Impacts of Increased Energy Efficiency in Buildings and Transport on Energy Intensive Materials Industries

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ABSTRACT

Calls for 80% greenhouse gas (GHG) emissions reductions by mid-century are becoming the norm worldwide, and these reductions are likely to include a large component of energy efficiency-based GHG reduction strategies. The 2030 "extreme energy efficiency" goal to halve US energy use by 2030 can be viewed as a way to achieve deep GHG reduction targets such as reducing GHG by 80% from 1990 levels in 2050 (Obama 2009) using energy efficiency strategies only. This very challenging goal might be made easier for the industry sector if indirect reductions such as those due to reduced demand for high embodied energy materials in buildings and transportation translated into large reductions in industrial energy use. For example, in the US, roughly 30% of all industrial energy use is related to buildings, mostly owing to materials manufacturing. In this paper we examine such indirect impacts for the industrial sector. From our analysis, we see that indirect industrial impacts of energy efficiency increases in buildings and transportation, while significant, are still only a fraction (~11%) of the impacts of direct energy efficiency requirements for industry under the extreme energy efficiency scenario. Similarly, preliminary analysis appears to show gains or losses in different materials industries lead to relatively minor gains or losses in other industries. We also found even the most energy intensive industries have the largest indirect effects on service industries.

Introduction and Overview

In the US DOE's Annual Energy Outlook (AEO) of 2009, total annual CO_2 emissions are projected to increase from 5.9 gigatonnes[2] in 2006 to 6.4 gigatonnes in 2030, an 8.6% increase[3]. This AEO "Reference" scenario accounts for positive effects from the Energy Independence and Security Act (EISA) of 2007, resulting from increased efficiency mandates in areas including vehicles, appliances, lighting and industrial electric motors. Options for US greenhouse gas (GHG) emissions reduction policy is a topic of intense policy development effort in the US and worldwide. For example, the US House of Representatives' Energy and Commerce Committee approved H.R. 2454, "The American Clean Energy and Security Act," on May 21, 2009. This legislation would reduce greenhouse gases (GHGs) by 42% in 2030, and by 83% in 2050. The Committee press release (HE&C 2009) referred to these as "science-based targets within the range agreed to by the U.S. Climate Action Partnership (USCAP 2009)". Regardless of how CO_2 and other GHGs are controlled, the impact will be substantial on energy intensive industries.

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[1] The views expressed herein are the authors' views and do not necessarily reflect the views of the U.S. Department of Energy or its contractors.
[2] A 'gigatonne' is 1000 million metric tons.
[3] This is about half the increase seen in the AEO2008 of 16% over 2005-2030.

While US manufacturing must be prepared for potential negative impacts, new business opportunities also will arise including climate-friendly technologies and products that improve efficiency and reduce energy intensity.

Introduction and Background

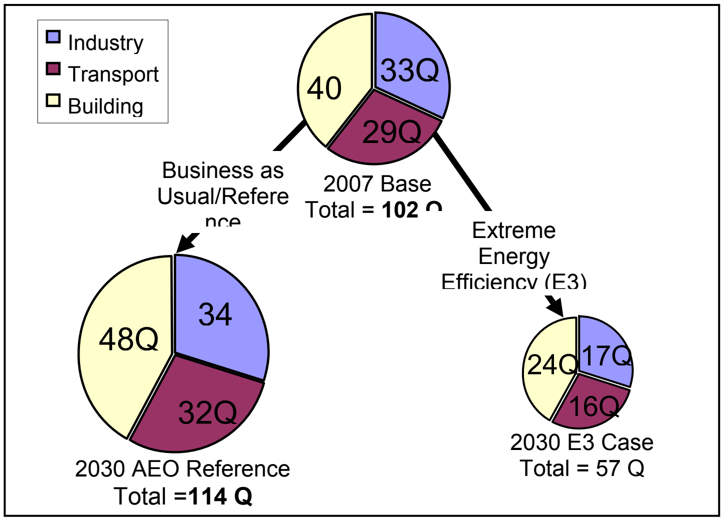
We studied what would happen to our industrial infrastructure and our basic materials industries to the US economy if individuals and organizations dramatically increased investments in (1) direct energy efficiency (e.g. with highly insulated passive solar buildings, efficient hybrid cars, and other energy efficient technologies), or (2) indirect energy efficiency (e.g. by switching to Combined Heat and Power (CHP) from purchased electricity or through reduced use of high embodied energy materials). Together these types of actions enable the "extreme energy efficiency" (E3) goal set in earlier work (Kaarsberg et al 2007) to halve US energy use in 2030. This goal is consistent with the Obama Administration's goal to reduce carbon emissions by 80% by 2050 compared with 1990 levels.

