SOCIETY AND ENERGY BY 2025

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ABSTRACT: This article presents a vision of how the energy sector might progress over the next 15 years or so, together with an examination of the broader socio-political problems that need to be addressed if renewable energy is to fulfil its potential on this time-scale.

Keywords: Greenhouse gases; Fossil fuels; Electricity generation; Energy conservation and storage; Renewable energy**.**

RESUMO: Este artigo apresenta uma antevisão de como o sector energético poderá evoluir nos próximos 15 anos, bem como uma apreciação dos problemas sócio-políticos globais a solucionar se o potencial das energias renováveis se desenvolver neste período.

Palavras chave: Gases de estufa; Combustíveis fósseis; Produção de electricidade; Conservação e armazenamento de energia; Energias renováveis.

1. INTRODUCTION

Attempting to predict the future is notoriously difficult and anyone who does so is providing a hostage to fortune. In 1965, Penguin Books published *The World in 1984*, a paperback that was based on a series of articles that had appeared in *The New Scientist* in 1964. These articles were written by eminent scientists and industrialists of the day, who were asked to predict the likely developments 20 years ahead in their respective fields of specialization. Re-reading this fascinating book today, two general conclusions emerge:

(i) there was much optimism over how quickly new technology might evolve – almost 45 years on, some of the developments are still awaiting realization, for instance: the widespread use of supersonic jets for long-haul flights and electricity generation by magnetohydrodynamics;

(ii) some of the really important advances that have subsequently taken place were not foreseen at all, e.g. integrated circuits, micro-processors, and the world-wide-web.

Notwithstanding these two generalizations, the various contributors showed good foresight, even if some of the timings were incorrect. History has shown, however, that elsewhere there have been some disastrously wrong forecasts by eminent ‘authorities’, for example:

> *“The ’telephone’ has too many shortcomings to be seriously considered as a means of communication.”*
> Western Union internal memo, 1876.

> *“Aeroplanes are interesting toys, but of no military value.”*
> Marshal Foch, 1911.

> *“I think there is a world market for maybe five computors.”*
> Thomas Watson, Chairman of IBM, 1943.

With respect to energy sustainability, the predictions have been uniformly poor. In 1920, geologists forecasted that the world’s petroleum reserves would be exhausted by 1940. What they failed to anticipate were the major developments in the technology of prospecting that resulted in the discovery of many more oil fields, both on-shore and off-shore. Similarly, in 1971, the ‘Club of Rome’ commissioned the use of large computer models to map out the future of the world. The resulting report – *The Limits to Growth* – became an international cause célèbre that sold nine million copies in 29 languages. It was concluded that the world would run out of petroleum in 1992. Again this did not happen, thanks largely to further improvements both in prospecting methods and in the technology for exploiting oil fields on the continental shelf. Huge new supplies of natural gas were also discovered, which were not expected and subsequently assumed many of the roles formerly played by petroleum, e.g. space heating and electricity generation.

Predicting the future supply and demand for energy and associated advancements in technology is difficult enough in a stable world situation. It is made infinitely more difficult by the intrusion of global political issues such as: the nationalization of Middle East oil fields in the 1970’s; the imposition of embargoes and sanctions directed against export to (or import from) specified nations; the Organization of Petroleum Exporting Countries (OPEC) quasi-cartel; the problem of global warming and the Kyoto Protocol; and now, in the 21st century, the fear of global terrorism. When all of this is considered, looking ahead – even for 15 years – lies more in the realm of crystal-ball gazing than of science.

Nevertheless, this is no reason not to try. Accordingly, the prospects and challenges for world energy in 2025, without claiming any greater insight than many others may have, are presented here.

One of the incontrovertible facts is the growth in the world's population: two billion in 1939, over six billion today, and heading for 9 or 10 billion before it stabilizes, even if it does then. Associated with this is the ever-growing aspiration for an improved standard-of-living for all, especially for the developing and poor nations. Globalization is slowly bringing this about following the decision of manufacturing industries (and now, given the improvements in telecommunications, also service industries) to move their operations to low-cost countries. Globalization is, however, a controversial issue and whether it will provide true benefits for all remains to be seen. Experience has shown that there is a direct correlation between standard-of-living (or Gross National Product per head) and energy consumption. Unless this link can be broken, the demand for more energy will grow inexorably. If the increased requirements were to be met by the world's 'energy capital' (fossil fuels), the consequences in terms of global emissions of greenhouse gases and resource depletion would probably be catastrophic. Clearly, over the coming decades, it is necessary to implement an entirely new energy infra-structure. In the near-term, this is likely to entail the clean-up of fossil fuels so as to minimize both pollution and the release of greenhouse gases. The sequestration of carbon dioxide at power plants would be an important medium-term development, if this could be achieved economically. In the longer term, an energy future that depends on sustainable sources will be required. Bearing in mind the enormous difficulties and the long-time scale that would be involved in replacing the entire conventional energy system, not to mention the daunting magnitude and cost of the task, it is not too soon to be addressing the matter seriously. This is one of the major issues facing the world today, but one that tends to be relegated to the 'pending' tray by politicians occupied with more pressing geo-political and social issues, and by industrialists concerned with making a profit and staying in business. It is up to those who are scientifically and environmentally aware, especially a new generation of well-educated young people, to take up the challenge of creating a sustainable energy future for generations yet to come.

2. GREENHOUSE GASES

When considering 'global warming', three facts seem incontrovertible [1-8]:

(i) there are certain gaseous molecules in the atmosphere (including carbon dioxide, methane and nitrous oxide) that absorb and re-radiate infrared radiation – the greenhouse gases;

(ii) the concentration of carbon dioxide in the atmosphere has increased steadily since the industrial revolution;

(iii) the mean global temperature is rising slowly.

Most authorities link these three facts and conclude that the temperature rise is a consequence of the anthropogenic release of greenhouse gases. While there is a compelling reason to make this link, it is by no means proven beyond all doubt. Another greenhouse gas is water vapour, which is more potent than carbon dioxide. The effect of water vapour is well known. One has only to compare the night-time temperature on a cloudless, starry night in winter with that on an overcast night to experience the effect of water vapour in absorbing infrared radiation. Even in the Sahara Desert, when there is no cloud cover, the nights can be very cold. It is at least arguable that the observed global warning is a consequence of a natural long-term trend towards more atmospheric water vapour. This, in turn, would lead to slight warming of the oceans with greater release of carbon dioxide that would increase the anthropogenic gases in the atmosphere. There is still much to be done in elucidating the mechanism of global warming, and the relative contribution to natural phenomena and man-made releases, but the following discussion is based on the premise (on which we have an open mind) that the majority view is correct and that carbon dioxide formed in combustion processes is the principal culprit responsible for global warming.

