"Ecowatts": Energy and environmental impacts of electrification

In the United States, electro-technologies have contributed to energy efficiency and cut greenhouse gases

by Mark P. Mills

For sound reasons, utilities, energy planners, and utility commissions across the United States are embracing programmes to reduce or minimize electricity consumption — Demand Side Management (DSM). The resource equivalent of nearly 25 000 megawatts of DSM is projected to be implemented in the 1990s. High-efficiency light bulbs have come to symbolize the benefits of seeking greater electricity efficiency — or, colloquially, the search for *negawatts*. The appeal is undeniable and substantive. Every 60-watt bulb replaced with a 15-watt high-tech bulb of equal luminosity cuts energy use, eliminating two pounds of carbon dioxide for every 30 hours of operation. There is little to debate about programmes that improve electric efficiency cost effectively and without socially undesirable side effects.

But preoccupation with saving electricity has already blinded many planners and prognosticators to a basic, although in today's climate seemingly heretical, fact — replacing fossil fuels with electricity saves energy, even when the energy required to make the electricity is taken into account. These energy savings translate into reduced emissions of carbon dioxide (CO_2), one of the chief "culprits" implicated in global warming. Fuel switching to kilowatts that support the economy and improve the ecosphere could be termed *ecowatts*.

Energy planners accept as a fundamental maxim that society should pursue activities directed towards maximizing overall energy efficiency. Disagreement occurs over which approach should be pursued. For some prognosticators the first target is to cut electricity use because of the energy losses which occur at the power plant when heat is converted into kilowatt-hours. Some have claimed that the energy efficiency of electricity is analogous to "cutting butter with a chain saw". The myth that electricity is wasteful results from ignoring the efficiency with which electricity is actually used and the inefficiency with which fuels are used in the marketplace.

For example, the best power plants convert about 40% of the energy consumed into electricity. However, electric motors convert 90% of electricity into useful motion. By comparison, even the most efficient automobile converts less than 20% of its fuel energy to a drive shaft. In other words, the efficiency with which electricity can be used more than offsets the inefficiency of making electricity. Meanwhile the efficiency with which fossil fuels can be used is remarkably low in most applications and, for reasons of fundamental physics, inherently limited.

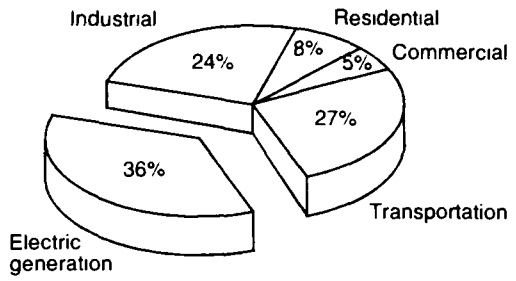
Thus steel made with coal-fired electricity uses less energy and emits less carbon dioxide than steel made in a coal-fired conventional blast furnace. This switch cuts energy use over 70% and eliminates about 2 pounds of carbon dioxide for every one pound of steel made *including* the energy and CO_2 needed to make the electricity. (The switch to all electric steel mills is, however, driven by the economic and productivity advantages of the technology — a typical motivation for most electro-technologies.)

This article is from an analysis entitled *Ecowatts: The Clean Switch* by Mr Mills, president of Science Concepts, Inc., a research-consulting and strategic marketing firm in metropolitan Washington, DC. The full analysis is available from Science Concepts, Inc., 2 Wisconsin Circle, Suite 470, Chevy Chase, Maryland 20815 USA.

Overall trends

Today utility planners effectively function like the Dutch boy in the fairy tale, trying to keep

Fuel use by major sectors, 1990



Note: Fuels required to make electricity delivered to other sectors are counted in the "electric generation" sector.

the waters back by putting a finger in the dike. US electricity consumption has been rising so long and inexorably that it appears to be a fundamental of modern society.

The growth in the consumption of electricity has outpaced overall energy growth, resulting in the share of total US energy used to making electricity increasing from 14% in 1950, to 24% in 1970, and reaching 36% today. It is easy to see why the electric sector has become an appealing, if not logical, target for energy savings and environmental programmes. More fuels are now used to make electricity than are used for any other activity in society. *(See graph.)* The transportation sector falls into a remarkably distant second place.