We first looked at an extreme energy efficiency (E3) scenario in 2003 (Kaarsberg et al 2004). We started by developing a list of more than a dozen cost-effective, emissions-reducing high impact energy savings technologies to cut US energy use in half within a decade. Our 2007 analysis built on the 2004 work with more comprehensive analyses and Input-Output (I-O) modeling of costs and of detailed impacts—including estimated employment impacts—in 188 different sectors. In this analysis, we separate out direct and indirect energy efficiency savings. This analysis focuses on industry subsector economic impacts.

Overview of Current and 2030 (Reference & E3) Cases

In 2007, the US consumed approximately 102 Quadrillion Btus(Q) of primary energy (on top in Figure 1). By 2030, the 2009 Energy Information Administration *Annual Energy Outlook* (AEO) Reference scenario (DOEb 2009) projects 114 Q of energy use (on the left in Figure 1). For the E3 case during the time period of 2009-2030, we assume that the US government implements energy and climate policies that result in halving US energy use to 57 Q by 2030 (on the right in Figure 1). That is, reducing US energy use by 45 Q from 2007. Figure 1 shows 2007 actual and the two 2030 scenarios and their relationships graphically.

Figure 1. 2007, EIA Reference, & E3 2030 Scenarios for US Primary Energy Use



Source: DOEb 2009, Kaarsberg et al 2007

<u>Buildings sector</u>: reference & E3 scenarios. In 2007, the US buildings sector used approximately 40 Q of primary energy. In 2030, the AEO 2009 Reference scenario (DOEb 2009) projects 48 Q of primary energy use (~19% increase). In the E3 case, new energy and climate policies result in halving US building sector energy use to 24 Q by 2030 or a reduction by 16 Q from 2007. Table 1 shows the technologies accelerated in the 2007 analysis to reach this goal. It summarizes the technical potential for energy savings from accelerated introduction of: (1) Architecture 2030 strategies (A2030 2009) that reduce energy use almost entirely through design—for example with passive solar systems, natural cooling, ventilation and daylighting strategies; (2) onsite renewable electricity such as photovoltaics (PV); and (3) combined heat and power (CHP) which is projected to greatly increase in buildings owing to increased availability of Integrated Energy Systems that combine on-site power technologies with thermally activated technologies to provide cooling, heating, humidity control, energy storage and other functions that use thermal energy otherwise wasted.

Table 1. Potential Efficiency Contributions of Building Technologies

Sector/Delivered Energy(Q)	**2030 Primary Energy Savings Compared to AEO 2009 Reference (Q)**
Architecture 2030 Building Design	14.1
CHP and Fuel Switching	5.9
PV and other onsite renewable electricity	3.8
Total	**23.8**

Source: Updated for 2009 based on: Kaarsberg et. al (2007).

<u>Transport sector</u>: reference & E3 scenarios. In 2007, the US transport sector used approximately 29 Q of primary energy. In 2030, the AEO 2009 reference (DOEb 2009) projects 32 Q of energy use (10% increase). In this paper we assume that the implementation of energy and climate policies results in halving US transport sector energy use to 16 Q by 2030 or by 13 Q from 2007. Table 2 shows the E3 technologies deployed to reach this goal. It summarizes the technical potential for energy savings from accelerated introduction of five extremely efficient vehicle technologies: Advanced internal combustion (IC) engines (light duty vehicles); advanced drag reduction; advanced diesel engines (heavy duty vehicles); hybrid vehicles including plug-ins (light duty) and weight reducing materials. While transport sector energy efficiency improvements require higher capital costs than other sectors, we note that weight reducing materials are the least expensive option in Table 2 partly due to indirect effects multiplying effect of weight reduction in vehicles -- if the vehicle is lighter, the engine is smaller, which makes it lighter, which allows more lightweighting in other systems, and so on.

