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Improving Industrial Energy Efficiency in the U.S.: Technologies and Policies for 2010 to 2050

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I. Introduction

Characterizing industry in the U.S. is difficult since it covers an extremely diverse range of activities. In 2000, industry was responsible for 30% of the greenhouse gas (GHG) emissions in the U.S. and consumed 35% of the country's primary energy. Over half of this energy was used in energy-intensive industries producing commodities such as steel, cement, paper, and aluminum; the remainder was consumed by light manufacturing industries. Economic development patterns are leading to a shift away from these energy-intensive industries toward lighter, higher value-added industries, which will be responsible for more than half of all manufacturing energy use by 2050.

Historically, industrial energy consumption in the U.S. showed an overall decline between 1973 and 1986 when energy prices were relatively high, but has grown annually since then. The U.S. Energy Information Administration projects that energy consumption and GHG emissions for U.S. industry will continue to grow and, extrapolating current reference case growth rates, will double by 2050. However, technologies and policies are available that can reduce this growth considerably.

II. Necessary Technical Advances

Currently many opportunities exist to improve industrial energy efficiency and there is a large potential for future efficiency developments. Improving industrial energy efficiency and reducing energy-related GHG emissions can be accomplished through technological improvements as well as changes in the structure of the overall industrial sector (in reaction to economic and environmental drivers). In addition, further reductions in GHG emissions from industry can be realized through reduction of process-related emissions, fuel switching to lower carbon fuels, and integrated pollution prevention and material efficiency improvement. All of these opportunities are available on the near-term and many will continue to be available in the medium- and long-term.

For a variety of reasons, many of the energy-intensive industries in the U.S. are relatively energy *inefficient* when compared to their counterparts in Europe, Japan, Canada, or to rapidly industrializing countries such as South Korea, suggesting considerable potential for energy efficiency improvement in the *short term*. Recent comparisons and analyses show that some heavy industries in the U.S., such as those that manufacture steel, cement, paper, and some chemicals, use more energy per ton of product produced than many of their international counterparts. Since 1976, the U.S. Department of Energy's Industrial Technologies Program and Industrial Assessment Centers have conducted almost 12,000 energy-efficiency assessments in virtually all industries in the U.S. and have made over 82,000 recommendations for actions to increase energy-efficiency in the facilities audited (Rutgers University, 2003). Audits of individual plants further demonstrate the existence of these opportunities (U.S. DOE, 2003a). Many companies implementing energy management systems also find substantial room for improvement in their operations. Based on these studies we estimate that through adoption of commercially proven cost-effective technologies and measures, most industries currently can reduce their energy intensity by 20% or more (Interlaboratory Working Group, 2000; Martocci, 1996; Phylipsen, 2000; Worrell et al., 1999). Furthermore, many of these existing technologies will positively impact productivity and environmental performance.

For most industrial processes, current efficiency levels are nowhere near thermodynamic optimal levels. This suggests that there will be ample future energy-efficiency improvement opportunities. Technology development and innovation improve the overall performance of industrial technologies and often result in improvements in energy efficiency. Hence, emerging technologies provide further opportunities for energy efficiency improvement beyond currently available technologies. In fact, several studies demonstrate that society will "not run out of technologies", but that investment in technology development and research will provide a steady menu of energy-efficient technologies. For example, a recent report on emerging energy-efficient technologies identified approximately 175 technologies for reducing energy use in a variety of industries that were under development or near commercialization (Martin et al., 2000). U.S. Department of Energy's Industries of the Future program has worked with 10 industrial sectors to identify the most promising technologies and practices to receive further research and development (R&D) funding. Each industry has identified around 100 to 150 technologies or processes in industry-specific R&D portfolios (U.S. DOE, 2003b). Other studies indicate long-term potential energy-efficiency improvements ranging between 30 and 65% in the major industrial sectors, 43% for nitric acid production, 34 to 50% for iron and steel production, and 50 to 70% for paper production (ATLAS, 2003; de Beer, 1998). These analyses show that many technologies will be available in the medium term and development will continue to offer a menu of further technologies in the long term.

Along with the development and deployment of energy-efficient technologies, patterns of energy use and associated GHG emissions change over time as the types of industries and products produced evolve in response to infrastructure development needs and consumer preferences. Studies of material consumption in industrialized societies show increases in consumption of basic industrial materials in the initial development of society to a maximum consumption level, which then remains constant or even declines as infrastructure needs are met, higher value-added products are produced, and material recycling increases (Williams et al., 1987; WRI, 1997). Production of primary steel from iron ore in the U.S., for example, peaked in the 1970s and steel demand is increasingly being met through the production of recycled steel (AISI, various years). This dematerialization will continue and contribute to changes in economic activities. Further potential for material efficiency improvement currently exists which can reduce industrial energy use through product design, product re-use, recycling and material substitution. Integrated analyses of the potential for GHG emissions reduction have shown that a strategy combining energy and material efficiency opportunities will provide a more cost-effective strategy (Gielen, 1995).