In 1992, the United Nations Conference on Environment and Development –better known as the 'Earth Summit' – met in Rio de Janeiro and adopted the United Nations Framework Convention on Climate Change (UNFCCC). Article 2 stated an aim 'to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. Unfortunately, nobody was able to define the level of greenhouse gases that would constitute 'dangerous interference'. Consequently, no targets were set. This issue was addressed at a subsequent meeting in Kyoto in 1997 and the industrialized nations of Europe, Japan and the USA were required to reduce their average national emissions of greenhouse gases over the period 2008-2012. The targets were based on the historical emissions that took place in 1990, less an agreed percentage. As part of the Protocol, it was envisaged that a system of 'emission trading' would be set up, whereby nations or companies wishing to exceed their allocation of emissions would be able to purchase permits from other license holders who had allowances surplus to their requirements. The environmental outcome would not be affected because the amount of permits allocated would be fixed.

In the seven years that have elapsed since Kyoto, there has been an increasing awareness of the difficulty in meeting the targets. To give just one instance, by December 1999, emissions in the USA had risen 12% above 1990 levels, and were on course to increase to 20-25% above 1990 levels by 2008. Adding to this the 7% reduction that the USA is required to make, the total cut required approaches 30% in the next four years. Bearing in mind the long economic life of the major energy consumers (e.g. power stations, buildings, road vehicles), the magnitude of the task becomes apparent. Indeed, it is said that 80% of the electricity-generation plant that will be in use in 2010 is already built. Premature replacement of all less-efficient plant would cost huge sums of money and this simply is not going to happen on such a short time-scale. The costs are politically unrealizable.

To solve this dilemma, the USA and other industrialized nations are relying heavily on purchasing emission permits. It has been suggested that Russia and the Ukraine, among others, may hold permits surplus to their requirements. The details of how such an emission-trading system might work are starting to emerge. Even within a single nation, there is the difficult question of how the government should apportion its national permit for emissions among industry, commerce, and individual citizens. An emission permit is, in effect, a property right that may be bought and sold. Companies and individuals will be anxious to maximize the financial benefit for themselves and there is scope for endless argument. Powerful negotiators will benefit at the expense of the less skilled, and a system of arbitration and appeal will be needed. A further complicating factor is that the emissions from a nation vary with economic growth and with technological changes, neither of which can be planned or controlled by governments to meet targets set years in advance.

Trading of emission permits between nations is likely to be even more fraught with difficulty. It has been estimated that, internationally, permits worth a trillion dollars or more would be required, and even then there is no guarantee that the Kyoto targets would be met. Many developing nations were not allocated targets, and it is precisely in these countries that the rate of energy consumption is increasing most rapidly. The Protocol has made no provision for how future targets are to be allocated, or for the monitoring and enforcement of emission trading. Ultimately, it will be necessary to have an international judicial body to enforce compliance, but international law is too weak at present to take on this task effectively. Inviolate targets and time-scales are simply not practicable to enforce in the light of changing circumstances. And meeting the Kyoto targets is just the first step along the road halting the build-up of carbon dioxide in the atmosphere.

From this brief discussion, it will be clear that there are major political, economic, technical and legal issues to be faced before an effective system for trading emissions will be in place. The situation has all the hallmarks of a bureaucratic nightmare and we very much doubt that it will be completed by 2010 or even by 2015, unless the deterioration of Earth's climate is so dramatic that minds will be focused away from disputes over property rights. A more straightforward approach would be to impose a heavy tax on all fossil fuels (a 'carbon tax') to pay for the 'externality' of polluting the atmosphere. Given that other wastes have to be recycled, processed or contained, in principle there is no reason why society should feel free to discharge waste carbon dioxide in the atmosphere without payment. This raises the question of what level of taxation should be imposed. As there is great uncertainty over the real external cost to the environment per tonne of carbon dioxide released, it is difficult to approach the question from this angle. A better method might be to allocate some of the tax raised to measures that are designed to promote energy conservation and renewable forms of energy. The remainder could be offset against existing taxes (such as general sales and services levies) so that the overall rate of taxation is not greatly changed. This should go some way to modify the taxpayers, although obviously there will be winners and losers.

If global warming and the role played by greenhouse gases are as serious as many believe, then international action becomes a matter of priority [9-13]. A carbon tax has the benefit of being immediate and would provide the incentive for industry to develop forms of energy conservation and renewable energy that are not competitive at today's low prices for fossil fuels. The carbon tax might start at a relatively low level and rise, year by year, according to a pre-published schedule. This would allow time to adjust to evermore costly fossil fuel and to develop new energy technologies. Such a procedure is already in force in the UK for the disposal of municipal waste by landfill, where the tax imposed rises progressively year-by-year from £7 per tonne in 1996 until it reaches £15 per tonne. This seems to be a better approach than attempting to formulate emission targets years in advance and then setting up monitoring and enforcement agencies. There are, of course, strong political voices against fuel taxes, the road haulage and motorist lobbies are vociferous, while even the poor need to keep their homes warm in the winter.

3. ENERGY CONSERVATION

When looking ahead to 2025, it is obviously important to mention the role that conservation will play in modifying the demand for energy. There are considerable opportunities for energy savings in almost all spheres of human activity.

3.1 Space Heating in Buildings

In temperate climates, many buildings are poorly insulated and wasteful of energy, both for winter heating and summer cooling. Old houses are usually built of stone (a good thermal conductor), or of brick, without any significant insulation. For example, it is only in the last 30 years that double-glazing and cavity-wall buildings are generally found in coldest countries – Scandinavia, Canada, Russia. If buildings in temperate zones were insulated to the same high standard, the fuel consumption could be substantially reduced. Indeed, experimental homes designed to high standards of insulation have demonstrated that in such regions it is possible to dispense almost entirely space heating, and rely on the heat generated by the 'occupants' bodies and by their domestic appliances.

