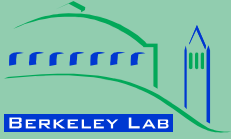


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ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

Technologies and Policies to Improve Energy Efficiency in Industry

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Abstract. The industrial sector consumes nearly 40% of annual global primary energy use and is responsible for a similar share of global energy-related carbon dioxide (CO₂) emissions. Many studies and actual experience indicate that there is considerable potential to reduce the amount of energy used to manufacture most commodities, concurrently reducing CO₂ emissions. With the support of strong policies and programs, energy-efficient technologies and measures can be implemented that will reduce global CO₂ emissions. A number of countries, including the Netherlands, the UK, and China, have experience implementing aggressive programs to improve energy efficiency and reduce related CO₂ emissions from industry. Even so, there is no silver bullet and all options must be pursued if greenhouse gas emissions are to be constrained to the level required to avoid significant negative impacts from global climate change.

Introduction to Industrial Energy Efficiency

The industrial sector consumes nearly 40% of annual global primary energy use and is responsible for a similar share of global energy-related carbon dioxide (CO₂) emissions. Even so, energy efficiency in industry is a neglected topic by scholarly groups, most likely because industrial energy efficiency is a very broad and complicated topic. Also, there is an underlying assumption that industry has both the financial incentive and technical capability to use energy efficiently, and therefore industrial energy efficiency doesn't require much further study. However, studies and experience suggest otherwise; there is still a large gap between actual and best practice in terms of the implementation of cost-effective energy efficiency measures in industry. This chapter summarizes the status of global industrial energy use and related CO₂ emissions. This is followed with a review of technical solutions for a number of energy-intensive industries, such as steel and cement. Lastly, policy options and progress are discussed, with examples from selected countries.

Between 1971 and 2004, industry's share of global primary energy (which includes the energy consumed to generate and distribute secondary energy such as electricity and petroleum products) dropped from 40% to 37%. During the same period, transportation energy use increased from 18% to 22%, residential building energy use dropped slightly from 30% to 29%, commercial building energy use rose from 9% to 11%, and agricultural energy use remained constant at 3% (see Figure 1). Figure 2 shows CO₂ emissions from the same five end-use sectors (de la Rue du Can and Price, 2008). Industrial energy-related CO₂ emissions were 9.9 GtCO₂ in 2004, of which direct emissions were 5.1 GtCO₂ and the remainder were indirect emissions from electricity generation, transmission, and distribution along with other indirect emissions. Industrial energy use and energy-related CO₂ emissions have grown rapidly in developing countries, where they increased from 18% of global emissions in 1971 to 53% in 2004 (Bernstein et al., 2007).

