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RENEWABLE ENERGY SOURCES

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Renewable Energy Sources

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Summary

This paper examines the role of renewable energy sources, and the scope for their deployment within the UK energy system over the period between now and the middle of the next century. For the most part, quantitative assessments of the potential for renewable energy are restricted to the short term (to 2010) and the medium term (to 2025). However, the long-term importance of renewable energy (to 2050 and beyond) is one of the principal conclusions of this study.

The ground covered in this report includes:

- **the physical basis for renewable energy;**
- **the technologies which are available to convert ambient energy flows into useful commercial forms;**
- **the experience in developing and operating these technologies throughout the world;**
- **the environmental impacts and benefits of individual technologies;**

- **the economic and commercial status of individual renewable energy sources;**
- **the institutional factors which are driving an increasing interest in renewable energy;**
- **the social implications of new energy technologies; and**
- **the policy frameworks relevant to their implementation.**

Section 1 of the report introduces the national and international context in which renewable energy is currently developing, pointing out key driving forces, and the impact which these are beginning to have on technological development.

Section 2 outlines the individual renewable energy technologies, identifying their present as well as their potential future contributions to energy supply in Europe and the UK. This section also provides anecdotal details of successful – and not so successful – development of renewable energy, at home and abroad. It draws from these experiences a number of important lessons for the future development of renewables in the UK.

Section 3 provides a more detailed discussion of the institutional and policy context in which renewable energy is developing, including in particular: the experiences gained through the UK's innovative Non-Fossil Fuel Obligation; the importance of international negotiations to reduce greenhouse gas emissions; the relevance of the EU's recent White Paper on renewable energy; and the burgeoning commercial interest in renewables by key multi-national companies.

Section 4 draws out some of the critical institutional and policy issues from previous sections and discusses them in more detail. Considerable attention is given to the question of appropriate pricing structures for renewable energy, taking into account the hidden costs of conventional fuels, the social impacts of higher fuel prices, the long-term economic and social benefits of renewable energy, the increasing liberalisation of the energy market, and the apparent willingness of consumers to pay premium prices for "green" energy. This analysis is set against an in-depth discussion of the vexed question of public acceptability, in particular in the light of difficulties in siting renewable energy plants in the UK.

Section 5 summarises the main conclusions from the study. It frames a number of critical questions about the development of a comprehensive policy framework for renewable energy. In particular, it discusses the future of an appropriate access mechanism for renewable energy in the wake of the Non-Fossil Fuel Obligation.

Key conclusions of this study are that:

- **the global renewable energy resource base is enormous;**
- **renewable energy could make a substantial contribution to global energy supply in the long term (up to 2050 and beyond);**
- **the environmental advantages of renewable energy are significant;**
- **renewable energy technologies also offer important secondary benefits in terms of improved energy security, local re-development, substantial export markets, and new employment opportunities;**

- **the UK is particularly well-endowed with certain renewable energy resources, and the technical prospects for long-term development are generally good;**
- **important experience in developing renewable energy has been gained through the UK's unique Non-Fossil Fuel Obligation;**
- **however, the UK's position as a world leader in renewable energy during the late 1970s and early 1980s has clearly slipped during the last decade or so;**
- **in the meantime, renewable energy has developed at almost astonishing speed in other countries and attitudes are changing fast in key international institutions;**
- **the full potential for renewable energy in the UK – and the government's target of a 10% contribution to electricity supply by 2010 – are both unlikely to be realised without a significant and committed policy initiative;**
- **failure to capitalise on indigenous opportunities for renewable energy could seriously jeopardise the UK's position in the energy markets of the 21st Century.**

1. Introduction

The term "renewable energy" refers to energy that flows naturally through the environment on a continual (though time-varying) basis. The origin of most of these energy flows is the solar radiation incident on the earth's surface. Notable exceptions are tidal power which results from the gravitational force between the moon and the earth, and geothermal energy which flows from the heat which is continually discharged from the core of the earth. Direct solar radiation is itself converted naturally into a number of other energy flows: wind energy arises from thermal gradients across the earth's surface; wave energy results from the interaction between the winds and the oceans; hydroenergy comes from the potential energy stored in the hydrological cycle; and bio-energy (or biomass energy) refers to the chemical energy stored in living organisms (usually plants) via the process of photosynthesis.

Fossil fuels like coal, petroleum and natural gas are generally believed to have been formed from decayed biomass. The energy which is stored chemically within such fuels is therefore also solar in origin. The critical difference between renewable and fossil energies is analogous to the difference between a current account and a deposit account. The renewable "current" account is constantly replenished by incoming solar (and gravitational) energy. However, the "deposit account" of fossil fuels was accumulated over many thousands of years of biological activity and is replenished, if at all, only very slowly. An energy system which relies mainly on fossil fuel resources has been likened to an economy which survives by depleting its capital reserves. From this perspective, the development of renewable energy resources – generating the ability to live within the constraints of the solar budget – is the path of long-term economic prudence.

Resource scarcity is, however, only one of the reasons for considering renewable energy. Increasingly, implementation of renewable energy is advocated on environmental grounds. The environmental problems associated with fossil fuel consumption are manifold and well-known. They arise in part from the mining, extracting and processing of mineral fuels, and in part from the inherently dissipative nature of energy conversion processes. Combustion processes release energy (in the form of heat) from the chemical bonds in the fuel; but they also release a wide range of material by-products: unburned hydrocarbons, particulate matter, sulphur and nitrogen oxides, carbon dioxide, and trace metals, for example. Some of these material by-products can be recaptured before they enter the environment; others are more difficult to manage. Perhaps the most intransigent of the environmental problems associated with fossil fuels is the release of the "greenhouse gas" carbon dioxide which is a major contributor to the problem of climate change.[1]

Renewable energy resources rely mainly on flows of energy which are carried in physical rather than chemical form. Generally therefore, energy conversion can take place without breaking chemical bonds and dissipating materials into the environment. The exception to this rule is bio-energy, where the useful energy *is* stored in the form of chemical bonds, and released as heat through combustion. As with all combustion processes, biomass combustion involves the dissipation of material by-products. For example, carbon dioxide is released into the atmosphere when biomass is burned. Provided that the biomass is sustainably harvested however, the rate of release of carbon into the atmosphere is less than or equal to the amount of carbon fixed in biomass. In other words – to use the same analogy used above – bio-energy recycles carbon within the constraints of the carbon current account, whereas fossil fuels release carbon which has been held in deposit over many millennia.

For these reasons, renewables are generally seen as inherently less polluting forms of energy supply than fossil fuels. In reality, no conversion process is entirely free of environmental impacts, and it is particularly important that the environmental and social implications of renewable energy technologies should not be glossed over in the search for sustainable energy systems. Nevertheless, it is generally true that renewable energy offers significant environmental advantages when compared to conventional supply systems, in particular in relation to the emission of greenhouse gases, and other conventional atmospheric pollutants.

It is largely these environmental advantages which have stimulated an increasing interest in renewable energy over the past decade. In 1987, the World Commission on Environment and Development argued that renewable energy "should provide the foundation of the global energy structure during the 21st Century".[2] In 1992, the United Nations Conference on Environment and Development called on participating nations to "increase the contribution of environmentally sound and cost-effective energy systems, particularly renewable ones".[3] The World Energy Council published two major studies in which they considered the feasibility of an accelerated penetration of renewables to supply up to 50% of energy needs by the middle of the 21st Century.[4] Several European nations including Denmark, Germany, Ireland, Italy, the Netherlands, Portugal, Spain and Sweden have adopted action plans for the energy sector which include specific implementation targets for renewable energy.

If anything, this interest has escalated during the last twelve months, spurred on perhaps by the negotiations which culminated in the signing of the climate change protocol at Kyoto last December. In November 1997, the European Commission published its White Paper *Energy for the Future*[5] calling for a doubling of the contribution to primary energy supply from renewables from 6% to 12% by the year

2010 and setting out an extensive action plan to achieve this aim. A part of that action plan is a scheme to install a million solar photovoltaic roofs in the European Union (EU) by 2010. The Clinton administration has recently established a similar scheme in the US; and in December 1997, the Indian government announced an ambitious programme to install a million and a half solar roofs by 2002.

The substantial technology market which is implied by this scale of expansion has prompted a flurry of activity from manufacturers. During 1997, two international oil companies announced major new investment programmes in the development of solar energy. After withdrawing from the Global Climate Coalition – a pro-fossil fuel lobby which campaigns actively against carbon emission reductions – BP is to increase its already extensive solar investment programme.[6] Shell has established a new core business (Shell International Renewables) which is to invest more than half a billion US dollars in renewables over the next five years.[7] The German government has been quick to support expansion of its domestic solar industries, and in November declared its aim of world leadership in solar photovoltaics production by early in the next century.[8]

The two major political driving forces for renewables in the EU have been their environmental advantages and the question of energy imports. The EU has taken a proactive international position on greenhouse gas emission reductions. At the same time its dependency on energy imports is currently 50% and is expected to reach 70% by 2020 if no action is taken. Renewables are therefore seen to offer indigenous sources of low-carbon energy where these are at a premium. But there are other factors prompting the European Commission to argue for an increased commitment to renewable energy. Many of the leading renewable energy technology manufacturers are European. Thus, to support renewables is indirectly to support European companies, with potential advantages in terms of increased employment and the promotion of an expanding export market in energy technologies.

The prospect of a substantial technological shift in the energy market has quite profound economic, social and geo-political ramifications. The promised expansion of the market in solar photovoltaics has already been likened to the growth in the automobile industry in the early part of this century or the computer industry in more recent times.[9] Those companies which are able to gain early competitive advantage are likely to reap large dividends in the transition. Those countries which take the lead in developing, implementing and exporting new energy technologies are likely to be dominant players in the emerging geo-political power structure. Conversely, those companies and countries which fail to take such opportunities may lose out substantially in the longer term.

The UK has been fortunate in possessing (and perspicacious in developing) extensive oil and gas reserves during a period when many other European countries have had to rely extensively on imported fuels. However, this good fortune has tended to obscure and at times impede the development of renewable energy in the UK. Following the oil shocks of the 1970s, Britain was at the cutting edge of research in new, renewable energy technologies, and was beginning to develop domestic manufacturing capabilities, for example in wind energy. A substantial cut in government research and development (R&D) spending in the mid-1980s had a profound effect on our position as world leaders in particular technologies. By the time the government introduced a support mechanism for renewables under the 1989 Electricity Act, it was too late to save some domestic companies: wind turbines installed under the Non-Fossil Fuel Obligation (NFFO) are almost exclusively manufactured by Danish companies.

The new UK government has a target to meet 10% of electricity demand from renewable energy sources by the year 2010.[10] Given that renewables currently supply only 2% of electricity demand – and 0.7% of gross inland energy consumption – this target is clearly an ambitious one. Whether or not it is realistic depends on a wide variety of different factors. These factors include not only the availability and viability of the technologies themselves, but also the economics of energy markets, the political and institutional context, the environmental implications, and the social aspects of technology implementation such as public acceptability, equity, and employment.