One of the problems of well-insulated buildings is that it is necessary to arrange for several exchanges of air each hour [14-17]. This is generally effected by means of exhaust fans, particularly in kitchens and bathrooms. Unfortunately, these fans extract warm air and replace it with cold. Thus, there is a clear need for inexpensive heat exchangers so that the exhaust air is cooled and the fresh air is preheated and humidity controlled. This is not a trivial task since the temperature differential is generally small. Also, the present low cost of energy does not provide a financial incentive to adopt such measures.

In many countries, there have been significant improvements in the energy efficiency of domestic appliances. Refrigerators and freezers are now labelled for their energy consumption, as are clothes and dish washers. Modern condensing gas boilers, used for central heating, extract most of the waste heat from the exhaust gases and transfer it to the incoming cold water. They are, therefore, more efficient in the utilization of energy.

There are also the options of the passive solar heating of buildings, active solar heating of domestic hot water and geothermal heat pumps, all of which serve to reduce the energy demand [18-20]. Just which of these are adopted in any particular situation is a matter of economics. If the price of fuel rises, as expected within a 20-year time-frame, there will be more financial incentive to reduce energy consumption in the home [21-24].

3.2 Lighting

Traditional incandescent filament lamps are notoriously inefficient, much of the energy being dissipated as heat. This is important when it is recalled that 25% of the world's electricity is used for lighting. Fortunately, by no means all of this electricity is used inefficiently in filament lamps. Fluorescent tubes play a major role, particularly in industry, commerce and street lighting.

There have been significant improvements in lighting in recent years [25-27]. The light output of fluorescent tubes has been enhanced by the development of new phosphor coatings. Compact high-energy lamps are becoming commonplace; a 20-W lamp gives the same light output as a 100-W incandescent filament lamp and lasts much longer. If all the traditional filament lamps in the world were replaced by high-efficiency lamps, or by fluorescent tubes, there would be a massive saving in electricity. In the longer term, there are good prospects for light emitting diodes (LEDs) to replace conventional lighting, but this will require substantial improvements in performance and reductions in cost. Red LEDs are already used in some traffic lights and in car brake lights. With the advent of gallium nitride based LEDs, which emit in the blue or green, there is a possibility of replacing the hundreds of millions of traffic lights around the world with LEDs to reach large savings in electricity consumption. New advances in photochemistry and in photoelectrochemistry [28] hold out the prospect of even more efficient forms of lighting.

3.3 Transportation

It has been estimated that between 2000 and 2025 the world population will grow from 6 to 8.5 billion (42% increase). Most of this growth will be in developing countries, where there is huge unfulfilled demand for private cars. On this basis, the Fiat Motor Corporation has projected that over the same period the global fleet will increase from 0.7 to 1.75 billion. If this demand is to be met, it will be necessary to conserve liquid fuels for transportation and there will be a requirement for vehicles that are much more fuel-efficient than at present. Also, there will be a need to exploit non-traditional sources of fossil fuel [29-31]. Of course, such predictions of the increase in the vehicle numbers neither take account of whether the Earth's atmosphere can absorb the carbon dioxide, nor of the outcome of the Kyoto Protocol negotiations.

For a new technology to succeed in the marketplace, it must not only be sound and appeal to the customers, but must also be backed by major industrial muscle and finance. The Japanese have demonstrated this point well with motor-cycles, cameras, and consumer electronics. Given the sizable effort that many automotive companies are now putting into electrochemical and electric drive-trains, there are good prospects that hybrid electric vehicles (HEVs) and perhaps even fuel-cell vehicles (FCVs) [32-33] will become commonplace throughout the world by 2025. This should make a significant contribution to energy savings in the transportation sector and will assist in the reduction of emissions of carbon dioxide and other harmful gases.

Aside from technical advances in the design of vehicles to enhance fuel efficiency, the greatest single improvement would be achieved by substituting public transport (mass transit) for private cars, particularly to travel into the city. Already in major conurbations (London, New York, Tokyo) more people travel to work by bus and rail than by private car. As public transport facilities continue to improve around the world, and as cities become even more grid-locked with traffic, it is likely that this trend will increase.

London has short-term plans to purchase 200 more buses and long-term plans to upgrade its underground system. A congestion charge has already been imposed on motorists coming into the central business district; other UK municipalities are actively contemplating similar action. Many urban communities across the world have introduced 'bus lanes' to give priority to these vehicles. These lanes, in conjunction with 'park and ride' schemes, facilitate access to city centers. Some authorities also give priority to passage to cars with more than one occupant; this encourages 'car pooling', and thereby saves fuel. Finally, with the construction of safe routes, more people are returning to cycling. The Scandinavian countries and the Netherlands have set good examples in this regard. All these are moves in the right direction to remove traffic jams, make cities more accessible, and reduce both fuel consumption and urban pollution. For Europe, this is a move back towards the 1940's and 1950's when the population was only a little less than it is today, when most people went to work by public transport or by cycle, and there were comparatively few cars so the roads were less congested.

The extent to which the motorcar can be replaced by public transport in the short term is generally limited by the distribution of the population. For many, it is impossible to get to work by bus or train, and often this is through conscious choices that they have made, either in where they have bought a house or taken employment. In recent years, people have been willing to drive long distances to work rather than move home or job. Indeed, compared with having a congenial place to live and a desirable occupation, commuting by car has assumed secondary importance for many individuals. At the same time, developments in electronic communications will mean that more people can work from home, at least for part of the time, and not to have to travel daily. In large cities, the choice is clear; either private cars are excluded from city centers, or admission fees imposed at a sufficiently high rate to dissuade drivers from using their cars. Both approaches depend upon the existence of acceptable 'park and ride' schemes. The alternative is gridlock – when, ultimately, many commuters will give up driving in disgust or engage in political protest.

In the field of car design, it is foreseen a movement away from advertising peak performance to that of fuel economy.

This view is based on the assumption that petroleum prices will rise significantly in real terms over the next 20 years. There is also the prospect of an increasing proportion in real terms over the next 20 years. There is also the prospect of an increasing proportion of diesel-engined vehicles on the road, because of their greater fuel economy, and of vehicles fuelled by liquefied petroleum gas (LPG), because of their cleaner exhaust (and, at present, the lower tax in some countries). The move towards diesel engines will be given a further stimulus when viable particulate traps have been perfected for cars, as well as for buses and trucks. It will be interesting to see whether the USA follows Europe in marketing diesel-engined cars and light-goods vehicles. This is only likely if petroleum prices in the USA rise nearer the European levels and, thereby, provide the incentive to make the shift. At present, the desire, in the USA and else-where, for sports utility vehicles poses a particular problem of heavy fuel consumption. Hopefully, the popularity of these vehicles will decline as petrol prices climb so that 'gas-guzzling' vehicles will become comparatively few in number.