Table 2. Potential Efficiency Contributions of Transport Technologies

Transport Technology	2030 Primary Energy Savings Compared to Reference (Q)
Advanced IC engines (light duty vehicles)	2.6
Advanced drag reduction	1.1
Advanced diesel engines (heavy duty vehicles)	1.4
Hybrid vehicles including plug-ins (light duty)	7.6
Weight reducing materials (vehicles)	2.5
Total	**15.3**

Source: Updated for 2009 based on: Kaarsberg et. al (2007).

<u>Industry sector</u>: reference & E3 scenarios. In 2007, the US industrial sector used approximately 33 Q of primary energy. In 2030, the AEO 2009 reference projects 34Q of energy use (5% increase). In this paper we assume that the Administration has implemented energy and climate policies that result in halving US industrial sector energy use to 17Q by 2030 or by ~15Q from 2007. Table 3 shows the E3 technologies accelerated to reach this goal in our 2007 analysis. It summarizes the technical potential for energy savings from accelerated introduction of: (1) waste heat recovery (including CHP); (2) 'best practices' and advanced technologies; and)3) new (nano- bio- info-) technologies. [Brown 2005] [A2030 2009], [DOEa MECS 2006]. The final "reduced demand" category accounts for the shrinkage of certain energy intensive industries due to reduced demand from other sectors. As with buildings, the reference forecast for industry appears to shows that much of the energy use increase by 2030 in the reference case is related to the electric industry.

Table 3. Potential Efficiency Contributions of Industrial Technologies

Technology Approach	2030 Primary Quads Saved compared with AEO2009
Waste Heat Recovery other than CHP	2.5
Best Practices and Advanced Technologies	3.3
New Technologies	1.8
CHP	8.0
Reduced Demand	2.0
Industry TOTAL	**17.6**

Source: Updated for 2009 based on: Kaarsberg et. al (2007).

Indirect Energy Savings

Earlier we suggested a definition of direct and indirect types of energy savings by providing examples. Here we provide a consistent definition that is necessary for the next portion of our analysis.

- A *direct* energy savings is when the new technology causes the technology user to use less energy.
- An *indirect* energy savings is when the new technology causes the technology supplier to use less energy.

This is our own energy-specific definition. As in our previous paper (Kaarsberg et al 2007), the attribution of energy savings to user or supplier varies. For example in the case of CHP, we attributed the savings to the building users and industry users. But in the case of reduced demand for energy intensive materials, the energy savings was attributed to the supplier industry. Although the providers' energy use is reduced with CHP the savings is attributed to the user because the user can 'do it yourself'. But with reduced demand for energy intensive materials, the user is reducing use of or switching materials and the energy savings is attributed to the supplier.

Sectors' Indirect Embodied Energy (EmE) Impacts

We have already noted that CHP savings fit the definition of an indirect energy savings because it describes avoided energy use in a different sector or subsector. In what follows, we illustrate another major category of indirect impacts—savings in reduced embodied energy of the materials used. Table 4 [A2030 2009] provides the EmE by weight and by volume for most of the materials discussed in this section. We note that they differ from each other by more than three orders of magnitude.

Table 4. Embodied Energy for Key Materials

Material	Embodied Energy	
	by weight (MJ/kg)	by volume (MJ/m^3)
Aggregate	0.1	150
Concrete (30 mpa)	1.3	3,180
Lumber	2.5	1,380
Aluminum (recycled)	8.1	21,870
Steel (recycled)	8.9	37,210
Glass	15.9	37,550
Steel	32.0	251,200
Aluminum	227.0	515,700

Source: A2030, 2009

In our previous work, we did not—with the exception of CHP and reduced demand in industry--examine indirect efficiency improvements. In this update we rely on a different I-O model to explicitly examine indirect impacts on subsectors output and employment. In what follows, we add for a handful of key materials in the other two end use sectors, the requirement to reduce embodied energy (EmE) of materials and components use. In each sector, the most commonly used materials were substituted with the most likely lower EmE materials.[4] We considered only small subsets of materials likely to be most affected by policies that encourage decreased use of high EmE materials.

