fuel for thought

ENERGY

ANTHONY D. OWEN

Burning Up

Energy Usage and the Environment

The use of energy by humankind has been an essential element in both the development of organized society and in the supply of food and physical comfort. Energy requirements were relatively modest for most of human existance, generally limited to the use of fire for warmth and cooking. In addition, wind and human "energy" permitted transportation by water, while the invention of the wheel gave similar advantages on land. Only in comparatively recent times have wind and water energy been harnessed to provide significant sources of power.

The first significant increase in humankind's energy requirements came with the dawn of the Neolithic Revolution. Humans moved from hunting and gathering to primitive agriculture with interrelated developments such as cultivation of plants, domestication of animals, settlement of communities, development of pottery, and improved tool-making. However, with a relatively small human population and modest per capita consumption of heat and power, it was still possible to maintain a balance between renewable energy sources and demand.

The development of mechanical equipment based upon water and wind power led to a substantial increase in the magnitude of power that could be harnessed. Watermills were initially used for irrigation and for grinding cereals, but were later used to drive sawmills. Windmills were used for similar tasks, although their value was limited by their intermittent operation. It was not until the development of metal technology that power supply sufficient for the output of "energy intensive" products was required.

Copper was the first metal to come into widespread use. Iron, while more abundant than copper, is much more difficult to "win" from the ore and was not widely used until furnaces that could smelt iron were developed around 1100 BC. New tools made from iron transformed farming practices across Europe, although not without significant environmental impacts in England, the prime supplier of iron and iron products.

By the early Middle Ages, the forests of England had become badly depleted and prices rose because of the relative scarcity of wood. The place of wood in household use was taken by coal, despite increased pollution due to impurities in the coal. Demand for coal was further stimulated in the early 18th century by the discovery that coal's impurities could be removed by heating, making the resulting product (coke) ideal for reducing iron ore.

The development of the coal-fired steam engine drove the British Industrial Revolution of the 18th century and generated immense demand for coal. The evolution of the internal combustion engine and methods of transportation such as the automobile were associated with corresponding growth in the petroleum industry, and oil rose to join coal as the dominant fuels of the 20th century.

Development of coal-fired generators in the 1890s saw the growth of an electricity market. Electricity provided a new way of generating power, heat, and light. Electricity was initially very expensive and was limited to small areas, varying in

ANTHONY D. OWEN is President of the International Association for Energy Economics.

quality and subject to interruptions. However, technological developments led to the creation of a very homogeneous, reliable, and time-saving energy carrier. This new form of energy supply extended the importance of coal, but in the last quarter of the 20th century, nuclear power and natural gas grew in importance. Thus, despite the thermal losses associated with transforming fossil fuels into electricity, households and many forms of economic activity have tended to become increasingly electricity-intensive.

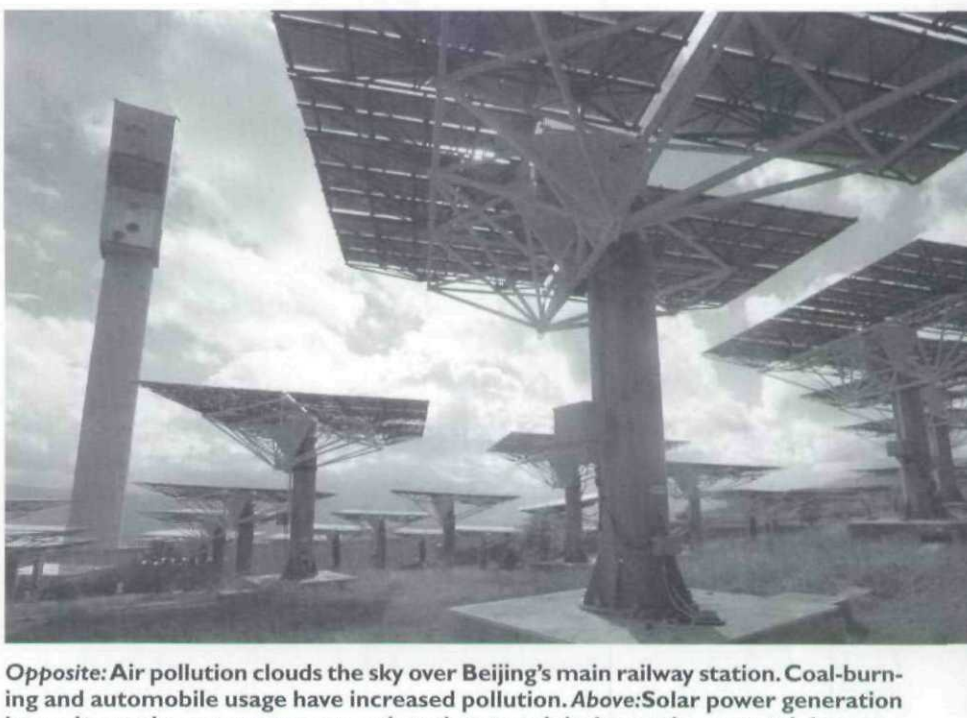
The 20th century also witnessed growing awareness of the impacts of large-scale energy use on the environment, although many of the same concerns were evident in more localized areas for many hundreds of years. Historically, regulatory instruments have been the basic mechanism for enacting environmental policy throughout the industrialized world. Environmental quality has been regarded as a public good that the state must secure by preventing private agents from damaging it. Direct regulation involves the imposition of standards, or even bans, regarding emissions or discharges, and product or process characteristics through licensing and monitoring. Legislation usually forms the basis for this form of control and compliance is generally mandatory with sanctions for non-compliance.