As discussed above, another probable development in road transportation will be the widespread introduction of the HEV, and maybe also the battery electric vehicle (BEV) for urban use [34-35]. The HEV will allow smaller and more efficient engines to be fitted without any reduction in vehicle performance. The BEV may not save much primary energy, but will effect a switch from petroleum to electricity, which can be generated from different primary fuels. It is envisaged that by 2025 many private cars will have some form of electromechanical (HEV) or battery (BEV) drive. By that time, most family-sized cars should return at least 60-80 mi per gallon of fuel (3.5-4.7 L per 100 km). These developments will be driven not only by considerations of fuel economy, but also by local authorities choosing to follow the pattern of Southern California and introducing regulations to reduce urban pollution.

The future of FCVs is still very much open to question. There are difficult technical problems to be solved, but progress has been made by the major automotive companies who are now taking the concept of the hydrogen FCV seriously. The principal challenges remaining are those of reducing cost to an acceptable level, ensuring reliability and lifetime, deciding which fuel is to be used and whether an on-board reformer is required. If a reformer is necessary, then it has to be well integrated with the fuel cell (for good thermal management and for producing hydrogen at the required variable rate), small and inexpensive. Should hydrogen be employed directly, then there is the question of on-board storage to be resolved, as well as the establishment of a supply infrastructure. There is also the cold-start problem and the need to eliminate impurities from the hydrogen. On the whole, people are inclined to be pessimistic about the rate of developing this technology for private cars, as a competitor to diesels and HEVs, and therefore do not expect to see a major swing to fuel-cell cars by 2025. Even so, one must recognize the dedication of many major automotive companies to the technology, and the power and influence they can bring to bear on the topic. It is possible that they may prove our pessimism to be unwarranted. If FCVs are indeed introduced in significant numbers during this period, it is more likely that they will be buses or trucks, where space to accommodate the power plant and the hydrogen store is not so restricted, and where generally longer journeys are involved.

In principle, the hybrid concept is equally applicable to railway locomotives. By having an electric hybrid locomotive, it would be possible to fit a smaller and more efficient engine that would run at constant speed and release less pollution. The problem here is that locomotives have a much longer service-life than cars, so it will take years to replace the existing stock, even after the concept has been proved in practice.

In the field of air transport, the recent trend towards quieter aircraft with lower fuel consumption will doubtless continue. There are plans to build even larger passenger aircraft than at present, with a view to reducing the operating cost per seat-kilometer. How enthusiastically the public would take to such behemoths of the skies remains to be seen.

4. FOSSIL FUELS

Fossil fuels or mineral fuels are fossil source fuels, that is, carbon or hydrocarbon found in the earth's crust.

Fossil fuel range from volatile materials with low carbon: :hydrogen ratios like methane, to liquid petroleum, to non-volatile materials composed of almost pure carbon, like anthracite coal. Methane can be found in hydrocarbon fields, alone, associated with oil, or in the form of methane clathrates. It is generally accepted that they formed from the fossilized remains of dead plants and animals by exposure to heat and pressure in the Earth's crust over hundreds of millions of years. This biogenic theory was first introduced by Georg Agricola in 1556 and later by Mikhail Lomonosov in 1757.

It was estimated by the Energy Information Administration that in 2006, 86% of primary energy production in the world came from burning fossil fuels, with the remaining non-fossil sources being hydroelectric – 6.3% , nuclear – 6.0%, and other (geothermal, solar, wind, wood and waste – 0.9%.

Fossil fuels are non-renewable resources because they take millions of years to form, and reserves are being depleted much faster than new ones are being formed. Concern about fossil fuel supplies is one of the causes of regional and global conflicts. The production and use of fossil fuels raise environmental concerns. A global movement toward the generation of renewable energy is therefore underway to help meet increased energy needs.

The burning of fossil fuels produces around 21.3 billion tons (21.3 gigatons) of carbon dioxide per year, but it is estimated that natural processes can only absorb about half of that amount, so there is a net increase of 10.65 billion tonnes of atmospheric carbon dioxide per year (one tonne of atmospheric carbon is equivalent to 44/12 or 3.7 tons of carbon dioxide) [36].

4.1 Petroleum

World petroleum prices are generally low in historic terms, thanks to the opening up of new oilfields in Nigeria, around the Caspian Sea, and elsewhere. At present, the supply of oil exceeds the demand, and this situation is expected to persist in the short term. There is, however, always the danger of prices collapsing completely, particularly if Iraqui oil is produced in abundance. The market for oil is extremely inelastic and, as has been seen in the past, small shortfalls in supply can lead to rapidly escalating prices, while over-production results in an equally sharp decline is the spot price. The problem facing oil-producing nations is that each individually wishes to maximize its income by exporting as much oil as possible, but if all do this collectively there is a glut and the price falls sharply. It was for this reason that OPEC was set up in the 1970's, to act as a quasi-cartel and to control the price of the crude oil by allocating supply quotas to each of the participating countries. This strategy has been only partly successful. From inception, OPEC has faced the dual problem that not all of the prospective members have joined and that new producers have come on line in recent years. The latter are not constrained and may produce as may oil as they choose, or regard as prudent. The consequence of low oil (and gas) prices is that the bulk energy is cheap and there is little financial incentive to invest in new technology for non-conventional forms of energy. Over the past 30 years, however, the price of crude oil has fluctuated wildly from less than US$ 10 to US$ 40 per barrel. By contrast, OPEC would like to stabilize the price in the range US$ 20-25 per barrel, which would provide some reassurance for consumers as well as producers. Nevertheless, as long as the possibility of a short-fall exists, whether politically inspired or otherwise, future high prices cannot be ruled out. For this reason, if for no other, it is prudent for oil-importing nations to be developing alternative energy and transportation technologies. It is salutary to note that, at US$ 20, the cost of a barrel (159 L) of crude oil is of the same order as the retail price of 1 L of whisky, and whisky did not take geological time to mature !