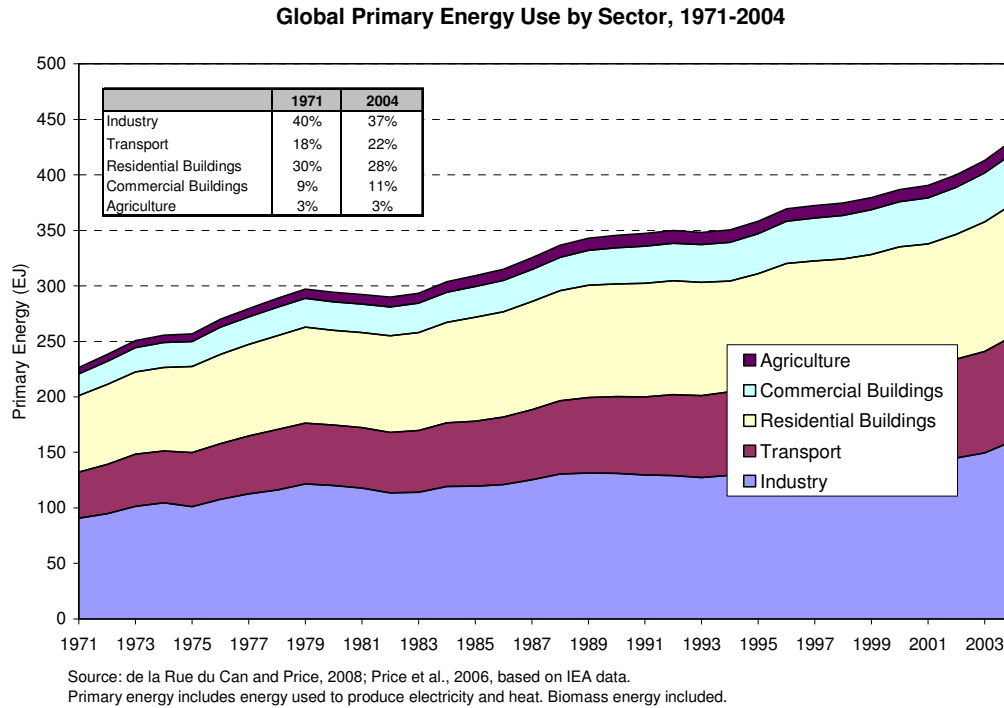


Figure 1. Global primary energy use by the industrial, transportation, residential buildings, commercial buildings, and agricultural end-use sectors (1971–2004).

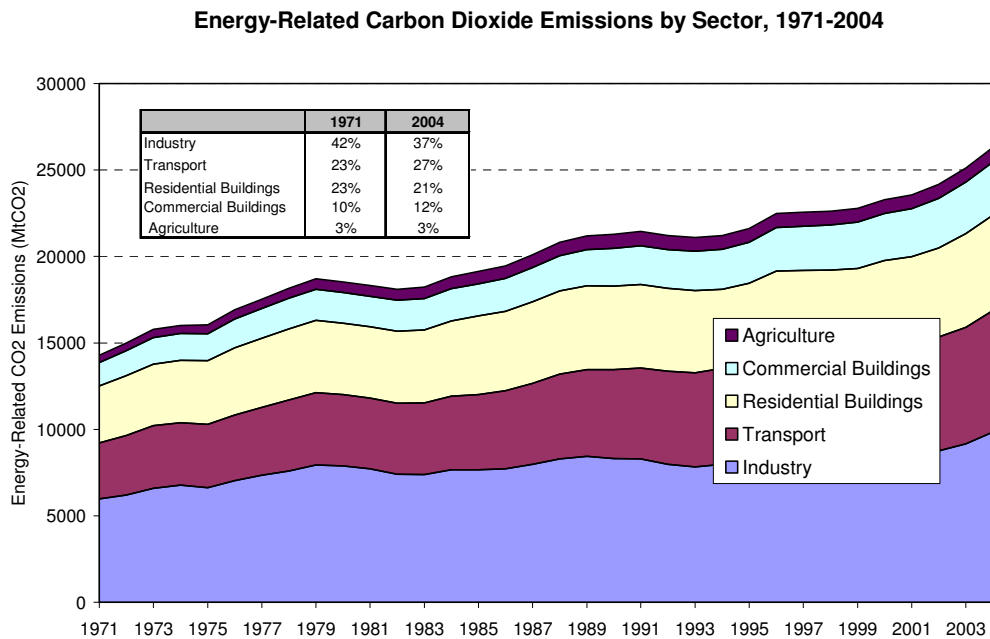
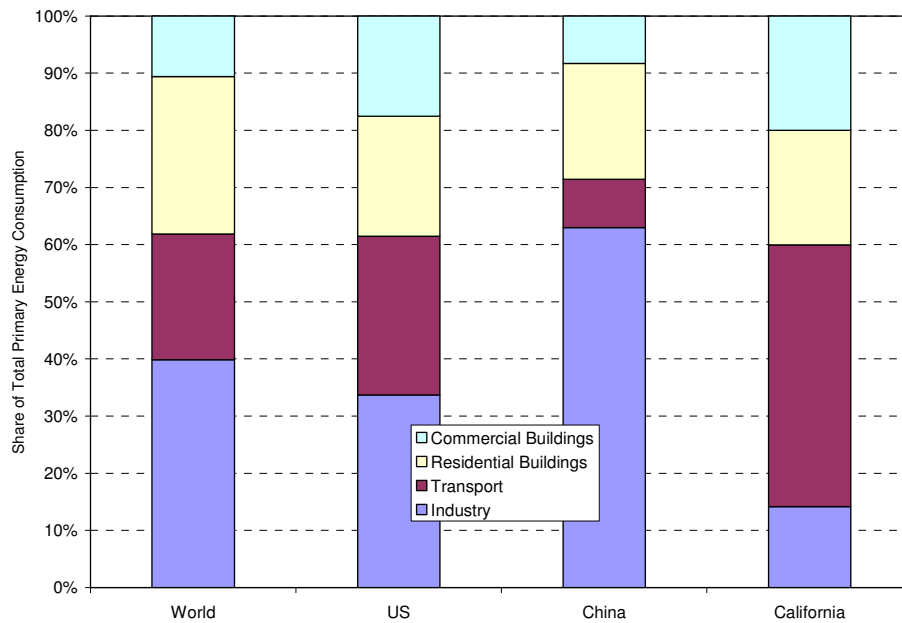