The more recent proposal to impose taxes on pollution is also far from new, having been proposed in the early years of the last century by British economist Arthur Cecil Pigou as a means of reducing London's famous fogs. His proposal was to tax pollution by means of a so-called externality tax in order to internalize the damages caused by pollution within ordinary market transactions and to avoid passing on the costs of pollution to the public. At the time, Pigou's proposal was regarded as an academic curiosity and largely ignored, but several generations later it was revived as the core of the "polluter pays principle."

Despite the apparent environmental attractiveness of renewable energy, its market penetration to date has been limited relative to past projections with the exception of hydropower. This fact has not, however, been due to any failure in its anticipated reduction in cost. For all major renewable technologies, future cost projections for successive generations have either agreed with previous projections or have been even more optimistic. Their lack of commercial success has instead been due in large part to declining fossil fuel prices for conventional technologies, combined with energy market reforms that have tended (at least in the short run) to return substantial cost savings for utilities employing these technologies. However, global environmental concerns over emissions of carbon dioxide and other so-called greenhouse gases (GHGs) are likely to exert significant pressure on governments in industrialized countries to encourage power generation by means of more environmentally benign technologies and micro-power supply sources.

Energy and the Environment Today

Contemporary energy policy issues are dominated, directly and indirectly, by major concerns at both local and global levels of the environmental degradation caused by fossil fuel combustion. The cost of environmental damage arising from energy production and consumption (whether based upon fossil fuel combustion, nuclear power, or renewable technologies) can be divided into two broad cost categories that distinguish emissions of pollutants with local and/or regional impacts from those with global impacts. The first type of costs are those associated with the damage caused to health and the environment by emissions of pollutants other than those associated with climate change (for example, sulphur dioxide, nitrogen oxide, and particulates). The second type are the costs resulting from the impact of climate change attributable to emissions of GHGs (pre-



Opposite: Air pollution clouds the sky over Beijing's main railway station. Coal-burning and automobile usage have increased pollution. _Above:_ Solar power generation is an alternative energy resource that aims to minimize environmental damage.

Photos Courtesy AFP/Getty Images

dominantly carbon dioxide and methane). The distinction is important because the scale of damages arising from the former is highly dependent upon the geographic location of source and receptor points. The geographic source is irrelevant for GHG emission damages.

When comparing the environmental footprints of alternative energy technologies, it is important that the power generation or combustion stage of the technology not be isolated from other stages of the "cycle." To accomplish this, the concept of life cycle analysis has been developed. Life cycle analysis (LCA) is based upon a comprehensive accounting from "cradle to grave" of all energy and material flows associated with a system or process. The approach has typically been used to compare the environmental impacts associated with different products that perform similar functions, such as plastic and glass bottles. In the context of an energy product, process, or service, an LCA would analyze the site-specific environmental impact of fuel extraction, transportation, and preparation of fuels and other inputs, as well as plant construction, plant operation/fuel combustion, waste disposal, and plant decommissioning. Thus, it encompasses all segments of the process, both upstream and downstream, and consequently permits an overall comparison (in a cost-benefit analysis framework) of short- and long-term environmental implications of alternative energy technologies. Central to this assessment is the valuation of environmental externalities of current and prospective fuel and energy technology cycles. It should be noted, however, that only material and energy flows are assessed in an LCA, thus ignoring some externalities, such as supply security as well as technology, reliability, and flexibility.

Life-cycle analysis is a scientific process involving the following methodological steps: the definition of the product cycle's geographical, temporal, and technical boundaries, the identification of the environmental emissions and their physical impacts on receptor areas, and the quantification of these physical effects in monetary terms.

Quantifying the physical impacts of emissions of pollutants requires an environmental assessment that ranges over a vast area—the entire planet in the case of carbon dioxide emissions. Thus the dispersion of pollutants emitted from fuel chains must be modelled and their resulting impact on the environment measured by means of a dose-response function. Generally, for damages to humans, such functions are derived from studies that are epidemiological—assessing the effects of exposure to pollutants in real life situations.