The aim of this paper is to provide an overview of each of these various aspects of renewable energy. The structure of the paper is as follows. The following section (Section 2) summarises the principal features of individual renewable energy technologies, providing anecdotal examples where appropriate, and highlighting the critical technical, economic, environmental or social issues associated with each technology. Some indication of the potential contribution from each technology is also provided in this section. For the most part, quantitative assessments are restricted to short and medium-term contributions. However, some assessments are also made throughout the paper of the potential long-term contribution from renewables. Section 3 discusses the changing political and institutional context for renewable energy in greater detail, highlighting in particular the implications of the action plan set out in the EU White Paper, the UK's NFFO, and the changing perceptions of renewables in major multinational energy companies. Section 4 addresses several issues which are critical to the development and implementation of renewable energy: internalisation of external social and environmental costs, liberalisation of the energy market, the premium pricing of renewable energy, and questions of public perception and social acceptability. Finally, Section 5 summarises the prospects for renewable energy, and highlights the most important issues for future analysis and discussion.

2. Renewable Energy Technologies

The extent of the global renewable energy resource base is enormous. Solar radiation is absorbed on earth at an average rate of 120,000 TW,[11] around four orders of magnitude (10,000 times) higher than the current global energy demand. Almost a third of this energy is converted to latent heat – and subsequently potential energy – in the hydrological cycle. Smaller quantities are converted to kinetic energy in the form of the winds and waves. Around 30 TW is converted via photosynthesis into biomass energy. Table 1 shows the breakdown of the global renewable energy resource base by type of energy.

Table 1: Global renewable energy resources

	Resource base TW	Recoverable resource TW
Solar radiation	90,000	1,000
Wind	300-1200	10

Wave	1-10	0.5-1
Hydro	10-30	1.5-2
Tidal	3	0.1
Biomass[12]	30	10
Geothermal	30	?

The Table also shows the estimated "recoverable resource" for each type of energy, taking into account known geographical constraints and state-of-the-art conversion efficiencies.[13] These recoverable resources are considerably smaller than the total resource base, and are likely to remain so for theoretical reasons. However, there are certainly some prospects for increases in the recoverable resource as conversion technologies improve. Furthermore, it is clear that the technical potential for renewable energy implied by Table 1 considerably exceeds the present rate of commercial energy consumption (~10 TW) – a view widely endorsed by experts in the field.

For a number of reasons, assessing the size of the recoverable resource does not satisfactorily answer the question of the viability of renewable energy as a source of commercial energy supply. In particular, of course, the cost of exploiting these resources must be taken into account. The energy flow itself may be free, but its often diffuse nature means that capture devices are likely to be spatially extensive and therefore capital-intensive. In addition, the requirement for capture devices is a requirement for material infrastructure. As with all material interventions, environmental burdens will occur both from intrusion in nature, and from the life cycle impacts of materials extraction, processing, use, and disposal. The idea that renewable energy is free and non-polluting is seductive, but inaccurate. As later sections of this paper will show however, renewable energy technologies do generally show considerable environmental advantages over conventional fuel cycles. Furthermore, there are a number of technologies already competitive with fossil fuels; and a number of other technologies likely to become competitive shortly.

It is to be noted from Table 1 that the indirect forms of solar energy (wind, wave, hydro and biomass) offer considerably lower recoverable resources than direct solar radiation. Nevertheless, these sources represent significant concentrations of the diffuse solar flow at given locations. In particular, hydro and biomass energies can be highly concentrated, making them relatively easy to convert to useful power. It is partly for this reason that biomass and hydro provide the most significant contributions to commercial energy use today. Approximately 20% of global energy consumption currently comes from renewable energy with hydro providing around 6% and biomass 14%.[14] Contribution to global energy supplies from other renewables is negligible. In the EU, renewable energy sources accounted for 5.4% of gross inland energy consumption in 1995: 3.3% came from biomass and 1.9% from hydro.[15] In the UK, hydro currently provides around 2% of electricity demand and 0.7% of total primary energy supply, with much smaller quantities coming from biomass, and very little from any other renewable technology.[16]

Another reason for the relatively high contribution from biomass and hydropower is that the conversion technologies for these energy sources are now mature and well established in the energy markets. In the past two or three decades however, a range of new, or improved, conversion devices drawing their power from widely different renewable energy flows have entered the arena. These new technologies are developing, in some cases, extremely fast. Rapid improvements in conversion efficiency are improving the technical and economic viability of the technologies, and some of them are already competitive with conventional sources of power.

One of the inherent features of renewable energy is the multiplicity and variety of technologies involved. There are some surface similarities between certain kinds of technology: for instance, a group of technologies comprising tidal energy, wave energy, and ocean thermal energy are sometimes grouped together (and we have followed that tradition in this paper) simply because they all involve the ocean. Beneath the convenience value of this grouping, however, lies a complexity that simply does not exist in conventional energy supplies. In fact, the three ocean technologies have little in common with each other at all, and even less in common with most of the other technologies. Sources of energy are different; types of energy are different; resource characteristics are different; conversion technologies are different; economic, institutional, social and environmental implications are different.

Partly as a result of this complexity, determining the significance and relevance of renewables to the UK is no easy task. We will argue later in this paper that it is misguided simply to demand of renewables commercial power at a competitive price, and short-sighted to assess the technologies purely against this yardstick. This argument requires however, a broad understanding of the range of issues which renewable technology raises. The following subsections aim to achieve that task. They will necessarily be too brief to provide a detailed discussion of individual technologies. But will hopefully be sufficient to establish our arguments later in the paper. More detailed information can be found in the references listed in endnote 17.[17]

One of the tasks that we have undertaken in the discussion that follows is to identify the current extent of implementation of different technologies and the prospects for implementation in the future. For the main part, we have tried to identify both the longer-term resource potential and the prospects for commercial implementation by the year 2010, as predicted by various expert sources. This has been done at three geographical scales. Firstly, we have collected together certain estimates of the global potential. These have mainly been drawn from two studies carried out by the World Energy Council.[18] Next, we have addressed the European scale. For this task, we have made substantial use of The European Renewable Energy Study, parts one (TERES I) and two (TERES II).[19] This study has also formed the basis for the recent European White Paper on Renewable Energy, which draws some justification for specific targets from the TERES "best practice" scenario.

At UK level we draw extensively, although not altogether uncritically, on a study on renewable energy commissioned by the DTI and carried out by ETSU in 1994.[20] The ETSU study identifies the potential for implementation of electricity-producing renewables in several different ways. Firstly, it estimates what is called an "accessible resource" at a cost of 10 p/kWh or less. This estimate represents "the resource which would be available for exploitation by a mature technology after only primary constraints are considered". Next it estimates a "maximum practicable resource" at a given price which takes account of "additional constraints" on development. Finally, it reports on the results of a modelling exercise, to estimate the actual implementation of renewables under different scenario assumptions. For reasons which we discuss later, assessment of widely different technologies under such criteria is not always satisfactory and is, in some cases, misleading. Nevertheless, we have included information from this study where we have felt it to be useful.

Finally, we should include a brief word about numerical units. There are a number of different conventions concerning which units to use for different kinds of energy supply, and also about how to account for primary electricity in the fuel mix. A great deal of confusion is engendered because different units and conventions are used in different places. In the following we have attempted to translate numbers taken from different sources into a consistent framework. Primary inputs and thermal outputs are both expressed in terms of million tonnes of oil equivalent (mtoe). Electricity outputs are always expressed in terawatt hours (TWh). Where it becomes an issue, we have followed the Eurostat convention of accounting for primary electricity inputs (from wind, wave, hydropower for example) in terms of the electricity delivered, rather than the fossil fuel equivalent input.

2.1 Bio-energy

Bio-energy or biomass energy is the energy recovered from biomass – that is, from the chemical bonds formed via photosynthesis in living (or once-living) matter. Before the discovery and widespread exploitation of fossil fuels, biomass was the main source of fuel for heating, cooking, and industrial smelting. It remains the single most significant source of energy in the developing world today providing 35% of total primary energy supply in developing countries.[21] Traditionally, the main source of biomass fuels has been wood and the main conversion technology has been simple combustion in open fires, kilns, or ovens. Today, a variety of other biomass fuels are recognised, and new conversion technologies have been, or are being developed.

In addition to wood fuels, sources of biomass include the following:

- agricultural residues
- animal residues
- urban refuse
- industrial waste
- sewage sludge, and
- energy crops.

Increasing attention is being paid to the last of these sources, that is to agricultural crops grown specifically for their energy content. A wide variety of different crops have been suggested for this purpose including short-rotation, fast-growing trees (such as willow or eucalyptus), herbaceous crops (like miscanthus, sorghum, sugar cane, or maize), and vegetable oil-bearing plants (such as soya, sunflower, rapeseed, and palm). One of the driving forces behind the renewed interest in energy crops – particularly in the EU – is the crisis which has been gathering pace in agriculture for a number of reasons, mainly historical over-production. Energy cropping is seen as a means of maintaining a healthy agricultural sector of the economy, whilst avoiding the massive over-production of foodstuffs.

Some types of biomass are used directly. Others are converted first to intermediate fuels which are later used to produce heat or electricity production. Intermediate fuels include charcoal (still used for smelting for example), bio-ethanol (from the distillation of sugar cane), sewage gas (from the digestion of sewage and animal residues), landfill gas (a by-product of landfill waste disposal), and other forms of biogas (for instance from the gasification of energy crops).

The principal biomass conversion technology remains *direct combustion*. Biomass resources of various types are burnt in stoves, furnaces and boilers either to provide energy directly to end-users, or else to raise steam for electricity generation in steam turbines. However, *thermochemical* and *biochemical* conversion processes are becoming increasingly important.

The basic thermochemical process is *pyrolysis* which uses heat to break down solid biomass into a gas mixture, an oil-like liquid and an almost pure carbon char. The proportion of each of these components depends on the conditions under which the pyrolysis takes place. *Gasification* is a pyrolytic technology which has been used since 1830 to produce biogas – a mixture of methane and carbon dioxide – from organic matter. It has been estimated that a million gasifier-powered vehicles helped to keep basic transport systems running when oil resources were in scarce supply during the second world war. Interest in the technology was rekindled during the oil crises of the 1970s, and extensive demonstration programmes were carried out in some developing countries. In Brazil, for example, small charcoal gasifiers have been extensively installed in rural areas for power generation, or to provide gas for internal combustion engines.[22] In principle, gasification offers the possibility of using high-efficiency power conversion cycles.[23] However, the economics of gasification are currently marginal, particularly for power generation.

The main biochemical conversion process is *fermentation*, the breaking down of organic matter through the metabolic action of microbial organisms. *Anaerobic fermentation* is a simple, reliable, and versatile method of producing biogas from organic matter. There are reported to be five million *anaerobic digesters* in operation in rural China, and some 700,000 in India. The original purpose of the Chinese digesters was to reduce disease among rural communities by stabilising local sewage. However, their subsequent optimisation for biogas production has been a substantial benefit in terms of rural energy provision. *Ethanol fermentation* is another well-known and relatively simple biomass conversion process in which micro-organisms (usually yeasts) are used to convert carbohydrates into alcohol. Distilled ethanol can then be used, for example, as a transport fuel.