Buildings EmE. Materials that comprise the typical commercial building are, (in descending order by weight): concrete, wood, drywall, steel, plastics, aluminum, and other. We therefore looked at changing the amount and energy intensity of cement, concrete and steel. (Wiggington, 2008) We also looked at using more wood, especially engineered wood made from recycled materials. Such **forest products** materials—being far less energy and petroleum dependent and also sequestering carbon—are expected to increase if energy, carbon reductions are to be reached. In our scenario, the share of **Engineered Wood** will increase in residential buildings (at the expense of standard lumber) and in commercial buildings (at the expense of **concrete** and **steel**). While overall use of **concrete** is not expected to change in residential construction, the specific applications are expected to change—for example thin layered custom applications will increase their share as bulk concrete use decreases. In commercial and institutional applications, the amount of concrete is likely to decrease substantially, but the overall consumption of concrete (i.e., cement plus aggregate and other materials) will decrease only moderately. Next generation concrete is expected to have an increasing percentage of redirected waste materials (e.g. fly ash, recycled concrete, etc.) resulting in indirect energy savings within the industry sector. These indirect savings will lower the EmE of concrete and extend applications. The cement industry is also expected to greatly alter its specifications by 2030 to replace nearly half of the cement clinker with less energy intensive materials The ready-mix concrete industry's mixtures also will be dramatically altered to lower the EmE of the product. All of these indirect savings are counted in the industry sector.

[4]We found in our previous research that ignoring the substitutable materials could lead to incorrect conclusions. For example, we had modeled Demand Reduction in Energy Intensive Building Materials Industries by assuming it will be driven by architects and designers who have taken the Architecture 2030 Challenge to heart and cease to specify high embodied energy materials such as vinyl, aluminum and concrete. After further study, we realized that in many remodels, that vinyl was replacing aluminum—a far higher EmE product.. The key is to identify materials with much lower EmE than those they are likely to ***replace***.

Table 11. Potential Direct and Indirect Efficiency Contributions of Building Technologies

Sector/Delivered Energy(Q)	2030 Primary Energy Savings Compared to AEO 2009 Reference (DOEb 2009) (Q)
Direct	
Architecture 2030 Building Design	14.1
PV and other onsite renewable electricity	3.8
Fuel Switching	1
Indirect	
CHP	4.9
Engineered Wood (+)	Counted in Industry
Concrete (-)	Counted in Industry
Steel (-)	Counted in Industry
Recycled Aggregate (+)	Counted in Industry
Total	**23.8**

Source: Analysis in this paper and Table 1.

Transport EmE. Materials used to manufacture the typical vehicle are, (in descending order by weight): steel, glass, plastics, aluminum, and composites. The direct impacts of weight-reducing materials, shown in Table 2, are well known. It has been estimated that with every 10% drop in weight; the fuel economy increases 6–8% (DOE 2008). The indirect impacts associated with materials choice are not nearly as well known. We do know that a major weight reducing material switch for components has been to replace steel with aluminum components. In fact, by 2008, aluminum content had reached an all-time high of 8.6% of average vehicle curb weight continuing a nearly 40 year trend (AA 2009. From an embodied energy standpoint, however, Table 4 shows that aluminum use has the opposite effect on energy use. Aluminum (Al) is far and away the most energy intensive vehicle material—either by volume or by weight. Thus in our scenario where embodied energy use is to be reduced, 2008 would represent the peak of Al use, with Al being replaced increasingly by lightweight, high performance structural materials such as advanced high-strength steels (AHSSs), thermoplastics, fiber reinforced composites (glass and carbon fiber), and magnesium castings which can cut vehicle components' mass in half (DOE 2008). Both energy intensity and use of glass and steel would decrease overall.