In other cases, the link between the environmental burden, physical impact, and monetary cost is far more complex. In reality, much of the required data is either incomplete or simply does not exist. A number of policy objectives that are more difficult to quantify are also of significance in the planning of future technology options. Currently, the most important of these would appear to be the security of the supply of energy resources and their associated transmission and distribution systems.

To effectively address these environmental matters and energy supply security concerns, radical changes in power generation, automotive engines, and fuel technologies will probably be required. Such changes must offer the potential for achieving negligible emissions of air pollutants and GHGs and must diversify the energy sector away from its present heavy reliance on fossil fuels, particularly gasoline in the transportation sector. A number of technologies, including those that are solar- or hydrogen-based, offer long term potential for an energy system that meets these criteria.

"CONTEMPORARY ENERGY POLICY ISSUES ARE DOMINATED, DIRECTLY AND INDIRECTLY, BY MAJOR CONCERNS...OF THE ENVIRONMENTAL DEGRADATION CAUSED BY FOSSIL FUEL COMBUSTION."

Transportation Sector

Concerns over the health impacts of small particle air pollution, climate change, and oil supply security have combined to encourage radical changes in automotive engine and fuel technologies that offer the potential for achieving near-zero emissions of air pollutants and GHG emissions as well as the diversification of the transport sector away from its present heavy reliance on gasoline. The hydrogen fuel cell vehicle is one technology that offers the potential to achieve all of these goals, provided that the hydrogen is derived from a renewable energy source.

Fuel cells are not, *per se*, a new energy source, but are a new form of primary energy conversion devices. Fuel cells convert hydrogen and oxygen directly into electricity. They have three major advantages over current internal combustion engine technology in the transport sector. The first advantage is the gain in energy efficiency. "Well to wheels" efficiency for gasoline engines averages around 14 percent, for diesel engines 18 percent, for near-term hybrid engines 26 percent, for fuel cell vehicles 29 percent, and for the fuel cell hybrid vehicle 42 percent. Thus, up to a three-fold increase in efficiency is available relative to current vehicles. The second advantage of fuel cells is their very low emission of air pollutants. Regardless of the type of fuel used, fuel cells largely eliminate sulphur and nitrogen oxides and particulates that are associated with conventional engines. The third advantage is the negligible emissions of GHGs.

Prototype fuel cell buses powered by liquid or compressed hydrogen are currently undergoing field trials in North America, while the European Union is supporting the demonstration of 30 fuel cell buses in 10 cities over a two-year period, which commenced in 2003. In addition, the United Nations Development Program Global Environmental Facility is supporting a project to demonstrate the technology using 46 buses powered by fuel cells in the heavily polluted cities of Beijing, Cairo, Mexico City, New Delhi, Sao Paulo, and Shanghai.

There are a number of reasons why hydrogen in compressed form seems to be a likely option for large vehicles, such as buses. Large vehicles return regularly to a depot, thus minimizing fuel infrastructure requirements, their large size minimizes the need for compactness of the technology, and they operate in urban areas, so low or zero emissions vehicle pollution regulations will assist their competitiveness as compared with diesel-powered buses. Additionally, subsidies may be available from urban authorities in order to demonstrate urban pollution reduction commitments. Hydrogen buses also avoid pollution problems related to diesel buses and operate almost continually over long periods, making them attractive fuel-efficient technology.

Fuel cell cars are currently being developed by all of the world's major automobile companies, but there are significant obstacles to their widespread adoption within the foreseeable future. Briefly, these include the relatively high cost of fuel cells in the absence of economies of scale in production, on-board storage space of hydrogen, the lack of a hydrogen-refueling infrastructure, and public perceptions with regard to the safe use of hydrogen. Nevertheless, concerns relating to the security of oil supplies have encouraged the governments of many developed nations to invest significant resources into hydrogen research to overcome these shortcomings as soon as practicable.