The Brazilian Proalcool programme is the most extensive ethanol fermentation programme in the world, currently producing 12 billion litres of ethanol a year, equivalent to around 60% of the country's automotive fuel requirements. Eight million petrol-driven cars now run on fuel containing 22% ethanol without modification, and with no mileage penalty. A further 4 million cars use hydrated ethanol in specially designed Otto-cycle engines. Between 1976 and 1985 the Proalcool programme was estimated to have cost Brazil around US$6.5 billion (in 1986 prices). At the same time however, it saved almost US$9 billion in avoided petrol costs. In spite of such economic gains, the programme has not been without its problems. Perhaps the most significant of these has been the disposal of the "stillage" produced during the distillation process. The earlier solution of dumping these wastes in rivers has turned out to be environmentally unacceptable. Increasingly, the wastes are now subject to further treatment. Anaerobic digestion is used to generate biogas (which can be used for energy) and liquid fertilisers (which can be recycled to the sugar cane fields). A number of other countries including the USA, Zimbabwe and Malawi have also developed bioethanol programmes.

The use of bioenergy has been widely advocated in Scandinavia. Five Nordic countries now produce a total of 15 mtoe of bioenergy annually and the exploitable potential is estimated at twice that figure. Of these countries, Sweden has almost half the exploitable potential, and biomass already accounts for 17% of primary energy consumption. Swedish policy-makers first became interested in promoting biomass-for-energy use following the 1979 oil embargo, a time when Sweden was dependent on oil for more than 70% of its energy needs. In the mid-1980s, concern to reduce oil consumption subsided, but in its place policy-makers began advocating the use of biomass-fired electricity as a way of alleviating the difficulties of a proposed phase-out of nuclear power. Over the past twenty years the Swedish government has invested more than 2 billion Swedish kronor (almost £200 million) in developing biomass.[24]. Subsidies covering up to 25% of the capital cost of plant have resulted in a doubling of the contribution from biomass between 1970 and 1995. Much of this capacity has been installed in the pulp and paper sector, with a significant further contribution in the form of district heating plants.

Several other countries have developed successful biomass programmes. For example, Austria has increased the contribution of biomass to primary energy supply from 0% to 10% in little more than a decade. More than 10,000 woodchip-fired combined heat and power/district heating schemes have been installed. During the same sort of period of time, the USA has expanded biomass-fired electricity generation from 250 MW to 9,000 MW. In addition to the Proalcool project, Brazil produces around 7 Mt of charcoal a year to replace the use of coal in pig-iron and steel production. In the UK, a variety of different kinds of biomass projects – ranging from incineration of residues to gasification of energy crops – have been set up under the NFFO (see Section 3 below).

The costs of biomass energy vary widely, and are heavily dependent on a number of factors, including the type, availability and quality of the feedstock, and the conversion technology employed. Some biomass feedstocks – those which are drawn from industrial wastes and residues for example – may have a "negative cost" in certain situations because of the avoided costs of alternative disposal, and give rise to highly competitive generation options. In countries with extensive biomass contributions, such as Sweden, the market for woodfuels is relatively well developed. But costs – in the region of £2-3 per gigajoule (GJ) – are competitive with conventional fuels. Other biomass options – such as gasification of energy crops for electricity generation – are still not competitive with conventional sources of power at the present time, but could become competitive within a decade or so.

Assessing the scope for increased exploitation of bioenergy is complicated by a number of important factors. Some of these factors are positive, in the sense that they favour biomass development, and others are negative, or at least sound a cautionary note with regard to the wide-scale exploitation of biomass resources.

Biomass is the only renewable resource in which energy is stored in the form of chemical bonds in matter. Even this simple fact has contradictory connotations. It is a positive advantage in the sense that these chemical bonds operate as an energy storage medium. Bioenergy can therefore be delivered flexibly at the point of demand as and when required. The energy density of most biomass fuels is not so high as that of most fossil fuels. Nevertheless, solid biomass can generally be stored in sufficient quantity to ensure flexible operation of furnaces or boilers; liquid biofuels provide an appropriate mobile fuel in the transport sector; and biogas can be drawn off, compressed in storage tanks, and used as required to meet demand.

The negative side of the nature of biomass as a chemical fuel is that useful energy is released through the process of combustion, involving an inherent dissipation of the material constituents of the fuel. In fact, uncontrolled burning of woodfuels, although usually less polluting than combustion of fossil fuels, can nevertheless release a range of pollutants into the atmosphere including particulate matter, sulphur, carbon dioxide and toxic heavy metals. Some of these pollutants can be controlled or removed – at a cost – from the flue gases. Removing carbon dioxide from the flue gases is still problematic. Biomass can only be regarded as sustainable from the point of view of the carbon cycle, if the rate at which carbon is released into the atmosphere through combustion is no faster than the rate at which carbon is fixed from the atmosphere in new biomass by photosynthesis.

Historically at least, this constraint has not generally been met. Biomass exploitation has tended to exceed supply, leading to deforestation, and sometimes even the desertification of former woodlands. This is a common story in many developing countries today. Woodfuel shortages were a critical factor in the transition to coal which took place in the UK between the seventeenth and the nineteenth centuries. Coal was a well-known fuel before that time but, as Adam Smith remarked,[25] it is a far less pleasant fuel than wood or charcoal, and no one ever used it unless wood was in short supply or too expensive. It is salutary to note that the population of the UK in 1700 was still only 6 million people. In other words, traditional exploitation of woodfuels was already unsustainable before the industrial revolution for a much smaller population than exists in the UK today.

Today, a whole range of different sources of biomass and considerably more efficient conversion systems have emerged. Energy crop yields are considerably higher than could have been envisaged three centuries ago. On the other hand, such yields depend on modern agricultural techniques: the availability of chemical fertilisers and insecticides, and the use of farming machinery. These techniques are themselves energy intensive, and the use of agricultural chemicals has impacts on human health, water quality and soil quality.

The overall message is that the cultivation of energy crops does offer some potential for rejuvenating the European agricultural sector. But if extensive contributions to energy supply are to be sought from biomass, then a careful assessment of the environmental impacts of energy cropping is essential.

When it comes to considering waste and residue-related biomass, the issues involved are no less complex. Amongst the positive features of waste-to-energy options are the secondary advantages in terms of waste management. For example, methane leakage from landfill sites is a significant health and safety hazard, and methane itself is a more powerful greenhouse gas than carbon dioxide. Drawing off and burning landfill gas will therefore avert local hazards and reduce the burden of greenhouse gases in the atmosphere. Likewise the generation of useful energy from sewage wastes has positive environmental impacts at the local level.

Recovering energy from the incineration of municipal refuse or industrial wastes reduces the quantity of wastes which have to go to landfill, and is clearly preferable to incineration without energy recovery. On the other hand, there are concerns about the environmental impact of emissions from waste incineration. Waste streams typically contain a wide variety of materials including sulphur, nitrogen, chlorine, fluorine, chlorinated hydrocarbons, heavy metals, and derivatives of these materials. Particular concerns exist about the formation of dioxins during the incineration process. Although modern technologies are now believed capable at least of limiting this problem, dioxins (and related chemicals) are acutely carcinogenic, and understandably attract considerable public concern. Public opposition to waste-to-energy plants must therefore be regarded as a significant obstacle to implementation (Section 4.2).

Increasingly, environmental management guidelines now emphasise the importance of waste prevention, that is of finding ways to minimise the quantities of waste which require disposal in landfill sites and incinerators. The development of waste-to-energy potentially conflicts with the general intention of this strategy. Successful waste prevention would reduce the flow of municipal solid waste and reduce the feedstock for waste-to-energy plants. On the other hand, the widespread development of waste-to-energy systems would reduce the incentive to engage in waste prevention, which for a number of reasons must be regarded as the superior waste management option.

These considerations suggest that predicting a sustainable contribution to energy supplies from biomass is not straightforward. In general terms, it should be borne in mind that:

- the scope for further sustainable exploitation of "traditional" biomass is generally regarded as limited;
- the development of energy crops could have a positive influence on the agricultural sector, but the environmental implications require careful consideration;
- appropriate development of energy from wastes could have secondary benefits in terms of improved waste management; but extensive implementation could conflict with waste prevention strategies.

The US Environmental Protection Agency has estimated that as much as 16,000 mtoe per year could eventually be produced from biomass, given a sufficient commitment of land.[26] This is getting on for twice the current global primary energy consumption and 16 times higher than current global biomass consumption. In spite of this enormous potential, the World Energy Council's "ecologically driven" scenario predicts only a modest increase in biomass use by 2010. Significantly however, the contribution from traditional biomass declines, and the increase is provided by a contribution of some 400 mtoe from modern biomass sources.[27] It is generally assumed that in the short to medium term expansion in modern biomass will come from wastes and residues, although by the middle of the next century around two-thirds of biomass energy could come from energy crops.[28] The most versatile biomass technology is generally thought to be ethanol. Gasification is believed to have a huge potential, but is not yet fully competitive with commercial energy sources.

In Europe, biomass currently provides around 45 mtoe or 3% of gross inland energy consumption.[29] The technical potential is currently believed to be over 200 mtoe, and under the TERES "best practice" scenario, it has been estimated that an additional 90 mtoe could be implemented by 2010. About 50% of this would come from energy crops with the rest made up from wastes and residues. For the UK, the ETSU report estimated the accessible resource[30] for electricity supply at around 250 TWh, equivalent to over 50 mtoe of primary energy. The bulk of this would come from energy crops.

2.2 Geothermal

Geothermal energy refers to the energy which flows out from the centre to the surface of the earth. Although the inner core of the earth reaches temperatures as high as 4,000^{o}C, the average energy flux at the surface of the earth is only 0.06 W/m^2. This flow is trivial by comparison with the average total flow of renewable energy at the surface of the earth which is in the order of 500 W/m^2. However, at certain specific locations the power density can be high enough to provide useful sources of heat and electricity.

Geothermal energy is most useful when it occurs in hydrothermal form: springs of hot pressurised water or steam known as *aquifers*. Low temperature aquifers have been used for centuries for bathing and space heating. More recently, subterranean geothermal aquifers have been tapped with wells, and then either used directly to provide process and space heating, or else converted to electricity in conventional steam turbines, or (more recently) binary cycle plants.

The total installed hydrothermal capacity in 1975 was about 3,100 MW thermal. By 1995, electrical capacity alone had grown to around 9,000 MW around a third of which was in the United States with a further 12,000 MW of installed thermal capacity providing around 9 mtoe of thermal energy. A significant geothermal exploration programme initiated by the United Nations Development Programme led to the development of geothermal resources in a number of developing countries. In El Salvador, geothermal electricity generation accounts for 30% of the total installed capacity. In total however, geothermal energy still represents less than 0.15% of the global primary energy supply. There is only one geothermal aquifer in operation in the UK, at Southampton, where it provides heat to a district heating scheme operated by Southampton City Council.