Further near-term reductions in GHG emissions, beyond those from improvements in energy and materials efficiency, can be realized through reductions in process-related emissions. Non-energy-related GHGs, including carbon dioxide (CO_2), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6), are emitted during manufacturing of cement, aluminum, semiconductors, adipic acid, nitric acid, magnesium and electrical distribution equipment. Technologies and measures to reduce these process-related emissions are well known and significant progress has been made in some areas to reduce these emissions. In cement manufacturing, 50 percent of the GHG emissions are process related. There is still great potential to reduce CO2 emissions through the use of blended cements. Blended cements replace some of the cement with other less CO2-intensive materials. Blended cements, while customary in virtually all areas of the world, are not typically used in the United States. (Worrell et al., 2001)

Finally, additional reductions in GHG emissions from industrial-related activities in the U.S. can be realized through fuel-switching to low- or no-carbon fuels. The switch in fuels would also allow the introduction of more efficient conversion technologies, such as combined heat-and power production using natural gas. In fact, historic global trends show a movement toward easy-to-use forms of energy, which are often low-carbon fuels (Nakicenovic et al., 1998). Increased use of biomass-derived fuels in the pulp and paper industry has limited the growth of CO_2 emissions, and new technology would allow manufacture of virtually CO_2-free paper when produced in efficient mills.

III. Necessary Policies

The process for identifying, developing, and integrating these myriad technologies and measures for reducing energy use and GHG emissions from industry is an inherently complex and "messy" one (Nakicenovic et al., 2000). Even so, it is important to develop a menu of policy options with the appropriate mix of policies determined by current conditions as well as immediate and longer term goals. Policies to accelerate technological change are key to ensuring that outdated technologies do not get adopted and "locked-in" when more efficient technologies are available. Such policies can also provide incentives to innovators and early adopters, encourage implementation of best practices, and accelerate the realization of potential energy savings. However, such policies will not be sufficiently effective to meet the challenge when implemented in isolation among many other policies. It is essential that an over-arching, climate-friendly policy framework create markets for currently available energy-efficient technologies, and by doing so provides a powerful driver for expanded and accelerated R&D by the private sector.

In the near term, further efforts are needed to ensure that innovative energy-efficient technologies are adopted in the marketplace. Regulations and standards, aimed at eliminating the most wasteful products on the market, can be updated and extended to new products as technologies advance. A recent analysis of the effect of nine appliance standards enacted and updated between 1987 and 2000 found cumulative energy savings of 4.0 Quads and economic savings of $10 billion (Meyers et al., 2002). Market transformation programs that provide incentives for consumers to purchase more energy-efficient equipment and technologies can help in introducing new energy-efficient technologies as well as "push" the market toward more efficient products. Government procurement programs that require purchase of energy-efficient equipment, as well as consumer rebates and tax incentives, are all effective means of moving the market away from inefficient products.

To assure availability of technology options in the long term, research and development (R&D) programs are essential for the fundamental work needed to identify and develop specific energy-efficient and GHG emissions reduction technologies. Both government-sponsored and private sector R&D funding in the U.S. have declined in recent years. Public sector R&D spending saw the most dramatic decline, illustrated by the Department of Energy's drop in such expenditures from $6.55 billion in 1978 to $1.92 billion in 1997 (PCAST, 1997). Given the significance of energy consumption and energy efficiency (e.g. energy expenditures account for about 8% of GDP in the U.S., energy consumption contributes to considerable environmental problems, and energy consumption is closely linked to national security issues), the President's Committee of Advisors on Science and Technology (PCAST), a panel that consisted mainly of distinguished academics and private sector executives, recommended that the DOE energy efficiency budget should be doubled between FY1998 and FY2003, and estimated that this investment could produce a 40 to 1 return for the nation including reductions in fuel costs of $15-30 billion by 2005 and $30-45 billion by 2010 (PCAST, 1997). State-level R&D efforts, such as those in New York and California, can also make significant progress toward addressing state-specific energy efficiency needs.

Experience in a number of countries around the world using an innovative policy mechanism called Voluntary Agreements has shown that these programs, which push industry to achieve aggressive energy-efficiency targets with support from the government, could be attributed with about 50% of the observed energy-efficiency improvement or emissions reductions (Dowd et al., 2001). For example, in The Netherlands the historical energy intensity improvement rate of about 1% per year was more than doubled during the 10-year period covered by the industrial Voluntary Agreement program (Kerssemeeckers, 2002). These "voluntary" agreements are sometimes an integrated part of a larger national energy policy scheme that includes energy or GHG taxes or additional environmental regulations for those industries that do not sign agreements, providing further incentive and economic savings for those industries that participate.

The most effective means for improving energy efficiency or reducing GHG emissions is through adoption of an integrated long-term policy framework to address these challenges. Countries as diverse as China and the Netherlands have shown that a commitment to improving energy efficiency while allowing for continued economic growth can significantly reduce energy use per unit of production. Similarly, the United Kingdom has recently announced a goal of surpassing its Kyoto Protocol target of reducing emissions of CO_2 by 20 per cent below 1990 levels by 2010, to reduce carbon dioxide emissions by 60% by 2050 (UK DTI, DfT and DEFRA, 2003). A targeted approach is also successful within corporations, as evidenced by companies like BP and DuPont that achieved major reductions in GHG emissions within relative short periods. An integrated policy framework that provides clear direction on long-term goals, while providing market drivers for energy-efficient technology adoption, development and innovation can provide industry with a diverse menu of options to improve its energy and economic performance.

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