Table 12. Potential Direct and Indirect Efficiency Contributions of Transport Technologies

Transport Technology	2030 Primary Energy Savings Compared to AEO 2009 Reference (DOEb 2009) (Q)
Direct	
Advanced IC engines (light duty vehicles)	2.6
Advanced drag reduction	1.1
Advanced diesel engines (heavy duty vehicles)	1.4
Hybrid vehicles including plug-ins (light duty)	7.6
Weight reducing materials (vehicles) -direct -aluminum -AHSS -thermoplastics -fiber reinforced composites -magnesium castings	2.5
Indirect	
Weight reducing materials (vehicles) -indirect +aluminum -glass -steel	Counted in Industry
Total	**15.3**

Source: Analysis in this paper and Table 2.

Industry EmE. Rather than start by listing the most-used materials in industry (not as easy as for a building or a vehicle) and analyzing their embodied energy, for clarity we focus only on the indirect changes already identified that arise from other sectors' energy efficiency efforts.

Table 13. Potential Direct and Indirect Efficiency Contributions of Industrial Technologies

Technology Approach	2030 Primary Q Saved compared with [AEO2009] (DOEb 2009)
Direct	
Waste Heat Recovery other than CHP	2.5
Best Practices and Advanced Technologies	3.3
New Technologies	1.8
Indirect	
CHP	8.0
(Net) Reduced Demand in Materials industries -aluminum -cement **+engineered wood** -steel -**glass** +recycled aggregate	2.0
Industry TOTAL	**17.6**

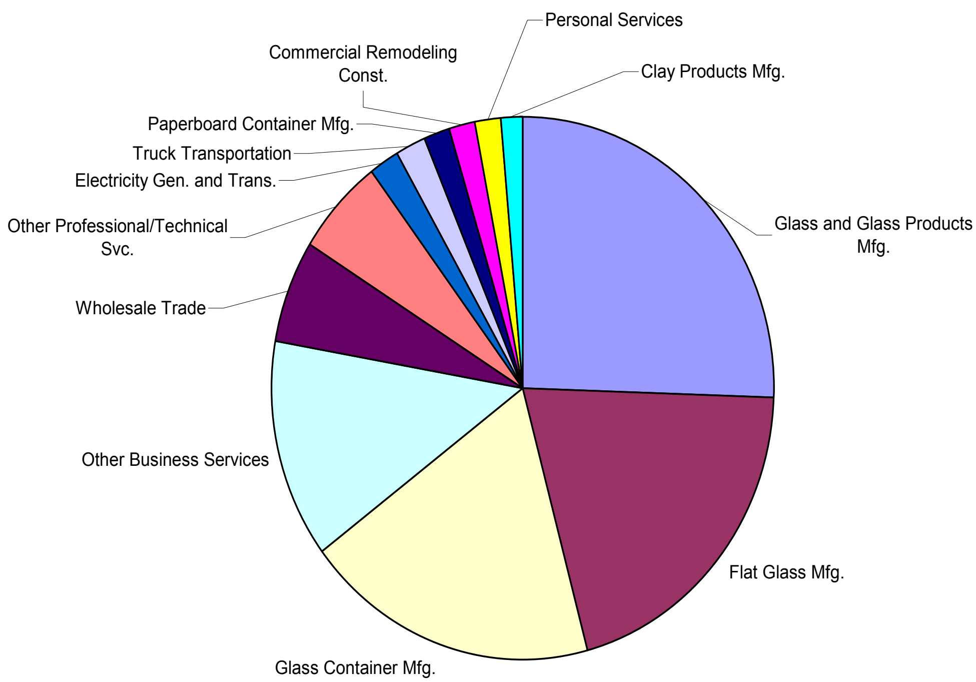
Source: Analysis in this paper and Table 3.

Indirect Impacts: Model Description and Approach

As in previous analyses, we use a customized I-O model to combine our calculations and estimate economic impacts. Economic I-O analysis is a well-established method to track flows through an economy. This time, however, rather than using the technology rich ImSET model (Roop 2005), we use the SEADs (Sectoral Energy/Employment Analysis and Data System) model, the output of which breaks out final commodity demand for 187 different sectors. Like ImSET, SEADs also was developed by one of the authors for the Department of Energy (Roop 2007). The model modifies the input output matrix to yield employment and earnings coefficients to calculate these demand impacts economy wide[5].