The Electric Power Research Institute in the US estimated that the potential global geothermal resource could be as much as 1,000 mtoe. The trouble is that the vast proportion of this resource is not in the form of aquifers, but occurs in *hot dry rocks* (HDR), where the energy is much more difficult to extract. HDR energy extraction has been the focus of research efforts for more than two decades. At one stage, during the 1980s the UK was at the forefront of this research. An experimental research station at the Camborne School of Mines, at Rosemanowes in Cornwall, was one of two leading experimental sites in the world, the other being a multinational project funded by the IEA at Fenton Hill, New Mexico in the USA.

The aim of the Camborne School of Mines project was to establish a hydraulic connection with heat reservoirs located some 2 to 3 km below the ground. Three boreholes were drilled. Success with the first two boreholes was limited: the hydraulic connection was relatively poor with only about 60% of the water being recovered. The hydraulic connection was improved at the third borehole but a review of the project in 1990 concluded that fundamental technical difficulties made the commercial development of HDR unrealistic in the foreseeable future. The UK remains involved in the European HDR programme, which has two experimental sites one at Soultz, near Strasbourg in France, and the other at Bad Urach in Germany, but the downhole work at Rosemanowes has now stopped. The feasibility of HDR power production is now most likely to be demonstrated at the US site, where long-term flow tests have been under way for several years.

A third potential source of geothermal energy is the *magma* – or molten rock – lying in shallow chambers below the earth’s crust. In the two decades since interest was first shown in magma energy, the scientific feasibility has been established, and some successful heat extraction experiments have taken place in the Hawaii Volcanoes National Park. However, the extent of the recoverable resource is not known, and considerable research will be necessary before magma can be considered a viable energy source.

The World Energy Council envisages a fourfold increase in hydrothermal extraction over 1990 levels by the year 2010, although this will still mean less than 0.5% of primary energy supply coming from geothermal sources. The EU’s "best practice" scenario suggests a doubling of the electrical output from geothermal aquifers in the same period. Again, however, the contribution to primary energy supply in 2010 remains almost insignificant. In the UK, tests have failed to reveal any significant opportunities for further geothermal aquifers, and in the absence of a breakthrough in HDR technology, Southampton looks destined to remain the only domestic source of geothermal energy for several decades.

2.3 Hydro

Hydropower – the power of falling water – has been used by human civilisation for centuries to carry out mechanical work – milling, grinding, or simply irrigating agricultural lands. During the period immediately prior to the Industrial Revolution there were between 10,000 and 20,000 working water mills in the UK, delivering a mechanical energy equivalent to around 2 mtoe. The first large-scale hydroelectric scheme in the UK was built in Scotland in 1896, and in the intervening century hydroelectric power has become established world-wide as the foremost source of renewable electricity generation. Hydropower now accounts for 18% of global electricity, 13% of EU electricity, and 2% of UK electricity generation.

Hydroelectric installations are characterised as either large scale or small scale. Schemes with an installed capacity of more than 10 MW are usually considered to be large scale, and those of 10 MW and less are small scale. In the UK however, the dividing line is taken to be at 5 MW. In some applications, water is stored in a reservoir and power is drawn from the water flowing through turbines integrated into a retaining wall or dam. In other applications (usually smaller scale), there is no storage and turbines draw their power from the flow of water in the "run-of-river". A useful variant is the pumped storage scheme in which electrical power is used to pump water from a low storage area to a high storage area when the demand for electricity is low. This water can be run back down to the low reservoir through a turbine to provide additional power at times of peak demand. Although extremely useful for the purposes of load management, pumped storage schemes are not generally counted as additional sources of electricity generation.

A large number of hydroelectric stations have been built in the UK ranging from less than 1 kW in size to more than 100 MW. Large-scale hydro in the UK is confined (for geophysical reasons) to mountainous regions in Scotland (1.22 GW) and Wales (134 MW). The majority of the small-scale hydro is also located in Scotland, with around 20 MW installed capacity in England and Wales. The technology itself is now fully mature over the whole range of installed sizes. Reliability of the turbines approaches 100%, and the only constraints on availability are those determined by the flow of water (in run-of-river schemes) or the degree of storage (in reservoir schemes).

Commercial competitiveness of hydroelectricity depends on a number of factors. Turbine costs tend to be closely constrained, but the balance of system costs – civil works and connection to the grid – can vary widely as a result of geographical differences in the nature of the terrain or the proximity to existing power lines. The economics of hydro are almost entirely dominated by the up-front cost of capital, and hence the unit cost of electricity is highly sensitive to the interest rate charged on capital and the period over which loans are repaid. Typically, power sector investments operate under capital repayment periods in the order of 15 to 20 years. The engineering lifetime of most power stations will not exceed thirty or thirty-five years. Hydroelectric schemes can sometimes remain operational, delivering extremely cheap electricity, for periods in excess of fifty years. Capturing the benefit of this longevity in conventional cost-benefit analysis at market discount rates is not straightforward.

Aside from their role in energy generation, some hydroelectric projects can operate as part of a multipurpose project delivering a number of benefits including:

- flood protection
- cooling water for thermal plants
- navigation
- fresh water supply
- recreation and
- irrigation.

However, diverting rivers, damming lakes, and flooding valleys to create large-scale hydroelectric projects has considerable *negative* social and environmental impacts, including:

- visual intrusion;
- displacement of human populations;
- shifts in the local hydrology; and

- biodiversity loss in local ecosystems.

For these reasons further development of large-scale hydro is likely to be constrained, at least in the developed world. In developing countries, the situation may be slightly different. Last year the Chinese succeeding in damming the Yangtse river in China in the process of constructing what will eventually be the largest hydroelectric power station ever to be built. Allegedly conceived by Sun Yat-sen, who toppled the Qyng dynasty in 1911, the project will take 12 years to complete, creating a lake 371 miles long, and a dam which rises 607 feet above the downstream riverbed. The finished power station – which will cost an estimated $29 billion – will deliver 18,200 MW of electrical power operating at its peak. Although such extensive projects will surely be the exception rather than the rule, the World Energy Council projects a doubling of large-scale hydropower in developing countries by 2010. Small-scale hydro is also predicted to increase almost threefold by 2010, with most of the expansion coming from North America, Western Europe and China.

In the 15 EU countries, annual electricity generation from hydro is currently in the order of 330 TWh, of which around 90% is large-scale hydro. The TERES study puts the technically exploitable hydro resource at just under twice this level of generation. However, only a limited proportion of the additional capacity is expected to come from large-scale schemes. Very little new large-scale capacity is likely to be installed in Germany, France or the UK because the cheaper sites have already been exploited and remaining sites present increased levels of technical difficulty, higher costs and greater environmental impacts.

Small-scale hydro (< 10 MW) on the other hand represents only 10% of total hydropower in the EU, but the TERES "best practice" scenario envisages a 50% expansion in capacity by 2010. Some at least of this expansion is likely to occur in the UK. Government programmes have aimed to stimulate a wider uptake of commercially available small-scale hydro, in particular through the mechanism of the NFFO (Section 3.1 below); and to support the research, development and demonstration of novel technologies for extracting energy from low-head hydro.[31] The accessible small-scale hydro resource has been estimated at more than 500 MW, some 25 times higher than the existing installed capacity.[32] Even if all of this potential were tapped however, the contribution to annual generation (around 4 TWh) would represent less than 1.5% of current electricity demand.

2.4 Ocean Energy

The oceans represent a considerable source of renewable energy, in several different forms. Some of this energy – wave energy and ocean thermal energy – is solar in origin. Ocean thermal energy conversion exploits the temperature gradient between shallower and deeper layers in the deep ocean. Wave energy arises from the interaction between the winds and the surface of the ocean. Tidal energy by contrast has its origin in the gravitational attraction which exists between the earth and the moon. These different types of energy are all transmitted by the medium of the oceans, and it is therefore convenient (and conventional) to label them together as ocean energy. However, the individual resources and the technologies which are used to exploit them differ significantly from each other. For this reason, we discuss each technology type separately in the following paragraphs.

Tidal Energy

Of the three types of ocean energy, tidal energy is the only one with any significant installed capacity world-wide. It is also the only technology which can be regarded as fully mature. In fact, tidal mills are known to have operated around the coasts of Britain as long ago as 1100 AD. A number of different kinds of devices have been used to convert tidal energy to a useful output. But the commonest and most effective method remains the same as that used in the old tide mills. Typically, these mills operated by filling a storage pond at high tide, and allowing the water to flow back to the sea again through a water wheel, while the tide was out.

Modern-day electricity generating tidal schemes operate on very much the same principle. Tidal schemes are usually situated in river estuaries where the tidal flow has become concentrated to create a large range between high tide and low tide. In the simplest modern tidal scheme, usually called "ebb generation", a barrage is placed across the estuary to create the upstream storage pond, and the old water wheel is replaced with a turbine to generate electricity on the ebb tide. This scheme typically has three main stages of operation:

- the filling of the basin on the flood tide;
- storage of the flood water until sufficient head is created by the receding tide to generate electricity;
- electricity generation, by allowing the stored water to flow back out to sea through a turbine.

There is also sometimes a "holding" period after the ebb flow has reduced the head, and before the inward sluices are opened to re-fill the basin.

In principle, there is nothing to stop generation from being carried out on the flood tide rather than the ebb tide, although this is usually less efficient than ebb tide generation because of the geography of the basin. Some modern schemes – called "double-effect" – generate electricity on both ebb and flood tides. This is sometimes, although not always, more efficient than single-effect generation. In both cases, output can usually be increased by pumping to increase the height of the water in the basin before ebb generation.

One of the problems of tidal schemes is that they can generate only intermittently because of the periodic nature of the tides. This problem can sometimes be avoided by creating linked or paired basin schemes. In linked basin schemes, the general idea is to use two basins, one of which is kept full, by topping it up whenever the tide is high, and the other empty, by draining it whenever the tide is low. Water is sent through a turbine from high basin to low basin whenever electricity is required. The paired basin scheme operates by generating electricity on the flood in one basin, and on the ebb in the second. In principle, it would also be possible to improve the continuity of generation by pairing geographically separated basins, situated such that the ebb tide in one basin corresponded to the flood in another. Another method of providing more continuous flow is to establish a separate pumped storage hydro scheme in the river upstream of the tidal dam. However, such methods increase the capital costs associated with tidal generation.

The first and largest modern electric tidal plant was built in the 1960s and is situated at La Rance in France. It operates a 240 MW, single-effect, tidal barrage, delivering annual generation of approximately 0.5 TWh. Operating experience has generally been very positive both at this site and at other smaller sites in Canada and the former USSR. However, tidal power has been criticised extensively on the grounds of environmental impact, particularly during construction. The French scheme was built "in the dry" behind a temporary "cofferdam" and critics argued that the total closure of the estuary during construction caused "the almost complete disappearance" of the indigenous bird species.[33] Modern construction methods would generally avoid the extremity of this problem, but environmental opposition to proposed schemes has been high, in particular in the UK.