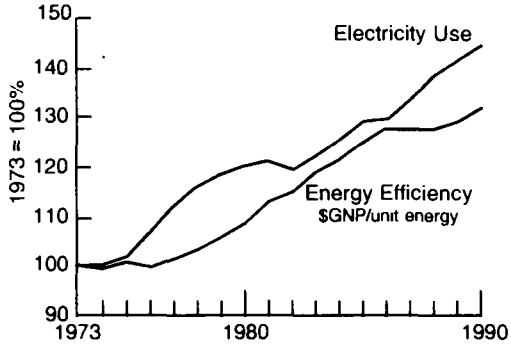
The electric sector is also appealing as a target for energy conservation programmes because no other energy activity literally tethers the user to the supplier. Programmes implemented by a single utility can directly and instantaneously affect energy use with millions of customers. This tightly linked relationship does not exist for fuels used in the marketplace.

Not only does the electric sector use the most energy, but virtually all the increased fuel consumption since the first oil embargo of 1973 has been used to make electricity. *(See graph.)* This trend is expected to continue.

The fact is, there are substantial opportunities to improve energy efficiency in the generation and use of kilowatt-hours. But this fact should not be interpreted as tacit evidence that using electricity is inherently "wasteful". Rather, substantial electric-efficiency opportunities exist precisely because of the inherent advantages of electric devices, appliances, and processes. These are the same advantages that drive the switch from fuels to kilowatt-hours in the first place.

When fuels are burned, the natural limit of energy efficiency is set by fundamental laws of physics relating to the temperature of combustion. For example, there is little room for significant improvement in the energy efficiency of an automobile *engine*. Gains in auto fuel efficiency come from such factors as reduced vehicle weight and air resistance, lower friction, lower rolling resistance, better transmissions, and so on. When electricity is used, on the other hand, a vast opportunity exists to manipulate electrons and magnetic fields. For example, an electric vehicle rolling to a stop runs the drive motor in reverse to generate electricity to recharge the batteries. No engineering trick can turn kinetic energy back into gasoline.

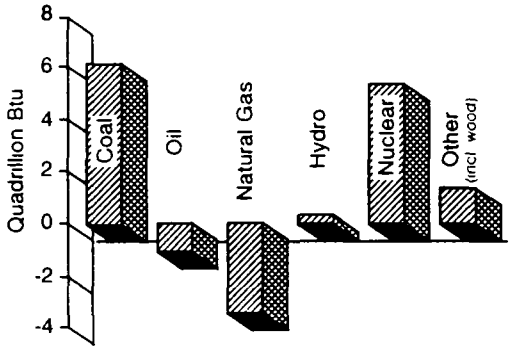
Electric sector fuel use and national energy efficiency, 1973–1990



The evidence that using electricity increases energy efficiency can be seen in overall national trends. The growth in fuels used to make electricity has occurred along with the rise in national energy efficiency. *(See graph.)* If using fuels to make electricity were wasteful, the magnitude of the electric sector's fuel consumption would be driving down the nation's energy efficiency. Instead, the opposite is happening. More and more economic output is being supported by decreasing amounts of primary fuels. The past 17 years has seen a 50% rise in the fuels used to make electricity, and at the same time a 40% rise in overall energy efficiency, including the fuels needed to make electricity.

Improving energy efficiency is widely acknowledged as the most effective tactic for deal-

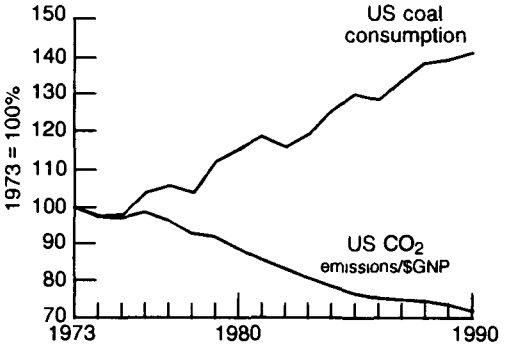
Changes in US energy consumption, 1973 vs 1990



ing with the emission of carbon dioxide, a principal contributor to global warming. Thus a basic indicator of national progress towards reducing the potential for global warming will be the amount of carbon that is emitted to the atmosphere per unit of gross national product (GNP). This is a critical indicator that identifies society's underlying efficiencies.