Figure 2. Energy-related carbon dioxide emissions of the industrial, transportation, residential buildings, commercial buildings, and agricultural end-use sectors (1971–2004).

The share of energy consumption by end-use sectors is plotted for the world, the U.S., China, and California in Figure 3 (de la Rue du Can and Price, 2008; Murtishaw et al.,

2005; Price et al., 2006; US EIA, 2007; NBS, 2005). Due to the high level of demand for energy for both construction of its own infrastructure and manufacturing products for global markets, industrial energy use in China is over 60% of total primary energy consumption, compared to the world (39%), the US (33%) and California (15%).

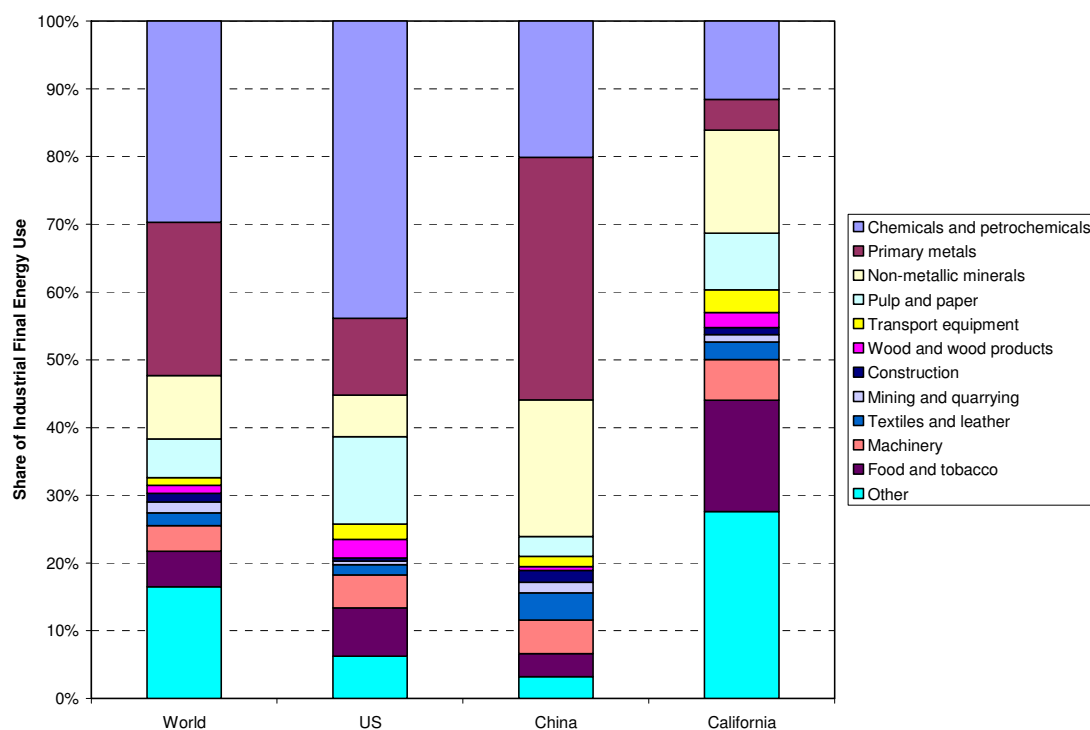
Additional detail on the energy used for specific industrial sub-sectors is provided in Figure 4. While the production of chemicals, petrochemicals, and primary metals such as steel dominate in the U.S. and China – as well as worldwide – California’s industrial energy use is consumed for the production of non-metallic minerals like cement, as well as food and beverages, and electric and electronic equipment such as semiconductors that make up a large share of the “other” sector shown in the figure (IEA, 2007; Murtishaw et al., 2005).



