, as well as use of the energy value of non-thermal waste streams. A new study (DOEh 2006) indicates that gaseous waste streams from U.S. industry contain substantial fuel value. A prior study (LBNL 2005) also identified ~100 GW of potential in non-CHP waste heat recovery (aka recycled energy).

Figure 4. Schematic of CHP Replacing Manufacturer's Use of Grid Electricity and Boilers



Source: Kaarsberg & Roop 1999 updated with data from DOEa MECS 2002

Best practices and advanced technologies. In modeling the penetration of existing industrial technologies needed to reach the 2030 industry sector target we drew heavily on a series of 'energy bandwidth' studies carried out by DOE's Industrial Technologies Program for several energy intensive industries. Bandwidth analysis quantifies the differences between theoretical minimum energy, practical minimum energy, and current energy use, based on average values in today's manufacturing environment. Analysis begins with: 1) basic energy needs (such as melting of metals); (Theoretical Minimum Energy in Table 4), 2) energy use considered to be practical in current situation; (Practical Minimum Energy in Table 4), Current average energy use (Industry Average in Table 4). Table 4 illustrates potential energy savings (some are partial) for chemical (DOEd, 2006), mining (DOEe, 2007), petroleum refining (DOEf, 2006), and pulp & paper (DOEg. 2007) industries. We assume here that the 'practical' minimum can be achieved by 2030 through a combination of best-practices and technology advances.

Table 4. Energy Savings via Efficiency in Four Energy-Intensive Industries

Industry	Industry Average (Q)	Practical Minimum (Q)	Theoretical Minimum (Q)
Chemical	1.70	0.50	0.20
Mining	1.25	0.58	0.18
Petroleum Refining	2.10	1.31	0.68
Pulp and Paper	2.36	1.45	1.35

New technologies. Additional energy reduction can come from entirely new technologies enabled by advances in areas such as microchannel-, thermoelectric-, bio- and nano-technology. Examples include advanced separations and near-net shape casting. These are part of a general trend to move from chemical to mechanical means in fabrication, separation and energy storage & conversion. Unlike chemical approaches, which have definite thermodynamic barriers to increased efficiency, mechanical (e.g. nanotechnology) have no such intrinsic limits and thus offer huge potential for efficiency improvements (Ross, 1997). Just two examples of such technologies: replacing distillation with advanced separations (membranes or adsorption) and using new super-durable materials for industrial boilers, chemical reaction vessels, and furnaces could contribute 1.8 Q of savings by 2030. (Brown, 2005)

Demand reduction in energy intensive building materials industries. Roughly 30 percent of industry energy use is related to buildings (mostly materials manufacture). This type of industrial energy use will decrease as designers who have taken the Architecture 2030 Challenge to heart cease to specify high embodied energy materials such as vinyl and concrete. We model 1.3 Quads of reductions. We arrive at this estimate by assuming the 2.6 Q used by Plastics Materials and Products and by Cement (DOEa 2002) is cut by 50 percent by 2030 due to Architecture 2030-driven material specification changes. While uses of energy-intensive materials are drastically reduced, demand for wood, glass, lightweight metals, and ceramic will hike dramatically.

Buildings

In calculating energy savings costs and environmental impacts for buildings, we assumed that the percentage of each fuel type used, (.e.g. oil natural gas, and delivered electricity) remains constant between now and 2030. Table 5 summarizes the contribution of three different technology approaches to the buildings energy efficiency increase.

The first 'technology' we model for the buildings sector are the strategies for achieving the architect's 2030 °Challenge goals for fossil energy savings (A2030, 2007). The 2030 Challenge sets a an immediate goal of 50 percent reduction in fossil energy use for new and renovated buildings and then ratchets down the goal for new building to zero fossil energy use (carbon neutral) by 2030. The Challenge requires that nearly all reductions be achieved through efficiency with a maximum of 20 percent use of onsite renewable energy. What makes this 'technology' unique is that energy use reductions are achieved almost entirely through design—for example with passive solar systems, natural cooling, ventilation and daylighting strategies. Most of the technologies that do require additional capital cost, such as advanced glazing technologies and solid state lighting, are relatively inexpensive—the one exception would be onsite solar electricity with photovoltaics (PV). By 2030, 'Architecture 2030' technologies reduce energy consumption by 22 Q compared to the reference case.