There is, of course, a close interaction between the technology employed in discovering and producing oil and the size of the reserves available. In the 1920's, a Hungarian physicist, Baron von Eötvös, developed a device for detecting slight changes in gravitational attraction. This led to the discovery of the huge oil reservoirs of Texas and Oklahoma, and to many others since. Then, in the 1940's and 1950's, off-shore exploration and drilling were carried out in the shallow waters of the Gulf of Mexico. As off-shore technology improved, it became possible to look for oil in deeper water and in rougher seas, which led to the development of the North Sea oil and gas fields. By building on this expertise, and using further technical advances in oil pros-pecting such as 3D seismic analysis and horizontal drilling techniques, oil companies are opening up more off-shore fields around the globe. Greater scientific understanding of the structure of sedimentary basins, and of the interface between oil droplets and the porous rock, has resulted in dramatic improvements in rate of oil recovery, as well as the quantity obtained before a well is no longer economically viable. Much of this technology is now mature, but there is no reason to believe that further research and development will not lead to improved techniques for the exploration, drilling and recovery of oil. Although society should not be complacent about the future availability of oil supplies, especially in the face of political uncertainties and growing demand, neither should it rely upon shortages of petroleum in the period to 2025 to drive the alternative energy scenario.

Another aspect of the developed world's almost total reliance on oil and gas is that individual countries or regions are vulnerable to interruptions in supply caused by factors quite distinct from resource availability. Such factors might include unusually severe weather, war or terrorism, mechanical breakdown or fire at the refinery or power station, and industrial action by operatives or delivery drivers. Disruption through industrial action has already been experienced in the UK – in 1974, when a general strike in coal mines had a major impact on the electricity generation industry; and again in September 2000, when a strike of petroleum tanker drivers disrupted supplies of fuel to service stations. On such occasions, the public becomes acutely aware of its dependency on fossil fuels for all aspects of modern life. Similarly, there have been occasions in France and the USA when supplies have been disrupted locally and have led to long 'gas lines' at service stations. With these experiences in mind, security of supply is an important consideration; diversity of energy type and source enhances this security.

With regard to oil supplies, it is worth observing that much of the world's crude oil has to pass through two narrow straits on its way to market. In 2000, 15.5 million barrels per day passed through the Strait of Hormuz and 10.5 million barrels per day through the Strait of Malacca. The latter is only 0.5 km wide at its narrowest point and carries 10 000 tankers (oil or liquefied natural gas) annually. Any obstructions of these two seaways, whether as a result of accident, natural disaster or political action, would constitute a major disruption to energy supply.

Since the USA has been obliged to import oil, its consumption pattern has changed radically. Before the 1970's, 20% of the US electricity was generated from petroleum; now it is less than 10%. Today, most of the output from the US oil refineries is used in the transportation and chemical sectors of the economy. This is a trend that is likely to occur worldwide and, by 2025, it is expected that most of the liquid fuel will be consumed in these two sectors.

One of the problems for any new energy technology in competing with fossil fuels is that the users of the latter are not generally required to pay for the cost of disposal of the products of combustion. Carbon dioxide is a greenhouse gas but, as noted above, there are at present few restrictions or cost penalties on releasing it to the atmosphere. Contrast this situation with that of nuclear electricity where the radioactive waste has to be stored in perpetuity by, and at the expense of, the generating company. Clearly, this is unfair competition. A carbon tax would go some way towards this imbalance, and it seems possible that such a tax will be imposed in the next 20 years, at least on the major fuel users. The level of tax will be determined by political considerations rather than by cost estimates of the externality. As a very small step in this direction, vehicles in the UK are now taxed on the basis of the amount of carbon dioxide they emit. This is an inducement to purchase smaller cars with more efficient engines.

4.2 Natural Gas and Liquefied Petroleum Gas

Natural gas is attractive since, among fossil fuels, it liberates the lowest amount of carbon dioxide per unit heat produced.

Several factors are contributing towards its greater use in industry, in commerce and in the home for space heating:

- discoveries of massive amounts of gas have been made in many parts of the world, both on land and off-shore;
- gas pipelines have been laid to bring supplies to centres of population;
- as a medium for heating, it is clean, convenient, and cheaper than liquid fuels;
- the user does not require a storage tank.

Wherever natural gas is available, it will be preferred to liquid fuels for heating. Over the next 20 years, we expect to see this trend accelerate as natural gas is brought to more people around the world. More long-distance pipelines will probably be laid, for instance from Russia and some of the former Soviet republics to Western Europe. A pipeline already exists under the Mediterranean Sea from North Africa to Europe and, in due course, this might link up with one from the West African oil and gas fields. Where distances are too great, for instance to supply gas to Japan and Korea, there will be an expansion in the shipment of liquefied natural gas, which is fast becoming a major item of commerce [37].

It can also be anticipated a continuation in the move towards using more natural gas to generate electricity, both centrally in large power stations and locally in combined heat and power (CHP) schemes. Centrally, the driving factors are the high efficiency of combined-cycle gas turbines for electricity generation and the tightening restrictions on the liberation of sulfur dioxide from coal-fired power stations.

Finally, on a much more modest scale, it is envisaged a growth in the market for LPG, which is a clean fuel used traditionally for portable applications in leisure activities and, more recently, as a vehicle fuel. It appears likely that LPG will be employed more extensively as an automotive fuel, particularly in cities. In Europe, increasing numbers of service stations are installing LPG pumps and this wider availability of the fuel will encourage its greater use.

5. ELECTRICITY GENERATION

It seems inevitable that, by 2025, coal will still be the basis of much electricity generation worldwide. This is because some countries have large reserves of coal, but are short of other fossil fuels. Also, many large coal-fired power stations already exist and are expected to be still operating in 15 years time. The challenge faced by technologists and the business community is to reduce the emissions of sulfur dioxide and nitrogen oxides from these existing plants within a competitive cost framework. High-sulfur coal will become of very little value unless a low-cost method is found to remove the sulfur before combustion, or for trapping the sulfur dioxide released. At present, flue-gas desulfurization units (where fitted) impose a significant cost penalty on coal-fired power stations. Looking further ahead to a time when supplies of natural gas start to dwindle, the vast coal stocks will have to be used in an environmentally friendly fashion and therefore will require effective 'clean coal' technologies [38-40].

It is equally important that methods for the sequestration of carbon dioxide be found. Underground storage or disposal in the sea, for example, would require new utilities to be built near suitable reservoirs on the coast, otherwise a transport system would have to be established for the convenience of carbon dioxide, either by pipeline for the gas or by tanker for the liquefied form.