Note: industry includes agriculture

Sources: de la Rue du Can and Price, 2008; Murtishaw et al., 2005; Price et al., 2006; US EIA, 2007; NBS, 2005

Figure 3. Energy consumption by sector for the world, the US, China and California.



Sources: IEA, 2007; Murtishaw et al., 2005

Figure 4. Industrial energy consumption for 12 sub-sectors for the world, the US, China and California.

Potential to Save Energy

The conventional wisdom is that industry is already relatively energy efficient. Many studies and actual experience, however, indicates that there continues to be significant potential to reduce the amount of energy used to manufacture most commodities. The savings potential estimated by the International Energy Agency for five industrial subsectors is considerable: 13% to 16% for chemicals and petrochemicals, 9% to 40% for iron and steel, 11% to 40% for cement, 15% to 18% for pulp and paper, and 6% to 8% for aluminum (IEA, 2007; IPCC, 2007). In addition to sector-specific energy efficiency opportunities, there are also potential savings from improvements that are common to many industries such as motor and steam systems, increased use of combined heat and power, process integration, increased recycling, and energy recovery.

A recent study of the potential for improving the energy efficiency of industry in California identified 56 electricity and 36 natural gas energy-efficiency technologies and measures for California's manufacturing sector. These measures are estimated to have an economic potential of saving 4.4 million metric tons of CO₂ (MtCO₂) through 2016 (2 MtCO₂ from electricity savings and 2.4 MtCO₂ from natural gas savings), which represents savings of 15% of electricity and 13% of natural gas from their present baseline use (KEMA, 2006).

CO₂ emissions from the industrial sector in the U.S. can be reduced by between 10% and 29% below a business-as-usual baseline using policies to improve industrial energy efficiency through increased implementation of efficient practices and technologies such

as preventative maintenance, pollution prevention and waste recycling (e.g. steel, aluminum, cement, and paper), process control and management, steam distribution system upgrades, improved energy recovery, cogeneration (CHP), and drive system improvements. A large share of the efficiency improvements can be achieved by retiring old process equipment and replacing it with the state-of-the-art equipment, especially for many capital-intensive industries (IWG, 2000; Worrell and Price, 2001).

Both the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA) have a number of programs designed to provide information to various industrial sectors regarding energy efficiency improvement opportunities. The U.S. EPA has published a number of guidebooks which identified 90 energy-saving technologies and measures for the petroleum refining industry (Worrell and Galitsky, 2005), 102 for pharmaceuticals manufacturing (Galitsky et al., 2005), 150 for food processing (Masanet et al., 2007), 40 for cement manufacturing (Worrell and Galitsky, 2004), 114 for glassmaking (Worrell et al., 2007), 45 for breweries (Galitsky et al., 2003), and 93 for vehicle assembly (Galitsky and Worrell, 2003). DOE's Industrial Technologies Program provides many software tools for assessing energy efficiency of motors, pumps, compressed air systems, process heating and steam systems, as well as Sourcebooks that provide information on these industrial systems and a Quick Plant Energy Profiler software tool that helps industrial plant personnel understand how energy is being used at their plant and how they may save energy and money. Fact sheets or brochures contain information on energy efficiency methods, technologies, processes, systems and programs, or provide results from demonstration projects or annual reports. The DOE also provides case studies that describe energy-efficiency demonstration projects in operating industrial facilities in the aluminium, chemicals, forest products, glass, metal casting, mining, petroleum, steel, cement, textiles, and other sectors and tip sheets, technical fact sheets and handbooks, and market assessments for industrial systems. A recent DOE report identified about 90 new technologies for aluminum, chemicals, forest products, glass, metal casting, plastics, mining, petroleum refining, steel (U.S. DOE, 2007).