The global technical potential for tidal energy has been estimated at 2,000 TWh per year, although only about 200 TWh of this is likely to be commercially exploitable.[34] In the EU, the technical available tidal resource has been estimated at 105 TWh per year. In spite of this, the TERES study foresees no significant additional implementation of tidal power before the year 2020. The principal reason for this is that the economic cost remains prohibitive, particularly in a liberalised energy market. As with many renewable energy technologies, tidal schemes are heavily capital-intensive. The design life of tidal schemes is expected to be in excess of 120 years, but the long-term benefits of this are virtually invisible under the influence of commercial sector financing where effective discount rates can be well over 10%.

Sometimes the financial feasibility of tidal schemes can be improved if barrages can be designed to offer additional, non-energy related benefits, such as recreational facilities or a new bridge. Generally speaking however, it is now recognised that tidal schemes will require government financing if they are to be implemented. In progressively liberalised energy markets, such funding seems increasingly unlikely.

The UK is particularly well endowed with tidal resources. The technical resource is around 50 TWh per year – almost half of the total EU potential. Ninety per cent of this resource is located at 8 larger sites (Severn, Dee, Mersey, Morecambe Bay, Solway Firth, Humber, Wash and Thames) with around ten per cent located at 34 smaller sites. The largest of the sites is the Severn Estuary where a proposed barrage has been the subject of extensive feasibility studies for more than a decade. With an installed capacity of 8,640 MW, the proposed barrage would generate an annual output of 17 TWh, equivalent to 5% of UK electricity demand. The cost of the electricity has been estimated at around 8 p/kWh using an 8% discount rate, rising to almost 18 p/kWh using a 15% discount rate. Electricity at a similar cost could be obtained from the (700 MW) Mersey barrage. The best of the smaller sites is believed to be the Wyre barrage with a projected capacity of 62.6 MW, producing electricity at 7.5 p/kWh (13.5 p/kWh using the higher discount rate).

The ETSU study envisaged a maximum practicable contribution of 1.6 TWh per year from some of the smaller tidal schemes by 2005, with more significant contributions coming on line by 2025.[35] However, the previous government's position on tidal power was uncompromising: the closure of the Tidal Programme was announced in July 1993 and Energy Paper 62 published in 1994 foresaw no deployment of tidal power under any scenario considered before 2025, mainly because of the high p/kWh costs compared to conventional electricity.[36]

Tidal Stream Energy

An alternative to the building of tidal barrages is to capture the energy of the tides by situating a turbine directly in the tidal stream, in much the same way as wind energy is generated. Several advantages may flow from this type of device, including lower environmental impacts, more constant output, the modular nature of the technology,[37] and a wider range of sites than for tidal barrage schemes. The European tidal stream resource has been estimated at around 23 TWh per year.[38] At the moment, however, the technology remains speculative and has not been included in short– or medium–term forecasts for renewable energy.

Wave Energy

The UK once operated the most extensive, and indeed the most ambitious, wave energy research programme in the world. Wave energy is generated as a result of the interaction of the wind on the surface of the oceans. Some estimates suggest that the technical potential for wave power along the Atlantic coast of Europe could be as high as 600 TWh a year.[39] Wave-forms initiated in the middle of the Atlantic carry an average power density of between 30 and 50 kW/m. Ireland and the UK have wave power in the upper end of this range.

During the period between 1974 and 1985, over 200 wave energy converter designs were tested under the UK's wave energy programme. Eight large-scale (2 GW) offshore devices were taken to the design stage before the funding was dramatically cut in the mid-1980s. On the basis of the test designs, the government concluded (controversially) that large-scale offshore wave energy converters would not become economic for several decades, and decided to concentrate a substantially-reduced research effort on smaller shoreline devices. However, the programme spawned a quite remarkable range of wave energy devices which have formed the basis for almost all subsequent wave energy research and experimentation around the world.

The technologies themselves attempt to capture the energy generated by the motion of waves in three different directions – horizontal (surge devices), vertical (eg heaving devices) and rotational (pitching devices). Amongst the most well-known devices are:

- the tapered channel: a shoreline device which uses a tapered structure to channel surging water into a reservoir; the water then flows back to the sea through a conventional hydroelectric turbine.
- the Edinburgh duck: a device which rolls or "nods" with the pitching motion of the waves, returning to the vertical through the force of gravity; electricity is generated from the rotational motion.
- the SEA clam: a ring-shaped device constructed in segments each of which contains a flexible membrane to capture energy from the surge of the waves.
- the oscillating water column (OWC): can be operated as a shoreline or an offshore device; it generates electricity from the motion of the air above a column of water which is oscillating as a result of the vertical motion of the waves.

A number of prototype shoreline devices have been developed. Amongst these is a 75 kW OWC device developed by Queen's University, Belfast and situated on the Isle of

Islay. The device incorporates the revolutionary Wells turbine, which rotates in one direction irrespective of the direction of the air flow through it. There are also plans for a 12.5 MW scheme involving five Clam devices to be moored off South Uist.

Little prospect for commercial development of wave power is envisaged in most short- to medium-term forecasts. Costs are still too high, and the technology remains uncertain. The World Energy Council's most favourable scenario includes a contribution of around 5 TWh by the year 2010. ETSU has estimated the European resource at between 116 and 179 TWh per year,[40] but the TERES report foresees a maximum contribution of 1 TWh per year by 2010. The UK has the best technical potential for wave energy in Europe, with an estimated potential of 43-64 TWh per year, or 15%-20% of current electricity generation. But the accessible resource for shoreline devices is estimated by ETSU at 0.4 TWh per year with only 0.03 TWh per year from offshore devices.

No other renewable energy development has generated the controversy generated by the UK's unique wave energy programme. Accusations of blind optimism on the part of developers and institutional bias (and worse) on the part of the reviewers were rife in the aftermath of the dramatic funding cuts of the mid-1980s.[41] The 2 GW design specification (bigger than a conventional nuclear power station) has been widely criticised as unrealistic. In 1990, the government finally admitted that the critical 1982 assessment of the wave energy programme had contained substantive errors.[42] But the task of developing energy capture devices, robust enough to operate in one of the harshest environments in nature, is not to be underestimated. The first near-shore OWC device, a privately developed 2 MW device called the ART OSPREY, was damaged at launch and sank in heavy seas in 1995. A second prototype is due to be launched this year.

In summary, the wave energy resource in the UK is among the best in the world, a wide variety of devices could generate power at costs which have been estimated at between 4 and 20 p/kWh.[43] A number of smaller shoreline devices now have several years of operating experience. To date, the UK government's approach to wave power has been criticised for resting on all-or-nothing assessments of the technology against current commercial conditions, and neglecting wider and longer-term considerations such as:[44]

- the seasonal characteristics of wave energy;
- the prospects for utilising the experience, infrastructure and skill-base of the marine construction industry in wave energy development and manufacture;
- the scope for improved performance and economics of conversion devices as a result of advances in construction materials;
- the potential for synergies between wave energy and other offshore energy technologies, in particular wind energy (see Section 2.6 below).

The successful further development of this technology requires a committed, and consistent research and demonstration effort which is unlikely to proceed without government support.

Ocean Thermal Energy Conversion

In most tropical or subtropical areas there is a temperature difference of some 20°C between water at a depth of around 1,000m and that on the surface. Exploiting this temperature difference for energy conversion was first proposed by French physicist d'Arsonval in 1881. Although the efficiency of conversion is very low, the resource itself is huge. In principle, therefore, ocean thermal energy conversion (OTEC) could provide a significant electricity output. A test-scale plant was developed in Cuba as early as the 1930s. A more sustained research effort was instigated as a result of oil price rises in the 1970s, and the first modern device was pioneered off Hawaii in 1979, producing net power of 15 kW.

The devices themselves can be ship-based or shore-based and are categorised as either open cycle – in which the working fluid is provided by sea water itself – or closed cycle in which warm surface water is used to evaporate a working fluid such as ammonia or Freon. The generation cycle is similar to that of a conventional thermal power station except that the operating temperature is much lower. Once auxiliary power for pumping is taken into account, the net efficiency of OTEC plant is usually 3-4% at most.

Two UK firms have designed OTEC plants, one a 10 MW device for operation in the Caribbean, the other a 500 kW closed cycle land-based plant for operation in Hawaii. Operating costs are low, but the capital costs of the devices are very high leading to generation costs of around 7 or 8 p/kWh. This is not currently competitive with conventional coal or gas-fired generation, but could be competitive with diesel generation in areas isolated from a mains electricity supply. The OECD has estimated that costs could fall by two-thirds in the long term.[45] A potentially significant advantage of the technology is the ability to produce de-salinated water as a by-product. Nevertheless, it is unlikely that ocean thermal energy will provide power to the UK grid in the foreseeable future, simply because of the distance from the source of generation. The EU envisages no contribution from OTEC in their short- or medium-term predictions for renewable energy.

Salt Gradient Energy

For completeness, it is worth mentioning that it is possible theoretically to generate electricity from the difference in osmotic pressure between fresh water and salt water. Allowing fresh water to flow through a semi-permeable membrane into a reservoir of salt water would raise the level of the reservoir by 240m. Electricity could then be generated by allowing the water to flow back to the sea through a turbine. The World Energy Council estimates a theoretical potential of 2.6 TW from this source. However, the capital costs are high, and the technology has the disadvantage – in contrast to the OTEC technology – of consuming fresh water.

2.5 Solar

The direct solar resource is massive. Table 1 indicates that the global resource base is some 10,000 times higher than the average global power demand. However, this considerable resource arrives at the surface of the earth as a relatively diffuse flow "like a very fine rain... a microscopic mist".[46] The annual average insolation rate in equatorial Africa is only 250-300 W/m^2. In the UK, this "microscopic mist" is even finer: the average insolation rate in summer is about 200 W/m^2, and in winter falls to

20 W/m^2 in the south of England, and less than half of this in the north of Scotland. This is equivalent to an average insolation rate of around 2.5 kWh/m^2 per day.[47]

To put this in perspective, if this energy could be converted to a useful form at an average efficiency of 5%, say, then the entire electricity needs of the UK could be supplied using less than 3% of the total land area. In practice, there are technologies which can convert direct solar radiation at higher efficiencies than this, and it has been estimated that the UK electricity demand could be met by integrating these technologies into existing building structures without the need for additional land area. The problem of using direct solar radiation for human purposes, therefore, is simply one of capturing it and converting it efficiently enough to warrant the material and economic investment in the conversion devices.

There are a number of different kinds of technologies for achieving this. These fall broadly into the following categories:

- Passive solar design: which has been used since time immemorial to provide space heating and cooling in dwellings.
- Active solar devices: which concentrate the sun's radiation so as to provide heat of sufficiently high quality for space heating, and sometimes electricity generation.
- Solar photovoltaics: which convert sunlight directly to electricity through the so-called photoelectric effect.

The following sections summarise the main developments and prospects for each of these technology types.

Passive Solar

The idea behind passive solar design is to maximise the free "solar gain" from incident sunlight to reduce the need for additional heating and cooling energy requirements within buildings. Techniques of solar architecture have been used by different cultures for centuries. Islamic architecture, for example, has traditionally used the sun to induce convection currents which keep buildings cool even in hot climates.