We illustrate the potential indirect economic impacts in key materials industries in Figures 2a and 2b. These figures for engineered wood and glass show the relative economic losses and gains in other sectors for a given financial impact in the sector noted.

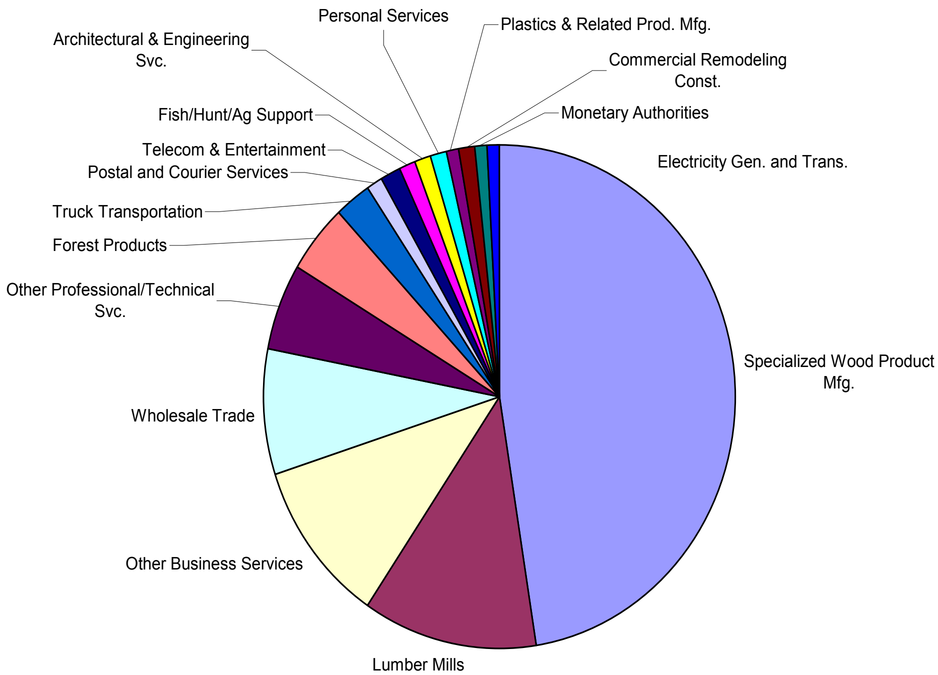
Figure 2a. Industry sectors impacted by a $1B loss in the Glass subsectors.



8,700 jobs lost $550M earnings lost

[5] This version of the SEADs model is not, however, updated to first order with our E3 scenario, so the impacts shown are for the current economy. We will be updating of the SEADs model in the near future but expect that many of the same subsectors will appear in the impacts.

Figure 2b. Industry sectors impacted by a $1B revenue increase in Engineered Wood



15,100 jobs added $645M earnings increase
Source: this analysis

Conclusion

From our analysis we see that energy efficiency trends in buildings and transportation, while significant, are still only a fraction (~11%) of the impacts of direct energy efficiency requirements for industry. Similarly, preliminary analysis appears to show that indirect impacts—the ripple effect of losses in materials industries leading to losses in other industries is only of fraction (>25%) of the direct impact on materials industries. Of special note is the wide dispersion of such impacts. For example, impacts on electricity and trucking (which one might expect to be affected) are of the same magnitude as impacts on the commercial remodeling and personal services subsectors. Such results greatly expanded our view as we tried and to some extent succeeded in linking the economic analysis with life cycle assessment (LCA) techniques which generally evaluate the environmental effects of a product or process by analyzing the entire life cycle from raw materials through consumer use (Conway-Schempf 2007). We also found even the most energy intensive industries have the largest indirect effects on service industries.

Despite our overall conclusion that indirect impacts outside and within industry are small and smaller, we think it is important to name and understand them—especially with imminent new energy and climate policies.

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