The Intergovernmental Panel on Climate Change (IPCC) recently summarized the available options for reducing greenhouse gas emissions in the industrial sector in the following categories: energy efficiency, fuel switching, power recovery, renewable energy sources, feedstock change, product change, material efficiency, non-CO₂ greenhouse gases and CO₂ sequestration (see Table 1). The IPCC estimates that the potential to reduce emissions in 2030 is 2.0 to 5.1 gigatonnes (Gt) CO₂-equivalent/year at a cost of \$100 per ton of CO₂-equivalent compared to a relatively low emissions business-as-usual scenario. Much of this potential is available at lower costs and is found in the steel, cement, and pulp and paper industries (Bernstein et al., 2007).

Sector	Energy efficiency	Fuel switching	Power recovery	Renewables	Feedstock change	Product change	Material efficiency	Non-CO ₂ GHG	CO ₂ sequestration
Sector wide	Benchmarking; Energy management systems; Efficient motor systems, boilers, furnaces, lighting and HVAC; Process integration	Coal to natural gas and oil	Cogeneration	Biomass, Biogas, PV, Wind turbines, Hydropower	Recycled inputs				Oxy-fuel combustion, CO ₂ separation from flue gas
Iron & Steel	Smelt reduction, Near net shape casting, Scrap preheating, Dry coke quenching	Natural gas, oil or plastic injection into the BF	Top-gas pressure recovery, Byproduct gas combined cycle	Charcoal	Scrap	High strength steel	Recycling, High strength steel, Reduction process losses	n.a.	Hydrogen reduction, Oxygen use in blast furnaces
Non-Ferrous Metals	Inert anodes, Efficient cell designs				Scrap		Recycling, thinner film and coating	PFC/SF ₆ controls	
Chemicals	Membrane separations, Reactive distillation	Natural gas	Pre-coupled gas turbine, Pressure recovery turbine, H ₂ recovery		Recycled plastics, biofeedstock	Linear low density polyethylene, high-performance Plastics	Recycling, Thinner film and coating, Reduced process losses	N ₂ O, PFCs, CFCs and HFCs control	Application to ammonia, ethylene oxide processes
Petroleum Refining	Membrane separation Refinery gas	Natural gas	Pressure recovery turbine, hydrogen recovery	Biofuels	Bio-feedstock		Increased efficiency transport sector	Control technology for N ₂ O/CH ₄	From hydrogen production
Cement	Precalciner kiln, Roller mill, fluidized bed kiln	Waste fuels, Biogas, Biomass	Drying with gas turbine, power recovery	Biomass fuels, Biogas	Slags, pozzolanes	Blended cement Geo-polymers		n.a.	O ₂ combustion in kiln
Glass	Cullet preheating Oxyfuel furnace	Natural gas	Air bottoming cycle	n.a.	Increased cullet use	High-strength thin containers	Re-usable containers	n.a.	O ₂ combustion
Pulp and Paper	Efficient pulping, Efficient drying, Shoe press, Condebelt drying	Biomass, Landfill gas	Black liquor gasification combined cycle	Biomass fuels (bark, black liquor)	Recycling, Non-wood fibres	Fibre orientation, Thinner paper	Reduction cutting and process losses	n.a.	O ₂ combustion in lime kiln
Food	Efficient drying, Membranes	Biogas, Natural gas	Anaerobic digestion, Gasification	Biomass, Biogas, Solar drying			Reduction process losses, Closed water use		

Source: IPCC, 2007.