The main principles of passive solar heating are to orientate glazed surfaces towards the sun, to site buildings in such a way as to provide protection from prevailing winds, and to avoid the heat loss that comes from windows which are in the shade. For passive solar cooling, the basic idea is to use solar heat to induce convection currents that cool living spaces. Passive solar lighting consists of increasing the availability of natural light – again through the appropriate use of glazing – and reducing the need for artificial lighting. More complex passive solar designs include the installation of glass atria, conservatories, and solar walls, and the use of roof space collectors. Passive solar is most effective when it is incorporated into the buildings at the design stage, in conjunction with a range of energy conservation measures. Nevertheless, it can also be cost-effective to retrofit certain passive solar design features, such as glass conservatories. Recent developments in passive solar design include the use of high performance glazing, which transmits light but has good insulation properties. This allows for a kind of enhanced greenhouse effect, trapping solar heat within the building.

Clearly, the existing building stock already utilises some passive solar heating potential, although it is extremely difficult to provide an accurate estimate of the extent of this. The potential for further implementation is also difficult to estimate, in part because it is linked so closely to other energy conservation measures. However, most of the technologies are fully mature, and are often commercially competitive with conventional energy supply. The EU White Paper (see Section 3.2 below) envisages an additional contribution from passive solar in the EU equivalent to 35 mtoe by the year 2010, representing 2% of the gross inland energy consumption, but most of this is expected to come from Southern European countries.

ETSU is cautious about the potential for passive solar design in the UK.[48] Acknowledging that the technology is generally mature and readily applicable, the report points to a number of failures in implementing passive solar, a misunderstanding of passive solar design concepts, and a lack of experience in implementing passive solar in mass market housing schemes. Their estimates suggest that the contribution from passive solar in the UK may be relatively limited in the short to medium term, and at best might provide around 0.12 mtoe by the year 2010.

Active Solar Thermal

Active solar technologies generate heat, usually in the form of hot water or steam, which can be used for space heating, domestic hot water requirements, or electricity generation.

Low temperature devices generally fall into two types: flat plate collectors and evacuated tube collectors. The flat plate collector has a blackened surface to absorb heat. Beneath this surface, pipes carry a fluid that is used to transfer the heat, usually via a heat exchanger, to the space heating or hot water system. Sometimes, the exchange fluid can be provided by domestic tap water, but this is less common in the UK where there is a high risk of freezing during the winter. The evacuated tube collector works on a very similar principle, except that each pipe (and its absorbing fluid) passes through an evacuated tube to reduce heat loss. Often the absorbing fluid is a volatile liquid, which evaporates on heating and condenses in a heat exchanger connected to the hot water system.

High temperature devices employ mirrors to concentrate the solar radiation onto a centralised collector. The heat generated in the collector is sufficient to raise steam, which is then used to generate electricity in conventional steam turbines. Again, there are a number of devices based on the same principles. The most common of these is the parabolic trough system, which was pioneered at utility scale in the Mojave desert during the 1980s by a company called Luz International. Supported initially by US state and federal tax credits, 9 commercial power plants were constructed before a combination of circumstances forced Luz to file for bankruptcy in 1992. A fall in oil prices, combined with sudden reductions in tax credits, hit both the immediate economics of the company and investor confidence in the future viability of the technology. In spite of this, the nine plants today generate over 350 MW of electrical power for commercial use. The other main types of solar thermal electricity generation are the parabolic dish system and the central receiver system. The two main obstacles to deployment of such systems in the UK are the (relatively) lower insolation rates, and the requirement for land area imposed by the collection system.

By contrast, there is already considerable interest in manufacturing and installing low-temperature solar collectors in the UK. By the early 1990s, there were about thirty UK firms manufacturing active solar systems. Between them they produced 36,000 m^2 of solar collectors a year, with a total sales value of £7.5 million. Two-thirds of these were exported. Of those sold in the UK, around 70% were installed for domestic water heating, with most of the remainder used to heat swimming pools. The total installed capacity in the UK provides only about 3 thousand tonnes of oil equivalent in heat.[49]

Unusually amongst the renewable energy technologies, ETSU predicts that the use of active solar for domestic heating will fall away to zero by 2015 under every scenario except one involving "heightened environmental concern". The reasons for this are that the technology is already mature, so that the potential for cost reductions is limited. But the cost of solar panels in the UK remains relatively high, and domestic heating alternatives are expected to become cheaper. Under the "heightened environmental concern" scenario, a limited uptake is envisaged, leading to total installed capacity to deliver just over 200 thousand tonnes of oil equivalent by 2025, still negligible in comparison to total primary energy supply.

In Europe as a whole the market is far from stagnant. By 1994, the European market had reached 500,000m^2 per year. German manufacturers dominated the market with sales of 180,000m^2. The market is still growing at around 18% per annum, prompted in part by subsidies in Austria, Denmark and Germany. The installed capacity is currently about 5 million m^2, and the target for implementation by 2005 – which is met under the TERES "best practice" scenario – is 30 million m^2.[50]

These considerations point directly at an issue to which we shall return several times in this paper. A combination of poorer resources (insolation rates) and fewer incentives for development has led to markedly lower levels of technology implementation in the UK than in some other European countries. This can only be expected to have a negative impact on UK manufacturers. A significant domestic market would not only provide a testing ground for technological innovation, but is also more accessible and incurs lower transaction costs than the export market. In the meantime, certain foreign manufacturers (most notably in Germany and Denmark) receive considerable support for the accelerated development of their own domestic markets. Based on this experience, these countries – which are sometimes but not always characterised by higher quality solar resources – are already beginning to dominate the wider European market and are establishing increasingly strong positions in the global markets.

Short-sightedness, and the failure to provide appropriate incentives for development, could have a devastating impact on UK manufacturers in a rapidly expanding global market, and by extension, unhappy repercussions on the balance of trade.

Photovoltaics

Originally developed for space applications, solar photovoltaic systems (PVs) convert sunlight directly into electricity using the photoelectric effect – through which light causes matter to emit electrons. Individual cells are usually based on wafer-thin layers of semi-conductor silicon with different electronic properties. When light falls on the cell, a potential difference is created between the top and bottom of the cell. Appropriately arranged contacts can then be used to collect an electric current from the cell. Individual cells are usually grouped together and incorporated into "modules" encapsulated in glass or plastic. The modules in their turn are arranged together to form a PV panel or array which is used to deliver either DC or AC power directly to a load, or via a charge controller and battery system. A complete PV system therefore requires a number of components in addition to the modules themselves. These components are often referred to as the "balance-of-system" components, and of course incur an additional balance-of-system cost over and above the cost of the modules themselves.

A number of different cell technologies are now in use. By far the most common technology is wafer-based *crystalline silicon*, which now accounts for about half of European PV production.[51] *Thin-film* technologies tend to have lower conversion efficiencies than crystalline cells, but also use much lower quantities of material deposited in very thin films on a glass substrate. The most common thin-film technology is *amorphous silicon*, which accounts for about 25% of European production. Emerging thin-film technologies include *copper indium diselenide* and *cadmium telluride cells*. *Concentrator cells* use lenses or mirrors to concentrate incident sunlight onto a small solar cell, in much the same way as mirrors are used to concentrate sunlight for solar thermal towers. The use of concentration devices imposes an additional capital cost, but leads to higher conversion efficiencies. *Multi-junction* concentrator cells – built up from several different layers each collecting a different part of the solar spectrum – have achieved conversion efficiencies as high as 37%.

Table 2: Efficiency vs module cost for different PV cell technologies
(source: Hill *et al* 1995, Table 7.1)

			Module costs (£/Wp) at different production scales		
Cell Technology	Research efficiency %	Commercial efficiency %	Production 1 MWp pa	Production 10 MWp pa	Production 100 MWp pa
Monocrystalline Si	23	14	3.0	1.5	1.0
Polycrystalline Si	18	12	3.0	1.2	0.8
Amorphous Si	14	6	2.0	1.0	0.4
Copper indium diselenide	17	>10	2.0	1.0	0.4
Multi-junction	37	NA	4.0	1.0	0.5

Table 2 illustrates that there is typically a trade-off in cell technology between reduced module costs and higher efficiency. The more efficient cells require greater material inputs and, sometimes, more complex manufacturing processes. The less efficient cells offer advantages in terms of reduced manufacturing and material input costs. Which of these effects dominates in terms of the electricity generation cost depends on a number of additional factors including the balance-of-system costs and the incident insolation level. Table 2 also shows the reductions in module cost which are expected for higher annual production outputs. At a production scale of 100 MWp[52] per annum, module costs could be a factor of three or four lower than for prototype production facilities. Production at this scale is still in the future: in 1995, total world shipments of PVs amounted to 72 MWp.[53] Nevertheless, economies of scale are one of the factors that have led to rapidly diminishing PV module costs over the last fifteen years.

Assessing the environmental impacts – and benefits – of PVs is a complex task.[54] Silicon itself is the second most abundant material in the earth's crust, but the production of semi-conductor grade silicon is a relatively energy-intensive process, typically incurring emissions of sulphur dioxide, nitrogen oxides, carbon dioxide and other energy-related pollutants. These emissions are an order of magnitude lower, per delivered kWh, than emissions from conventional power stations. Furthermore, amorphous silicon technology avoids the need for certain energy-intensive processes associated with crystalline silicon, and may therefore result in lower emissions of energy-related pollutants. On the other hand, the process of depositing thin films on a substrate involves the explosive and highly poisonous gas silane (SiH_4), presenting significant environmental and health hazards in production. Different cell technologies attempt to enhance performance efficiency by using exotic materials such as cadmium telluride. But some of these materials are extremely toxic in themselves and present dangers during use and potentially at the end of life of the modules.

Photovoltaic technology generates electricity on a completely different physical basis than either conventional generation or other kinds of renewable energy generation. It therefore presents a unique set of technical, economic, environmental, and institutional issues – both benefits and potential problems. It is also attracting increasing attention – not just among technological enthusiasts but also from large industrial interests, and from policy-makers.

At the moment, PVs are mainly being used in relatively small-scale niche applications, in consumer products (calculators, watches, etc), and in stand-alone applications remote from the grid (such as isolated communities in developing countries). In the UK, many hundreds of small systems provide power for meteorological stations, energy and water utility control devices, estuary buoys and markers, caravans and so on. But the total power output from these systems remains negligible in terms of overall electricity demand. The commercial market in the UK is always likely to lag behind other countries with better solar insolation rates. Even in Europe however, the installed capacity amounts to only 70 MWp, delivering less than 0.1 TWh per year or 0.003% of annual European electricity consumption.

In the light of these really rather modest contributions from PV technology, it is worth highlighting some of the factors which might be taken to indicate a more extensive role for PVs, if not in the next decade, then certainly within a couple of decades.