Even though it is considered to be an industrial technology, CHP could be a major contributor to building energy savings. In the reference forecast, electricity use fraction of building energy use (delivered) jumps from 47 to 54 percent by 2030 while the fraction of primary energy use due to 'Electricity Related Losses' jumps from 49 to 51 percent--in the reference case more than half of building energy use is due to energy wasted in delivering electricity. Onsite CHP is clearly an opportunity to save energy in buildings. Several assessments of the potential for CHP in commercial and institutional buildings have shown the technical potential to exceed that for industry (Kaarsberg et al. 1998), (Onsite 2000). The market potential for this sector was estimated to be 35 GWe by 2020 (Resource Dynamics, 2002). Even residential CHP potential is significant (Kaarsberg et al., 2000). Part of the reason for this potential in buildings is due to approaches such as Integrated Energy Systems (IES) that combine on-site power technologies with thermally activated technologies to provide cooling, heating, humidity control, energy storage and/or other process functions using thermal energy normally wasted.

Table 5. Architecture 2030 and CHP Contribution to Building Energy Savings

Sector/Delivered Energy(Q)	2030 Primary Energy Savings Compared to Reference (Q)
Architecture 2030 Building Design	17.6
PV and other onsite renewable electricity	4.4
CHP	5.7
Total	**27.7**

Sources: Architecture 2030 (A2030, 2007), Resource Dynamics, 2002 updated.

Transport

Transport's share of the efficiency doubling goal is to reduce energy use from 28.1 Q today to 18 Q by 2030. In calculating energy savings costs and environmental impacts, we assumed a relatively large—but still small in absolute terms—increase in the fraction of electricity used. (Electricity accounts for 0.6 Q = 3.3 percent of transport energy in EEE case.) This is due to increased penetration of plug-in hybrids. —this still leaves oil responsible for fueling more than 90 percent of US transport.

Table 6 summarizes the energy savings from accelerated introduction of five extremely efficient vehicle technologies. Advanced drag reduction and nano-materials are less so, but overall, transport energy efficiency improvements have the highest capital cost. Fortunately, based on hybrid sales in the past few years, this sector appeared to have the lowest barrier to initial cost premium.

Table 6. Efficiency Contributions of Transport Technologies

Transport Technology	2030 Primary Energy Savings Compared to Reference (Q)
Advanced IC engines (light duty vehicles)	3.3
Advanced drag reduction	1.4
Advanced diesel engines (heavy duty vehicles)	1.8
Hybrid vehicles including plug-in (light duty)	9.6
Weight reducing nano materials (vehicles)	4.2
Total	**20.3**

Source: Clay et al 2005, updated.

Results and Conclusion

Overall, across all sectors, according to our model, the EEE technology scenario would

- Create jobs
- Substantially reduce energy usage, and
- Dramatically lower GHG emissions.

However it also would cause

- Slight decreases in economic output, and
- Potentially painful structural changes in the economy.

Table 7 summarizes the difference between the EEE Scenario and the AEO 2007 reference case for each sector—with buildings further divided into residential and commercial building. Energy savings and CO_2 emissions reductions are in physical units while, output and employment in percentage terms for easier comparison. Although the economic output numbers are all negative, except for the transport sector they are indistinguishable from no impact within the errors of our very rough estimate.

Table 7. Sector Environmental and Economic Results

	2030 Primary Energy Savings (Q)	2030 CO_2 Reductions (Giga Tons)	*2005 CO_2 emissions (Giga Tons)*	Output (%)	Jobs (%)
Industry	16.9	0.38	*1.68*	-0.25	0.66
Residential Buildings	12.8	0.35	*1.25*	-0.04	0.81
Commercial Buildings	15.0	0.46	*1.05*	-0.04	0.69
Transport	20.4	0.46	*1.96*	-4.18	4.84
Total/Avg	**65.1**	**1.66**	***5.94***	**-0.46**	**1.75**

Overall, this level of efficiency improvements for very low costs that provide new jobs, save energy and dramatically reduce CO_2 suggests that Extreme Energy Efficiency is an idea whose time has come. More rigorous analysis is needed, however, to buttress the results of this *Gedanken Experiment.*

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