Table 1. Selected Examples of Industrial Greenhouse Gas Emission Mitigation Measures

Industrial Energy Efficiency Policies and Programs¹

Barriers to the implementation of industrial sector energy efficiency and greenhouse gas emission mitigation options include slow capital stock turnover, a lack of willingness to invest in efficiency and mitigation options, lack of information and high transaction costs, profitability barriers, lack of skilled personnel to install the measures, and other market barriers. Policies and programs designed to address these barriers and encourage adoption of energy efficiency and emissions mitigation options include regulations and standards, energy and/or CO₂ taxes, emissions trading, agreements and target-setting, emissions reporting, benchmarking, audits or assessments, and information dissemination and demonstration.

Target-setting agreements, also known as voluntary or negotiated agreements, have been used by a number of governments as a mechanism for promoting energy efficiency within the industrial sector. A recent survey of such target-setting agreement programs identified over 20 energy efficiency or GHG emissions reduction voluntary agreement programs in 18 countries, including countries in Europe, the U.S., Canada, Australia, New Zealand, Japan, South Korea, and Chinese Taipei (Taiwan) (Price, 2005).

International best practice related to target-setting agreement programs involves establishment of a coordinated set of policies that provide strong economic incentives as

¹ Some of the material in this section has been previously published in McKane et al., 2007.

well as technical and financial support to participating industries. Effective target-setting agreement programs are based on signed, legally-binding agreements with realistic long-term (typically 5-10 year) targets, require facility- or company-level implementation plans for reaching the targets, require annual monitoring and reporting of progress toward the targets, include a real threat of increased government regulation or energy/GHG taxes if targets are not achieved, and provides effective supporting programs to assist industry in reaching the goals outlined in the agreements.

The essential steps for reaching a voluntary agreement are the assessment of the energy-efficiency potential of the industrial facility as well as target-setting through a negotiated process. Participation by industries is motivated through the use of both incentives and disincentives. Supporting programs and policies, such as facility audits, assessments, benchmarking, monitoring, information dissemination, and financial incentives all play an important role in assisting the participants in understanding and managing their energy use and GHG emissions in order to meet the target goals. Some of the more successful voluntary agreement programs include trading as well as the use of a mechanism to reduce environmental regulations or taxes for participants.

Netherlands – Long-Term Agreements and Energy Benchmarking Covenants

In The Netherlands, voluntary agreements – called the Long-Term Agreements (LTAs) -- between the government and industrial sectors consuming more than 1 petajoule (PJ) per year were established in support of achieving an overall national energy-efficiency improvement target of a 20% reduction in energy efficiency between 1989 and 2000. Each industry association signed an agreement with the Dutch Ministry of Economic Affairs committing that industry to achieve specific energy efficiency improvements by 2000. In total, 29 agreements were signed involving about 1000 industrial companies and representing about 90% of industrial primary energy consumption in The Netherlands. The average target was a 20% increase in energy efficiency over 1989 levels by 2000. The LTA program ended in 2000 with an average improvement in energy efficiency of 22.3% over the program period (Nuijen, 1998; Kerssemeeckers, 2002; Ministry of Economic Affairs, 2001).

Evaluations of the LTAs found that the agreements helped industries to focus attention on energy efficiency and find low-cost options within commonly used investment criteria (Korevaar et al., 1997). Various support measures were implemented within the system of voluntary agreements (Rietbergen, et al., 1998). It is difficult to attribute the energy savings to a specific policy instrument; rather, it is the result of a comprehensive effort to increase implementation and development of energy-efficient practices and technologies in industry by removing or reducing barriers. This emphasizes the importance of offering a package of measures that includes financial, technical, and informational assistance instead of a set of individual measures. A recent evaluation calculated that the cost of the LTAs was about \$10-\$20 per tonne of CO₂ reduced, depending upon whether full costs of all subsidies are included (Blok et al., 2004).