Gas-fired, combined-cycle, power stations are now preferred to those fuelled by coal, on the grounds of both higher efficiency and lower emissions. The extent to which such plants can be introduced depends on many factors such as: the availability of gas supplies; fiscal considerations of the cost of importing gas (where necessary) rather than using indigenous coal; political issues where coalminers' jobs are at stake; the matter of diversifying the fuel base of electricity to ensure security of supply. These factors will vary from nation to nation.

The growing dependence of Western Europe on natural gas imported from countries of the former USSR and from North Africa is a potential cause of concern. These sources involve very long transmission pipelines that carry massive quantities of gas and are open to disruption as a result of accident or sabotage. In the event of restricted gas supplies, the electricity industry would be the first to be rationed and priority would be accorded to domestic and commercial users. This would be decided on safety grounds. When gas supply is interrupted and taps are left open, air can back-diffuse into the line and lead to the possibility of an explosion. With millions of households this is a real danger, whereas professional users, such as electricity utilities, have safe shut-down procedures. The more dependent a nation is on imported gas for its electricity, obviously the more serious would be the consequences following the cessation of power due to gas shortage. Constructing gas-storage facilities might mitigate short-term disruptions in supply. One example would be to re-inject Russian gas into depleted North Sea gas fields as a large-scale store. With the benefit of hindsight, a better option might have been not to deplete gaseous resources so quickly in the first place ! The swing to gas-fired electricity plant has undoubted advantages in the short term, both economic and environmental, but may be storing up problems for the longer term.

Distributed generation should make a growing contribution to overall electricity supply during the next 20 years. Nevertheless, it seems that distributed generation and electricity derived from renewables (excluding hydroelectricity, which is already well established) will still constitute only a minor component of the worldwide production of electricity.

Another growth area in electricity generation will be that of CHP. Obviously, it makes sense to use, where practical, the waste heat associated with electricity generation. The rate of growth of this sector will be determined by cost considerations and by the availability of a suitable market for the heat. Whereas the quantity of heat that is potentially available from a 1 to 2 GW power station is huge, the distance over which it can be conveyed is limited. Thus, district heating is only a practical proposition in situations where the station is adjacent to a city. Moreover, installing district heating in a city is both capital intensive and highly disruptive. Although the overall efficiency of a CHP plant (electricity+heat) is high, the requirement to operate with exhaust gases at a higher temperature results in a reduced efficiency for electricity generation. For all these reasons, it is likely that CHP installations will be confined to relatively small distributed systems and not to large central power stations. Similarly, stationary fuel cells, if they come to pass, will almost certainly be relatively small units.

The largest uncertainty lies, by far, in the future of nuclear industry. Whether or not more nuclear stations will be approved and built is essentially a political question that is unlikely to be resolved until there is a consensus on the reprocessing of nuclear fuel and how best to store radio-active waste indefinitely. With so much public opposition to nuclear power, despite its record of reliable and safe operation in many countries, it may be difficult for governments to approve the construction of further nuclear stations. This situation will certainly vary from country to country and will be determined by a given nation's energy needs and resources, as well as the strength of public opinion. There is also the separate question of the large up-front capital cost and the long lead-time in constructing nuclear stations. Now that responsibility for electricity generation is moving from the public to the private sector in many countries, this may be a deterrent to further major investment. At present, then, the future of nuclear power is very uncertain, but by 2025 the issues should be resolved one way or the other and the industry will either be in terminal decline or in a growth phase where ageing plant is being replaced. The success (or otherwise) of the pebble-bed modular reactor may also be a pertinent factor. Countries that derive a high proportion of their electricity from nuclear sources (e.g. France) will have a particular problem when reactors reach the end of their life and have to be replaced.

On the horizon, there is the prospect of generating electricity by nuclear fusion. Steady research progress is being made in major laboratories and the next significant step will most probably be a single world demonstration project. Not even the most optimistic of proponents, however, see this technology contributing to world electricity supplies by 2025.

6. RENEWABLE ENERGY

It is anticipated that the harnessing of renewable energy will expand rapidly, in the light of widespread concern over global warming and the remedial actions that governments are taking. Despite such good intentions, however, there is every indication that, overall, renewables will still make only a modest contribution in 2025. It is vital, therefore, that society continued to develop the various technologies and gains experience in their operation as a step towards growth later in the 21st century [41-45].

Combustion technology – agricultural and forestry waste, municipal solid waste, energy crops – may make a useful contribution to energy supplies in many countries. Common factors that will limit its take-up will be the low cost of competing fossil fuels (unless carbon taxes are introduced), resource availability, the capital cost of constructing facilities and, in some instances, public opposition to the sitting of these facilities. In the case of agricultural and forestry waste, the scope for expanding operations is strictly limited by the resource availability and by the cost and the amount of energy consumed in collection. A further factor to be considered is that much of the biomass when left *in situ* decays and helps to enrich the soil. All new landfill sites will be expected to have gas collection and combustion facilities. It should be noted, however, that the recycling of consumer products is an important and growing trend that will reduce the amount of waste going into landfill and consequently will decrease the amount of combustible gas that is generated. Schemes for growing energy crops will face competition from those wishing to use the land for agricultural purpose or buildings. Moreover, there is a public perception that turning over agricultural land to energy crops is not a good idea. Similar conversion of traditional forest or wild land is also likely to meet some opposition, due to the concern over loss of biodiversity and damage to the eco-system through soil degradation and depletion of essential minerals. In addition, there is a strong case for planting more forests to sequester carbon dioxide, rather than cutting them down in infancy to burn. In Europe, the situation is made more complex by the controversial Common Agricultural Policy that effectively determines agricultural land use, but which will probably be modified as further countries join the European Union.

Energy crops may also be grown to produce bio-fuels (methanol, ethanol, bio-diesel), as well as for direct combustion to generate electricity. The economic incentive for alcohols as petrol extender depends on the competing cost of petroleum. If fuel cells assume a significant role in road transportation, then methanol is a candidate fuel. In the foreseeable future, however, it would appear that methanol will be manufactured from natural gas rather than from energy crops.

A final word of caution regarding energy derived from biomass. Renewable bio-energy is not necessarily the same as sustainable energy. Careful account must be made of the input of fossil fuel in the form of fertilizers, and also of petroleum for the machinery to harvest and convey the biomass to the processing plant. Furthermore, there may be environmental and social impacts in the growing and harvesting of crops that outweigh the renewable benefits.