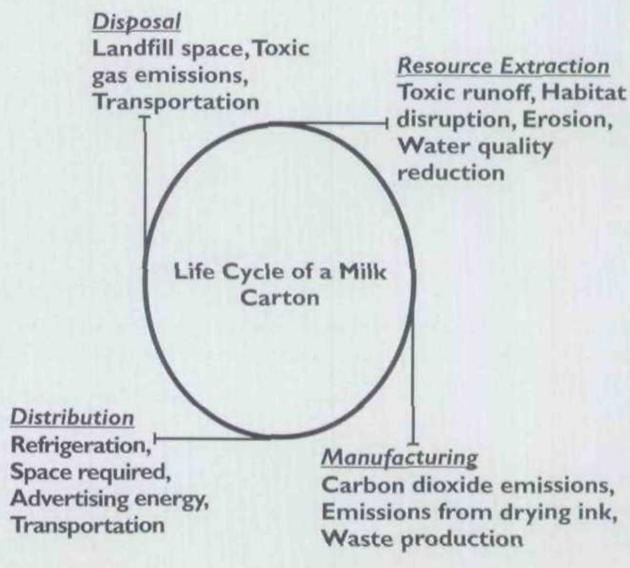
Electricity Sector

Currently, coal and gas technologies exhibit a clear absolute cost advantage over the bulk of currently available renewable technologies (with the exception of some hydro, geothermal, and biomass applications) in electricity generation, although "best performance" wind power has recently approached similar cost levels. The cost gap between renewables and conventional technologies has been narrowed significantly over the past two decades—a process that is expected to continue into the foreseeable future. However, significant policy actions to increase investment in research and development and to stimulate economies of scale in production and dissemination of renewables will be required if environmental commitments on global climate change are to be met in any major way over the next decade.

Distributed generation technologies are generally viewed as the most desirable option for the future. They directly produce power on a customer's site or at the site of a local distribution utility and supply power to the distribution network at distribution-level voltages. In this system, the requirement for transmission, with its associated energy losses and visual pollution, is removed. Although individual unit-generating capacity is usually small, individual units account for a significant proportion of total power supply in many parts of the world. Most distributed generation systems in commercial operation today consist of diesel and natural gas reciprocating engines and gas turbines. These are likely to dominate in the short term. However, some

MILKING ITS WORTH

Beginning with resource extraction, the diagram below depicts the life cycle analysis of a milk carton. Life cycle analysis is a method to determine the environmental impact of a product throughout the course of its existence.



http://www.pac-it.org.nz/

renewable technologies, particularly those that are solar-based, can be deployed in a distributed modality. By 2020, the International Energy Agency anticipates that as the cost of fuel cells falls, fuel cells may emerge as the predominant generation technology.

Fuel cells have a number of advantages over conventional power generating plants in electricity markets characterized by increasing competition and environmental regulations. The advantages include high thermodynamic efficiency, low air pollutant emissions, and quiet operation. Due to higher efficiencies and lower fuel oxidation temperatures, fuel cells emit less carbon dioxide and nitrogen oxides per unit of power generated. This makes them ideal for application in areas where there are stringent emission standards in force. Additionally, because fuel cells have no moving parts (except for those that are a necessary part of any power-producing system), noise and vibration are practically non-existent and maintenance requirements are low. Negative impacts are a high initial cost and short operating life, in addition to the general lack of operating experience with the technology. The lack of operating experience is particularly significiant in the context of the recent deregulation of the power industry in many countries where private companies may be deterred from making high-risk investments.

Cuba's oil field pumps are part of the country's attempt to find domestic reserves to rid itself of dependence on foreign, and largely Venezuelan, oil.

Security of Energy Supply

The economic, environmental, and social objectives of sustainable development policies require secure energy supplies. The economic and social implications of breakdowns in the energy delivery system can be very severe. There is a marked asymmetry between the value of a unit of energy delivered to a consumer and the value of the same unit not delivered because of unwanted supply interruption. Given that it is difficult and expensive to store energy, interruptions or threats of interruptions can swiftly lead to widespread disruption. The lack of resilience of energy systems to extreme events is a major problem confronting industrialized societies.

Energy security is widely perceived as being a public good that is the responsibility of governments. Without government intervention, it may be argued that market imperfections would lead to an under-provision of security. In extreme cases, such as acts of terrorism, this is clearly true. However, risk is an intrinsic factor in all markets and prices should generally incorporate consumer's willingness to pay for different levels of exposure to risk.

From a fuel security viewpoint, renewable energy technologies bring significant additional advantages that are not generally quantifiable because most renewable energy technologies supply comes from "local" sources. Conversely, fossil fuels must be transported to their point of combustion, sometimes over large distances, thus raising issues of security of supply lines. While the supply security "premium" will differ for different fuels and different end uses, the availability of alternative fuels would deliver a substantial premium for gasoline use in the transport sector.

The current interest in a "hydrogen economy" derives from the fact that, at this stage of human development, hydrogen is regarded as the ultimate "fuel" for the 21st century. Provided it is derived from renewable sources, it has near-zero emissions of both local pollutants and GHGs when used with fuel cells. Moreover, all of a country's hydrogen requirements could be met by domestic sources, removing supply security concerns of fuel importation and the costs of holding stockpiles. Finally, fuel cells and hydrogen can be used for distributed power generation, thus avoiding centralized electricity generation and transmission costs, as well as their associated environmental externalities. ■

Photo Courtesy AFP/Getty Images