Firstly, the potential resource is enormous. Even in a country such as the UK where the insolation rate is relatively poor, PVs could produce an output equivalent to current UK electricity generation from barely 2% of the land area. In fact, it has been calculated that this output could be achieved by integrating PV modules into roofs and walls, without any additional demand for land.[55]

Integration of PVs into buildings is a relatively recent technological development but it provides a number of important technical, economic and environmental advantages over centralised PV electricity generation or even small-scale stand-alone systems. For instance, since electricity is delivered direct to the point of use, it avoids the losses associated with transmission, distribution and transformation of grid electricity. Furthermore, building-integrated PV panels replace other building materials such as roof tiles, and wall cladding. The avoided energy, environmental burdens, and cost of these substituted materials all represent additional benefits of PV. Even though the cost of stand-alone electricity generation from PVs in the UK can be as high as 60-80 p/kWh, it is already more economic to use PV cladding than to use polished stone cladding, and in this case the electricity can be regarded as a free resource.

An increasingly popular application of building-integrated PV technology is the solar roof tile. The availability of this easy-to-install, modular technology has prompted a number of ambitious, government-backed installation programmes. The first of these, and the biggest in the EU, was the German "thousand roofs" programme, which by 1995 had achieved its target of installing small (1-5 kWp) PV systems on the roofs of 1,000 domestic residences and small company properties. Last year, the US announced a programme to install 1 million solar roofs by the year 2010; and even more recently, the Indian government has announced an ambitious programme to install a million and a half solar roofs by the year 2002.

In the EU, there are a number of different targets for the implementation of PVs by 2010. The most ambitious of these, contained in what has become known as the Madrid Action Plan calls for the installation of 16,000 MWp by the year 2010.[56] The TERES study estimates that under existing policies only around 1,000 MWp will be installed by that date, although under a full set of "proposed policies" this could rise to almost 7,000 MWp. This represents a 100-fold increase over the current installed capacity, and a major opportunity for expansion by PV manufacturers.

Not surprisingly, targets and predictions like this have prompted a vigorous response from PV manufacturers. The Madrid Action Plan calls for an expansion of PV manufacturing capability in the EU from current levels (around 35 MWp per year) to 500 MWp per year. As we have already mentioned in the introduction, both Shell and BP last year announced their intentions to expand research and development efforts in PVs. Shell wants a 10% share of the global PV market by 2005. BP is looking for $1 billion turnover from PVs by 2010. Certain governments, most notably the German, have been quick to lend their support to domestic manufacturers, and for a very good reason. Shell predicts that the solar PV market will be worth $25 billion by 2025.

Set against these signs of massive expansion in PVs, it is worth remarking on a number of facts. Firstly, PV modules are still considerably more expensive than conventional electricity except in isolated locations removed from the grid. Secondly, in spite of rapidly falling module costs, the balance-of-system costs are likely to constrain further cost reductions at recent rates. Next, the cost of the German 1,000 roofs programme prompted one observer to write that it was "unlikely to be extended in the current financial climate".[57] Finally, even if the Madrid target of 16,000 MWp were achieved by 2010 – implying expansion at about 45% per year from 1995 levels – this would still only represent 1% of EU electricity supply.

In the UK, the predicted contribution from PVs in the ETSU study is considerably smaller even than this. Virtually no contribution at all is expected by 2010 except under the "heightened environmental concern" scenario, which sees a contribution amounting to less than 0.1 TWh per year or 0.03% of current electricity demand. On the other hand, this kind of prediction – carried out in 1994 – could quite simply be out of date in the light of events which have taken place in only the last twelve months. If that is the case, then to rely on such predictions could seriously jeopardise the UK's position in a rapidly expanding technology market which may one day be of vital importance to the energy sector.

Other Solar Technologies

There are a number of other solar-based technologies, none of which offer extensive potential at the present time, but should be mentioned here for the sake of completeness. These include:

- Solar ponds: in which heat is trapped at the bottom of the pond by an increasing salt concentration gradient; the trapped heat is used to generate a power cycle.
- Solar stills: in which incident sunlight is used to distil fresh water from salt water as a means of desalination.
- Photoconversion: a generic term covering the photoelectric conversion of sunlight to electricity (PVs), and the photosynthetic conversion of light to chemical energy (biomass) but which also includes a number of other conversion processes including photoelectrochemical (PEC) storage cells and photobiological hydrogen production.

None of these technologies is expected to make a significant impact on the market within the next few decades.[58]

2.6 Wind

Wind energy is generated from thermal currents induced by solar radiation. The basic pattern of wind is set up by the warming of equatorial air, and the cooling of polar air. This provides for surprisingly constant global wind patterns. In the UK for example, our weather is dominated by the prevailing North Atlantic westerlies, which deliver average wind speeds of between 4.5 and 9 metres per sec (m/s), providing one of the best wind regimes in Europe.[59] Partly for this reason, Britain has a long history of using wind power. Before the industrial revolution there were an estimated 10,000 large windmills in Britain capable of delivering mechanical work equivalent to approximately 1 mtoe.[60]

Modern electricity-generating wind turbines bear only a passing resemblance to their mechanical predecessors, although the operating principle is similar: the flow of the wind against the wind veins – blades in the modern terminology – creates a rotational motion which can be used either for mechanical power or to generate electricity.

Typically, modern electricity generating wind turbines have two or three blades mounted on a horizontal axis, generating power according to the cube of the wind speed. Wind generated electricity is generally regarded as being attractive in wind speeds of 5 m/s and above.

Recent interest in wind generated electricity stems, as with so many other renewable technologies, from the 1973 oil crisis. Evolution of the technology since that time has occurred in four distinct phases.[61] The first phase (from 1976 to 1981) was characterised by government programmes (mainly in the US, Sweden, Germany and Canada) attempting with mixed success to develop very large turbines. The second phase (1982-1985) saw the development of an expanding market for small and medium-sized turbines in the US. Favourable tax incentives led to an expansion of the installed capacity in California from 10 MW in 1981 to over 1,000 MW in 1986. The size of commercial units doubled from 50 to 100 kW, and the cost fell by almost two-thirds in the same five-year period. The third phase from 1985 to almost the end of the decade was dominated by the withdrawal of US tax credits, and the fall in oil prices. A number of wind turbine manufacturers went bankrupt, and others were forced to merge. UK wind turbine manufacturers were victims of this period. But the survivors – in particular the Danish firms – consolidated a more streamlined market, in which technological innovation and market pressure led to improved performance and reduced costs.

The final phase, from the late 1980s onwards, has been one of resumed expansion, seeded by increased commitments from national wind energy programmes, in particular in Denmark, Germany and the Netherlands. Turbine sizes have increased, with 500 kW machines now commonly available and some manufacturers building 1 MW machines. Performance has improved, and capacity factors[62] have more than doubled from a decade ago. As a result costs have come down significantly, and in good wind speed sites, wind energy is fully competitive with conventional electricity generation.

At the end of 1996, worldwide installed wind capacity was almost 6,000 MW. Over half of this capacity was in Europe, and much of the rest in the USA. Installed capacity in the UK was about 270 MW, mainly as a result of the introduction in 1991 of the NFFO (Section 3.1 below). The most spectacular expansion in wind energy has occurred in Germany. In 1994, installed capacity was around 632 MW, already slightly higher than Denmark, who was already dominating the market in turbine manufacture.[63] But by the beginning of 1998, the installed capacity in Germany had more than trebled to reach 2,079 MW, making the country the world leaders in wind power, ahead of the USA.[64]

The future of wind energy is likely to see at least some continuation of these kinds of trends. Performance continues to rise, costs continue to fall. Shell has estimated that the global wind energy market will be worth $133 billion by 2020. The World Energy Council has predicted a global contribution from wind power of almost 600 TWh by 2010, of which some 120 TWh could come from Europe. The accessible resource for wind energy in the UK has been estimated at over 700 TWh per year, more than twice the current electricity demand, and well over twice the resource from any other renewable energy source. The "maximum practicable resource" is less than a third of this, and the projected contribution only rises to 30 TWh per year by 2010 under the "heightened environmental concern" scenario.[65]

The environmental credentials of wind energy are generally very good. Operation and maintenance costs are low, and no significant environmental burdens are incurred during turbine manufacture. However, the visual impact of wind turbines is becoming increasingly important in determining the public acceptability of this power source. The best wind energy sites are also quite often sites with a high aesthetic or amenity value, and increasing public opposition has slowed down the implementation of wind energy in the UK, as it has in some other countries. In Section 4.2 below, we examine the implications of this situation in more detail.

A consensus seems to be emerging that if wind energy is to provide significant contributions to supply – in particular in countries where land is at a premium – it is most likely to come from turbines located offshore, where visual intrusion is at a minimum. In fact, offshore wind energy accounts for well over half the UK resource base. Currently, however, little practical experience with offshore wind energy exists, the operating environment is harsher, and the viability of the technology under these conditions is unproven. The DTI's official (1994) predictions for wind energy in the UK envisaged no commercial implementation of offshore wind energy before 2025.[66] On the other hand, in the light of more recent experiences (for instance in Denmark), these predictions could already be out of date.

2.7 Energy Storage and Related Technologies

Most renewable energy sources are intermittent in nature, with the exception perhaps of biomass – which is relatively easy to store and consume as required – and hydroelectricity – where storage capacity can be built in through dams and reservoirs. At low penetrations, this intermittence does not matter too much. Sufficient flexibility exists in the conventional energy supply system to cushion the impact of relatively small fluctuations from renewable sources. For example, the electricity grid system is designed to manage quite substantial changes in the demand for electricity; a substantial capacity margin is already built into the system to accommodate this. It has been estimated that renewables could contribute as much as 30-40% of electricity supply before the intermittent nature of the source proved to be a constraint.[67] At higher penetrations however, the intermittence of the source may give rise to substantial cost penalties, and eventually, the question of *energy storage* (to smooth out diurnal and seasonal variations in supply) becomes an important issue.

It would not be possible within the constraints of this paper to provide a comprehensive account of developments in this field. However, it is probably useful to identify the main storage technologies that are emerging today. These include: biological storage (in biomass), mechanical storage (either in flywheels or as pumped hydro – discussed in 2.3 above), thermal storage (for example in insulated underground wells), electrical storage (in a variety of batteries ranging from lead acid to the new metal hydride technologies), and chemical storage.

Amongst the possibilities for storage chemicals is *hydrogen* – increasingly regarded as an important energy carrier for the future. In principle, hydrogen could be produced either by electrolysis powered from renewable energy sources, or else from the gasification of biomass. Since the late 1980s, the German company Siemens in association with the utility Bayernwerk has been operating a test station which uses solar photovoltaic electricity to power hydrogen production by electrolysis in Bavaria. In the US, Battelle Laboratories have experimented in gasifying biomass to making hydrogen.[68]

There are several advantages in using hydrogen as a transport and storage medium. As a combustion fuel, hydrogen is clean and efficient, and can be employed in a variety of end-uses including heating, conventional electricity generation, and transport. It can also be used to produce electricity in fuel cells (see below). The technology of the solar hydrogen cycle is well known. The fuel-cycle costs are not currently competitive with conventional fuels, but the long-distance transmission of hydrogen is likely to be far less costly than long-distance transmission of electricity.