Recalling that it takes hundreds of large wind turbines to replace one major power station, it is doubtful that wind energy, despite showing rapid growth in percentage terms, will become more than just a minor contributor to overall electricity generation. A particular problem with on-shore wind farms is that of gaining planning permission for construction. Experience has shown that nearby residents often form pressure groups to oppose the erection of large wind turbines, power lines and pylons in their 'backyard'. Off-shore wind farms are not so open to objection and significant numbers of turbines are being installed off the North Sea coast. Nevertheless, enthusiasts in the UK, who advocate the building of many thousands of such turbines over the next decade, have been taken to task in a report from the Royal Academy of Engineering. This emphasizes the severe engineering problems to be faced, as well as the impracticability and high costs, in harnessing wind energy to meet most of the UK target of 10% electricity from renewable energy by 2010 (note, existing hydroelectric supplies are not counted). By contrast, wind power is ideal for many isolated communities provided that there is a grid to provide back-up. Otherwise, it is necessary to install battery storage and this adds significantly to the cost. An alternative is to have a hybrid system that comprises a wind turbine and a petrol-driven generator.

Marine-based technologies (tidal flows, wave energy, ocean thermal energy) will have less of an impact. For example, it is unlikely that the capital investment required to build major tidal barrage schemes will be forthcoming in the next 20 years and, in any event, there are very few suitable sites. Tidal barrages are not necessarily confined to rivers with large tidal ranges, they can also be set up in shoreline lagoons that flood. Many potential sites are available around the coasts.

Tidal marine currents present an opportunity and there may be a few of these constructed to generate electricity, probably under government stimulus to help encourage renewables rather than as a result of direct commercial competition with fossil- or nuclear-generated electricity. Wave energy also requires substantial capital investment if it is to be implemented on a large scale. No doubt some small wave-energy machines will be built and demonstrated, but there are very unlikely to provide a significant source of global electricity in the near future.

Finally, there are the solar technologies. Solar heating of buildings and domestic hot water offers many opportunities, as discussed above. Solar photovoltaic (PV) generation of electricity has also made important strides in recent years as the efficiency of silicon PV cells has improved and their cost has fallen. Building-integrated PV panels appear to be the most economic way forward. By 2025 this technology may well be widespread in sunny climates, particularly in countries where fossil fuels have to be imported. Polymer PV materials and dye-sensitized photoelectrochemical cells are at an early stage of development, but success in these ventures could lead to a dramatic fall in the cost of such electricity. This is an exciting area of research that should be pursued vigorously. Moreover, solar panels based on these new materials could be brought to market rapidly, building on the skills and experience of the existing PV industry.

7. ENERGY STORAGE

The various physical and chemical techniques for energy storage will all continue to be investigated and developed [46-48]. Of the physical techniques, pumped hydro and compressed air energy storage are the most promising for peak-saving and load-levelling within the electricity supply network, provided the terrain and other conditions are suitable. For smaller-scale storage, further research will be conducted on flywheels and on electromagnetic and electrostatic devices. Of these, electromagnetic storage is too expensive for general use. Flywheels may prove suitable for some specialized uses, but we doubt that they will find substantial widespread application. Electrostatic devices (electrochemical capacitors) complement batteries in being high-power, low-energy devices and show considerable promise for use in hybrid systems.

Hydrogen energy, the so-called 'ultimate' form of energy, is the Holy Grail for environmentalists – clean, abundant, non-polluting. This dream has been around for over 30 years. The principle of producing hydrogen in an electrolyzer (using a renewable source of electricity), storing it as a chemical hydride, and regenerating the electricity in a fuel cell when needed, sounds attractive at first acquaintance [49,50]. The practice and the economics are a quite different matter. In the early days of the dream, cheap abundant nuclear power was to have been the most practical means of generating the hydrogen. As this no longer seems likely, it will be necessary to fall back on solar- or wind-generated electricity. The requirements for three separate devices (electrolyzer, hydride-store, fuel cell) merely to store and use small quantities of electricity is not at all efficient from an energy viewpoint. Such an approach would therefore be a gross misuse of renewable energy. Moreover, the activity would be capital intensive and there would be the added cost of the power-conditioning equipment.

We do not see hydrogen being produced from renewables on a significant scale in the next 20 years. Rather, hydrogen for fuel cells will be produced, as is now, from fossil fuels. Meanwhile, electrolyzers will continue to be used mostly for the production and processing of chemicals and metals, and for the life-support oxygen in submarines and manned spacecraft. Recently, the largest hydrogen production plant in the UK, based on natural gas and producing 32 000 t of hydrogen per year, has come on-stream at a chemical manufacturing site in the North Teeside. From the point of view of greenhouse gas emissions, however, the use of fossil fuels to generate hydrogen for chemicals manufacture or for use in fuel cells is used only if the carbon dioxide that is inevitably produced can be sequestered. Practical technology for this does not yet exist and its development is an area for immediate attention.

The realization of a 'Hydrogen Economy' is linked irrevocably with that of the fuel cell. There is no doubt that fuel cells work best on hydrogen and this requires any other fuel to be converted to hydrogen, at least for use in low-temperature cells. Unless the fuel reformer is tied directly to the fuel cell and produces hydrogen at exactly the rate that the fuel cell demands, as is proposed in some of the electric vehicle concepts, it is necessary to have a buffer store for hydrogen. This may be a metal hydride or a chemical carrier. The alternative concept is to have a much larger, industrial-scale reformer, divorced from the fuel cell, and to establish a distribution system for the hydrogen. Some proponents of FCVs favour this approach and are considering setting up a chain of service stations where hydrogen is supplied on tap. There is then the problem of storing hydrogen on-board the vehicle. The two options are high-pressure storage in gas cylinders – bulky and heavy, though rapidly improving – or in a hydride storage bed. The latter is feasible in theory, but there are some complex heat and mass-transfer problems to solve. As mentioned earlier, we are pessimistic about fuel cells for cars, less so for buses and trucks. It should be noted that automobiles (particularly diesels) are becoming increasingly efficient. Clearly, the fuel cell is aiming at a moving target. Stationary fuel cells are quite another matter and it is possible that within 20 years these will be installed widely, with hydrogen piped in from a centrally sited reformer. From an environmental standpoint, however, such an arrangement would not be ideal. All the carbon atoms in the fuel used by a reformer finish up as a carbon dioxide so that there is no saving in greenhouse gas emissions, except in so far as the fuel cell is more efficient than an engine.