Following the LTAs, the Dutch government established a second LTA program – referred to as the Long-Term Agreements 2 (LTA2) program – for smaller businesses and industry. The LTA2 program, which runs from 2001 to 2012, differs from the first LTAs in that the LTAs were a voluntary agreement between Ministries and sectors, while the LTA2s are an agreement between individual businesses, sectors, and competent

authorities. The energy-efficiency target for a business or sector is set based on the results of an independent research assessment. A 2005 evaluation of the program indicated that 34 sectors were participating, representing a total of 906 companies. The industrial companies participating in this program achieved an energy efficiency improvement of 19.1% compared to 1998 (the reference year) (SenterNovem, 2006). The energy efficiency improvements made by these companies during the 2001-2004 period were equivalent to an emissions reduction of 2.8 MtCO₂ (SenterNovem, 2005).

United Kingdom Climate Change Agreements

In 2000, the United Kingdom Climate Change Program was established to meet the country's Kyoto Protocol commitment of a 12.5% reduction in GHG emissions by 2008-2012 relative to 1990 and a domestic goal of a 20% CO₂ emissions reduction relative to 1990 by 2010 (DEFRA, 2006). The Climate Change Levy -- an energy tax applied to industry, commerce, agriculture, and the public sector -- is a key element of this program. The revenues from the levy are returned to the taxed sectors and used to fund programs that provide financial incentives for adoption of energy efficiency and renewable energy (DEFRA, 2004). Through participation in the Climate Change Agreements (CCAs), energy-intensive industrial sectors established energy efficiency improvement targets and companies that meet their agreed-upon target are given an 80% discount from the Climate Change Levy. There are 44 sector agreements representing about 5,000 companies and 10,000 facilities. Companies that exceed their targets will have excess carbon allowances which they are allowed to trade with companies that do not meet their targets through the UK Emissions Trading Scheme (DEFRA, 2005a).

Table 2 shows that during the first target period (2001-2002) total realized reductions were nearly three times higher than the target for that period (Future Energy Solutions, 2004). Industries underestimated what they could achieve via energy efficiency. When negotiating the targets, most companies believed that they were already energy-efficient, but when they actually managed energy because of the CCA targets, companies saved more than they thought that they could, especially through improved energy management (Pender, 2004). Industry realized total reductions that were more than double the target set by the government during the second target period and that were nearly double the target during the third target period (DEFRA, 2005b; Future Energy Solutions, 2005; DEFRA, 2007). Industry is saving over \$832 million/year on the avoided energy costs as a result of meeting the CCA targets, in addition to the savings on the Climate Change Levy itself.

Absolute Savings from Baseline	Actual (MtCO₂/year)	Target (MtCO₂/year)	Actual minus Target (MtCO₂/year)
Target Period 1 (2001-2002)	16.4	6.0	10.4
Target Period 2 (2003-2004)	14.4	5.5	8.9
Target Period 3 (2005-2006)	16.4	9.1	7.3

Source: DEFRA, 2007. Note that adjustments to the target have been made due to significant changes in the steel sector; see referenced material for details.

Table 2. Results of the UK Climate Change Agreements: Periods 1-3

China – Top-1000 Energy-Consuming Enterprises Program

Between 1980 and 2000, China's energy efficiency policies resulted in a decoupling of the traditionally linked relationship between energy use and gross domestic product (GDP) growth, realizing a four-fold increase in GDP with only a doubling of energy use. However, during China's transition to a market-based economy in the 1990s, many of the country's energy efficiency programs were dismantled and between 2002 and 2005 China's energy use increased significantly, growing faster than GDP. Continuation of this trend in increased energy consumption relative to GDP growth – given China's stated goal of again quadrupling GDP between 2000 and 2020 – will lead to significant demand for energy, most of which is coal-based. The resulting local, national, and global environmental impacts could be substantial.