There has been an intriguing and virtually ignored trend in this regard. *(See graph.)* The overall global warming impact of US economic activity has been on the decline — i.e., the amount of carbon emitted per unit of GNP has been decreasing. One dollar of GNP resulted in 4 lbs of CO_2 emitted in 1973; by 1990 only 2.34 lbs were emitted per dollar of GNP. This is a remarkable fact considering that there has been a large increase in fuels used to make electricity since 1973, and further that 60% of all the increased electric sector fuel use has come from coal. Burning coal releases more carbon dioxide per unit of energy than any other fuel. Yet an

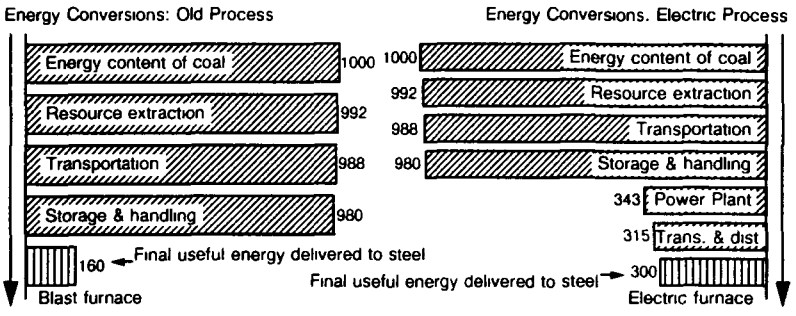
US coal use and carbon emissions per dollar of GNP, 1973–1990



increase in US coal consumption of 380 million tons per year between 1973 and 1990 was associated with a *decrease* in the amount of carbon dioxide emitted per unit of GNP.

The overall data suggests strongly that electricity, or coal-by-wire or any fuel-by-wire, is associated with increased energy efficiency and increased CO_2 efficiency — i.e., *decreased* global warming impacts. The improved CO_2 efficiency of the US economy *cannot* be fully accounted for because of increased use of non-combustion fuels (specifically nuclear energy) and improvements in the fuel economy of cars. Improved fuel efficiency of the nation's auto fleet and increased use of nuclear energy (i.e., both reducing CO_2 emissions) account for only 11% and 12% respectively of the total improvement in national CO_2 efficiency since 1973. Clearly, something else is happening to improve CO_2 efficiency. What is happening can be illustrated with some specific electric technologies and their impact on overall energy use and CO_2 emissions.

Energy conversion steps: Standard vs electric steelmaking



Using ecowatts to cut CO_2

Electric steel making offers one of the clearest and most tantalizing examples of using kilowatt-hours to cut energy use and carbon dioxide emissions. The electric melting process deposits essentially all of the energy directly in the melt where it is needed with virtually no energy wasted at the point-of-use. The energy lost in making the electricity is substantially less than the energy wasted by a typical blast furnace. *(See chart.)* The difference between the two processes is analogous to using a fire to boil water, instead of placing electrodes directly into a mug of water.

The US produces over 200 billion pounds of steel a year. For every pound of steel made electrically, two pounds of CO_2 are eliminated. This accounting considers the elimination of the coal burned and CO_2 emitted in the fuel cycle for the blast fumace, and assumes that only coal is burned to make the necessary electricity.

The one-pound-of-electric-steel eliminating two pounds of CO_2 suggest an interesting benchmark to explore other electrification opportunities. Thus this analysis considers specific technologies (including steel making) that can switch from fuels to ecowatts. No attempt is made to calculate the overall effect of fully converting to electric technologies, but the illustrations make clear that there are literally billions of opportunities to save two pounds of CO_2 by switching to electricity. *(See table.)* The examples help explain how the national efficiency trends, illustrated earlier, could have occurred.

The technologies chosen are intended to provide illustrations across a wide range of activities. In some cases, different assumptions would yield somewhat different answers, but in no case would the overall effect of reduced CO_2

Examples of "ecowatt" technologies

Fuel-burning replaced with electricity at point-of-use	Activity	Energy savings	Carbon dioxide eliminated
Make Steel use electric arc instead of blast furnace	Produce 1 pound steel	50%	~2 pounds
Cooking use microwave instead of gas oven	Cook 2 lb meatloaf	90%	~2 pounds
Paint Drying use ultraviolet dryer instead of gas heat	Dry paint on 1 one new car	90%	~2 pounds
Print Magazine use ultraviolet dryer instead of gas heat	Dry ink on pages of 40 magazines	60%	~2 pounds
Make Copper use electric induction instead of furnace	Produce 10 pounds copper	40%	~2 pounds
Fly to Nearby City use high-speed Maglev instead of airplane	Fly 2 passenger miles	75%	~2 pounds
Freeze concentrated milk use electric freeze distillation instead of heating & evaporating	Process 55 lbs milk	40%	~2 pounds
Secure Toxic Waste use electric vitrification instead of dig/transport/bury	Isolate 1 lb waste	20%	~2 pounds
Make Glass Bottles use electric furnace instead of fuel furnace	Make 12 bottles	65%	~2 pounds