Finally, we turn to the role of batteries for energy storage. Here, some real progress is being made. In the past 10-20 years, there have been improvements in the lead-acid battery, the nickel-metal-hydride battery has been invented and commercialized, and the lithium-ion battery has made its début [51,52]. In small sizes, the last-mentioned battery is sweeping the electronics market, and much work is in progress worldwide to scale it up to larger units, to ensure its safety, and to reduce its cost. Provided these goals are achieved, the lithium-ion battery and its off-shot, the lithium-polymer battery, have a promising future. Some larger storage batteries also appear encouraging. For example, sodium-nickel-chloride is targeted at the market for battery electric-vehicles while sodium-sulfur batteries (still being developed in Japan) would be appropriate for the storage of distributed electricity. Technically, the battery scene is looking promising for small-scale electricity storage, although there is still the issue of cost to be faced.

8. CONCLUSIONS

It is perhaps trite to observe that the laws of science that determine technical feasibility are immutable, whereas engineering design and manufacturing costs vary from place to place and from time to time. Thus, many goods that formerly were made in developed countries are now produced in lower cost, developing nations. Technical feasibility is, however, the *sine qua non* of any proposed new technology. Although outline costings are needed to determine whether a project promises to be economic, detailed manufacturing costs (with extrapolation to high-volume production) can only be ascertained after technical feasibility has been established and a prototype built. A technology that is too expensive for a particular application in a given nation at one point of time may be acceptable for a different application, or in a different place, or at a different time. This is one of the key problems facing anyone who attempts to predict the future prospects for technology on a global basis, and the task is further complicated by the need to factor in sociological and other considerations. Inevitably, therefore, some of the above-generalized predictions will not apply to specific applications in certain countries. A good example is Iceland or Brazil, where an abundance of cheap hydroelectric power might favour the production of hydrogen by electrolysis. Other forecasts will point in the right direction, but the timing will be wrong, as mentioned at the start of this article. Even so, it is hoped to have provided the reader with food for thought and stimulated some debate and discussion concerning energy futures.

Looking further ahead to 2050, the crystal ball becomes even more cloudy. Nevertheless, the lead-times for the energy technologies are such that it is necessary to take a long-term strategic view. Some governments have accepted this and stated that by 2050 it will be needed to have a clean and secure supply of energy that does not rely too heavily on fossil fuels.

Comprehensive energy reviews commissioned by different organizations and individuals had different, and often conflicting, viewpoints as to the future. Some favoured an expansion of nuclear power as the only realistic alternative to fossil fuels and emphasized the importance of following this course soon, before all the expertise and trained staff are lost. Others took diametrically opposed view and advocated the phasing out of nuclear plants permanently while vigorously developing all forms of renewable energy. Almost all parties accepted the need for a review of energy policy and agreed that tackling concerns over the security of the nation's energy supply and the environmental impact of greenhouse gases would necessitate changes to the energy-supply infrastructure. The area of disagreement was over the exact form that these changes should take. As might be expected, the general conclusion of the reviews was that options should be kept open so that a nation should spend more on energy research and development programs. As a working strategy, a good target model for electricity generation in the UK might be 30% coal-based, 30% gas-based, 30% nuclear, and 10% renewables. This would ensure that a nation had a diverse and secure base for its electricity supply.

In many countries, the situation may be quite different. France, for example, has little fossil fuel and is firmly committed to its nuclear program. Germany has plenty of coal, but little gas of its own. The Netherlands and Denmark have good wind resources and are therefore enthusiastic about renewables. Outside Europe, the USA has both coal and gas in copious amounts, so that there is little incentive to reinvigorate its nuclear programme. Japan has almost no indigenous fuel and is orientated towards nuclear technology and the importing of liquefied natural gas. Australia, like the USA, is rich in both coal and natural gas. Each country has to look to its own position to optimize its electricity generation. This makes for difficulties in forecasting, especially in meeting emission targets for greenhouse gases. In those countries where electricity generation is state-controlled, it is at least possible for the government to exert some influence over the fuels used. On the other hand, in countries such as the UK and the USA where a free and competitive market exists in electricity generation, the States has comparatively little control through legislation or subsidies. Liberalized electricity markets are hardly compatible with government energy planning.

One general conclusion can be drawn from this discussion of the developing energy scene to 2025 – there will be no overall shortage of fossil fuels. The world has ample reserves of oil and gas for the present and these are widely distributed, although still with preponderance in the Middle East. Other fossil fuels (coals, tar sands, asphalts, oil shales) are even more widely distributed, but their extraction and use impose technical and environmental problems. Moreover, barring political upsets or the imposition of a high carbon tax, fuels should remain comparatively cheap with modest increases in price above inflation. This will define a cost base against which renewable energy has to compete for business in most situations. The comparatively low cost of fossil fuels does nothing to address the greenhouse issue and there appears to be no easy answer to this problem. High carbon taxes, such as might make an impact, would be disruptive to the world economy and would be politically unacceptable. Unless and until the causative relationship between greenhouse gas emissions and global warning is established unequivocally and accepted by all, it is unlikely that the world will change dramatically its dependence on fossil fuels. Nevertheless, the time-scale for developing and implementing renewable energy technologies – decades – is such that efforts directed towards this goal should be continued and, moreover, enhanced.

In summary, some of the major energy problems facing the world today are:

- how to reduce greenhouse gas emissions to acceptable levels while there is cheap fossil fuel still to compete with renewables;
- how to persuade reluctant politicians and the general public of the need for a carbon tax;
- how to develop a practical and economic route for the sequestration of carbon dioxide without its release to the atmosphere;
- how to increase public awareness of the seriousness of the future energy situation and the need to start investing and planning now for a complete break from the present near-total dependence on fossil fuels; this is primarily a socio-political matter but does involve technological developments and choices;
- how to raise the huge amounts of capital investment that will be required to bring new sources of natural gas to market, to burn coal more cleanly, to sequester carbon dioxide, to build new nuclear facilities (if that route is chosen) and, in the longer term, to establish an entirely new, sustainable industry based on renewable sources of energy.

Whereas it is encouraging that schools, universities, interest groups and the media are enabling a new generation of young people worldwide, to gain a greater understanding of environmental and energy issues, the practical difficulties of moving from fossil fuels to renewables remains enormous. The world's scientists and engineers are striving to develop the required new energy technologies, but in the final analysis, politicians, financiers, bankers, industrialists and the general public must act together to establish an economic climate in which sustainable forms of energy can flourish in competition with traditional fuels.

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