In 2005, realizing the significance of this situation, the Chinese government announced an ambitious goal of reducing energy consumption per unit of GDP by 20% between 2005 and 2010. One of the key initiatives for realizing this goal is the Top-1000 Energy-Consuming Enterprises program. The comprehensive energy consumption of these 1000 enterprises accounted for 33% of national and 47% of industrial energy usage in 2004 (see Figure 5). Under the Top-1000 program, 2010 energy consumption targets were determined for each enterprise. The goal of the Top-1000 program is for the participating enterprises to save 100 million metric tons of coal equivalent from the expected 2010 energy consumption of these 1000 enterprises. Reported savings in 2007 indicate that the program is on track to reach this goal, which – if achieved – will save between 250 and 300 MtCO₂ in 2010, contributing somewhere between 10% and 25% of the savings required to support China's efforts to meet a 20% reduction in energy use per unit of GDP by 2010 (Price et al., 2008).

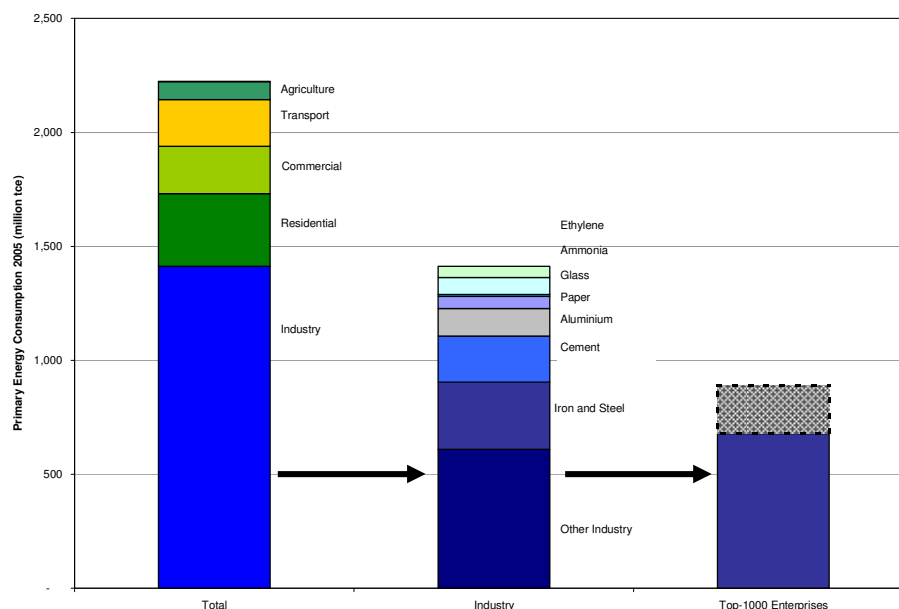


Figure 5. Energy Consumption of China, China's Industrial Sector, and the Top-1000 Energy-Consuming Enterprises, 2005. Note: Top-1000 program energy consumption is typically reported in final energy units (dark blue box). The shaded area provides the Mte equivalent of electricity generation, transmission, and distribution losses so that the Top-1000 program can be compared in primary energy terms with the other two bars. Industry sub-sector breakdown based on LBNL LEAP model, not Chinese statistics.

Conclusions

While there are no “silver bullets” for improving energy efficiency and reducing greenhouse gas emissions in the industrial sector, it is clear that there are hundreds of emission reduction technologies and measures for industry. The key issue is how to realize significant implementation of these technologies and measures. Industry excels at producing specific commodities, not at saving energy or reducing greenhouse gas emissions. Many policies and programs exist to motivate and assist industries in saving energy and reducing emissions. Some of the most successful programs involve setting clear and ambitious targets and providing government support for industries to reach their goals. Only through continued implementation of energy-efficiency and greenhouse gas emissions mitigation technologies and measures – often spurred by government and industry programs – will the industrial sector be able to contribute its share of the significant level of emissions reductions required to avoid significant negative impacts from global climate change.

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