Notes: "Energy savings" include the energy needed to make electricity and all losses in energy fuel cycles. "Carbon dioxide eliminated" includes emissions from electricity production and assumes that the fuel displaced by the electric technology is used to make the electricity.

with increased electrification be reversed. The reductions in energy use and associated reductions in CO_2 are illustrated for two cases:

- The fuel consumed at the point-of-use is replaced with electricity made with the same fuel displaced (i.e., if a microwave oven displaces a natural gas oven, natural gas is assumed to be used to make the electricity).
- The fuel consumed at the point-of-use is replaced by electricity generated with the mix of fuels currently employed nationally (i.e., 56% coal, 19% nuclear, 10% hydro, 8% natural gas, 6% oil) and thus the CO_2 emissions from that mix.

Following are some observations about the ecowatt technologies for which specific CO_2 benefits have been calculated.

Paint drying. Using ultraviolet (UV) light instead of a gas-fired oven to dry paint offers energy benefits analogous to a microwave oven. The motivation for using UV paint drying, however, has not been to reduce energy consumption and CO_2 emissions. Rather, UV dryers are faster (up to 10 times), and produce a more uniform and thus a higher quality finish.

Ink drying (print magazine). UV light can also be used to dry the ink on paper. Here too the process is sought for its productivity, throughput, and economic benefits. The energy and environmental benefits are an "extra". UV drying can be used for a range of activities in the printing industry, in the electronics industry for protective coatings on circuit boards, in the wood particle board industry, and in the hardening of coatings on no-wax floorings.

Maglev trains. Air transportation is typically held up as impossible to electrify. However, magnetically levitated (Maglev) trains "fly" on a magnetic field several inches off their tracks at speeds of over 300 mph. Maglev is the answer to eliminating fossil fuel use for continental, intercity air travel. The use of Maglev would not only improve intercity travel along dense corridors, but also reduce pollution at airports that are typically located in or near urban centres and the "breathing zone".

Toxic waste. Areas contaminated with toxic chemical wastes are typically cleaned-up by digging up the contaminated soil, transporting it by truck to a remote, approved site for disposal,

digging trenches that are lined with clays and/or plastic to prevent leaking of the waste, and, finally, burial of the contaminated wastes in those trenches. The entire activity involves the use of energy-intensive heavy earth-moving equipment and trucking. The electric alternative is to place electrodes directly into the contaminated ground and glassify, or vitrify the ground, leaving waste inert, safe, and leak-proof. Such a process eliminates substantial amounts of energy-intensive and CO_2-emitting activities, and confers an array of additional safety and economic benefits.

Glass making. Glass can be produced electrically in a fashion similar to the processes used for metals. Glass making can be entirely electrified or, by means of a process known as electric boosting, partially electrified. Electric glass making provides improved product quality, smaller facilities (with attendant reductions in capital and material costs as well as building space costs) and lower environmental impacts. As an ancillary benefit, it also uses less energy and produces less CO_2.

Light rail. Advances in electric motor controls and processors have further improved the energy advantages of electric-drive. The trend towards increased use of light rail will decrease overall energy use, but perhaps more importantly, decrease pollution in congested urban areas.

Fertilizer. Nitrogen in the air can be extracted and made into fertilizer using an electric arc process. The overall energy costs of producing such fertilizer at the site where it is required will be lower than the energy costs of conventional fertilizer production.

Electron beam welding. Like lasers, electron beams can weld all types of materials. Because the beam has an electric charge it can be very precisely controlled resulting in higher quality welds and greater productivity than conventional gas welds. Over 180 electron beam welds are used in a typical car. Not only can the welds be accomplished more quickly and with higher quality, but energy required per inch of weld is reduced tenfold.

New opportunities

Goals to limit global warming should not ignore the benefits of ecowatts. When processes switch to ecowatts instead of burning fuels, the net amount of pollution is reduced. These savings are calculated by *including* the fuels used to make the electricity. Ecowatts result from the inherent efficiency advantages of electric processes and devices.

As technology progresses, new opportunities for ecowatts will arise.

In the United States, greater use of electricity has increased energy efficiency and reduced overall emissions of carbon dioxide.