Not strictly a storage device, *fuel cells* are nevertheless an inherent part of storage concepts like that of solar hydrogen, because they convert storage fuels efficiently into electricity. Fuel cell technology is gaining ground as a method for providing heat and power efficiently and cleanly using a variety of input fuels, including hydrogen (see above), natural gas and biofuels such as methanol. There are now a wide variety of types of fuel cells. Some of these – most notably the Phosphoric Acid Fuel Cells – have several thousands of hours of operating experience in the USA and Japan. Costs are still higher than conventional heat and power production but are expected to fall as the technology develops and could become competitive in the medium to long term.

2.8 Technology Summary

The preceding sections illustrate, if nothing else, the technological variability of renewable energy sources, and the complexity of the economic and institutional issues which flow from this. Such diversity must surely be one of the reasons that the renewable energy technologies have found it hard to penetrate conventional energy markets. By the same token, formulating an appropriate development strategy for the renewables (as a group) is an extremely difficult task, fraught with the potential for wrong turnings, blind alleys, lost opportunities, and wasted resources.

One of the responses to this difficulty is to attempt some prioritisation of technologies, mainly on the basis of their commercial maturity and competitiveness with conventional generation. This approach tends to be followed, for example, within model-based predictive studies, such as the ones we have used in this study at global, European and UK level. It also tends to inform, and sometimes dominate, the policy measures. In our opinion, this is not necessarily an appropriate response to the diversity of issues with which renewable energy presents the policy-maker. Nevertheless, it is interesting to note that, within such attempts, there is a fair degree of convergence, at least on which technologies offer the best prospects for commercial penetration in the short to medium term.

As an example, the TERES report divides renewable energy technologies into four groups characterised by the commercial maturity of the technology on the one hand and its competitiveness on the other (Table 3). The short-list of immediately promising technologies (ie Group 1 in Table 3) is not entirely dissimilar to the characterisation which flows from the ETSU study, in which the technologies with best short-term prospects are identified as: onshore wind, small-scale hydro, landfill gas, waste combustion and passive solar design. As we shall see below, it is largely these technologies which are picked up for specific support in the UK's NFFO.

However, this not to suggest that there is unanimous consensus about the potential for the different technologies. For instance, the TERES categorisation places tidal power amongst the technologies that are commercially mature but not cost-competitive at present, whereas ETSU regards tidal as one of the resources "unlikely to be commercially deployed in the foreseeable future". Furthermore, such categorisations offer the capacity for significant surprises. Offshore wind is another technology given a very low priority by the ETSU study. Yet, in the time since that study was written, Denmark has pioneered and gained considerable operating experience with semi-commercial offshore wind installations. Furthermore, this experience suggests (unexpectedly) that the offshore machines perform better than their onshore counterparts, because of the greater constancy of the resource.[69]

Table 3: Status of renewable energy technologies (TERES study)

Group 1	***Commercially mature and can be competitive with conventional sources*** Hydropower Geothermal Wind (high wind speed sites) Active and passive solar heating Landfill gas Energy from wastes
Group 2	***Commercially mature but not cost-competitive at present*** Solar PV Liquid biofuels Tidal Wind (at lower wind speed sites) Small-hydro (at sites with lower density resource)
Group 3	***Technical development needed but will be cost-competitive by 2010*** Electricity and heat production from energy crops
Group 4	***Technical development needed with fewer prospects for competitiveness by 2010*** Wave energy Solar thermal electric

This situation highlights very clearly that it is potentially dangerous to promote renewable technology development through a kind of commercial "league table" approach. It may simplify short-term choices about which technologies to favour in policy decisions. But the complexity of the issues involved, the speed at which development is occurring, and the dependence of technological success on institutional will, all suggest a more eclectic selection framework. Examples of aggressive technology advocacy are legion. Danish wind energy, Swedish biomass, German photovoltaics, US solar power, Brazilian biofuels are a few of the examples which suggest that energy technology markets develop on the back of strong government commitments. Tomorrow's technology is not just a question of which technology is performing best today. It also depends – amongst other things – on which technology is *supported* today.

3. Policy and Institutional Context

Recent policy decisions at three separate levels have direct implications for the development of renewable energy sources over the next decade or so. On coming to power in May last year, the Labour government set in motion a review of what would be "necessary and practical to achieve 10% of the UK's electricity needs from renewables by the year 2010". In November last year, the EU White Paper on renewables set out policies and actions for doubling the contribution from renewables to energy supply in the EU from 6% to 12% by the year 2010. Finally, in December last year, the Parties to the Framework Convention on Climate Change signed the Kyoto Protocol committing Annex 1[70] countries to quantified greenhouse gas emission reduction targets by 2008 – 2012. In this section, we set out the implications of these initiatives for renewable energy development in the UK, and the prospective impacts of emerging commercial commitments to renewable energy.

In light of the fact that, currently, renewables account for only 2% of the UK's electricity needs, the 10% target for contribution to electricity supply from renewables by 2010 would appear to be more ambitious than that of the EU, in terms of a proportional increase. However, as John Battle[71] explained at a recent meeting of the Parliamentary Renewable and Sustainable Energy Group, an additional 3% of electricity demand is expected to flow from contracts which have already been awarded under the NFFO by about 2002 or 2003. This would leave a further increase from 5% to 10% contribution to be achieved between that time and 2010, some of which would be expected to come from the same Obligation. This mechanism is therefore a key element of renewable energy policy in the UK, potentially crucial to achieving the desired target.

3.1 The Non-Fossil Fuel Obligation (NFFO)

The NFFO was first established for England and Wales during the privatisation of the electricity supply industry in 1989. The Scottish Renewables Order was later set up for Scotland, and a similar mechanism has subsequently been implemented in Northern Ireland.

The NFFO requires regional electricity companies (RECs) to buy a certain quantity of non-fossil fuelled electricity, even if this electricity is more expensive than conventional supplies.[72] The additional cost to the RECs of purchasing this electricity is paid for via the "fossil fuel levy"; a payment levied on consumers' electricity bills. The current rate of the fossil fuel levy is 2.2% in England and Wales, and 0.7% in Scotland. The majority of the funds collected under the levy have been spent on nuclear power. However, an increasing proportion is being spent on renewable energy, and it is foreseen that about half of the levy will go towards renewables in 1998.[73]

Contracts to supply renewable electricity are awarded by the Department of Trade and Industry on the basis of a competitive bidding process within different technology "bands": wind, small-scale hydro, landfill gas and so on. Four NFFO orders have so far been awarded, offering a total of 530 contracts to install a total declared net capacity[74] (DNC) of 2,094 MW (Table 4). At the expected completion rate (see below), this capacity would bring the proportion of electricity generated from renewables in the UK to about 5%. A fifth and final order was announced in December 1997 and will be awarded during 1998.

Table 4: Contracts awarded in four NFFO orders
(Sources: OFFER 1997 and New Review, Issue No. 32, May 1997)

Technology band	1st Order 1990 MW DNC	2nd Order 1991 MW DNC	3rd Order 1994 MW DNC	4th Order 1997 MW DNC
Wind	12.2	84.4	165.6	340.8
Hydro	11.9	10.9	14.5	13.3
Landfill gas	35.5	48.4	82.1	173.7
Sewage gas	6.5	26.9	-	-
Waste-to-energy	86.1	301.6	241.9	241.3
Energy crops and agricultural residues	-	-	122.9	74.0
Total	152.1	472.2	626.9	843.1

Generally speaking, the NFFO has been recognised as an effective mechanism for encouraging an increased contribution from renewable energy technologies, and a measure of convergence has been achieved between renewable energy costs and the cost of conventional power sources.[75] The average bid price in the first two NFFO orders was around 7 p/kWh compared to the supply pool price of about 2.5 p/kWh. But the average price in the Fourth Order was just over 3.9 p/kWh.[76] A part of this fall in prices has been due to the change in contract period after the first two orders. NFFO1 and NFFO2 projects had to recover costs in only 6-7 years. Later projects were awarded 15-year contracts. Nevertheless, there have also been genuine cost reductions as a result of technology development and competitive bidding.

Table 5: Installed Capacity under four NFFO orders
(Sources: OFFER 1997 and New Review, Issue No. 34, November 1997)

Technology band	1st Order 1990 MW DNC	2nd Order 1991 MW DNC	3rd Order 1994 MW DNC	4th Order 1997 MW DNC
Wind	11.6	53.8	23.1	-
Hydro	10.0	10.4	7.9	-
Landfill gas	31.7	46.4	55.3	0.6
Sewage gas	6.0	26.9	-	-
Waste-to-energy	86.1	44.0	28.2	-
Energy crops and agricultural residues	-	-	-	-
Total	145.4	181.5	114.5	0.6

Perhaps the biggest difficulty associated with the NFFO is that the installed capacity has lagged some way behind the contracts awarded. By the second half of last year, less than half the number of contracts awarded had actually been installed, and these tended to be smaller projects, so that the installed capacity (442 MW) was less than a quarter of the total (Table 5).

How much of this shortfall is simply due to an inevitable lag time between the award of contracts and the installation of hardware is difficult to estimate. Since the Fourth Order was only announced at the beginning of last year, it is perhaps not surprising to see little of this later capacity installed. Most of the (much smaller) First Order has now been installed. From the Second and Third Orders, it is interesting to note how different technologies have performed. Most of the small-scale hydro, landfill gas, and sewage gas contracts have already been taken up in both orders. Waste-to-energy options and wind energy options (particularly from the Third Order) are still lagging a long way behind the contracted capacity. Since the technological lead-time for these kinds of projects is relatively short (in the region of 1-2 years), this suggests that some other factors are at work, slowing down the uptake of wind and waste-to-energy options.

The Office of Electricity Regulation (OFFER) identifies a number of possible reasons for low completion rates, including: the fact that some projects (in the waste-to-energy band) are competing for the same fuel sources; unforeseen cost increases which render projects uneconomical; and failure to secure planning permission.[77] The last of these is of particular interest, in part because it relates to the institutional arrangements under which the NFFO is operated, and in part because it reflects on the issue of public acceptability of renewable energy.

A part of the institutional arrangements under which NFFO proposals are considered is a procedure known as the "will-secure" test which is designed to weed out those projects which if accepted have little chance of actually being implemented. Included in this test is a planning review, but the requirements of this review are relatively weak. The applicant needs only to demonstrate awareness of the planning consents needed and to have established that there are no *a priori* reasons for planning permission to be rejected. Planning consent itself need not be established until the contract is awarded.

On the other hand, award of an NFFO contract "does not confer any special privilege in the planning process which must be carried out in the normal way."[78] This means that there is almost inevitably going to be a shortfall between the contracted capacity and the installed capacity, particularly in projects where there is likely to be opposition at the planning stage. Wind energy and waste-to-energy, in particular, are known to incur a good deal of public opposition – the first for its visual impacts, and the second because of public health concerns. This is now recognised as such a significant issue in the development of renewable energy in the UK, that we address it in some detail in Section 4.2 below.

One further aspect of the NFFO is worth commenting on; namely its relationship to EU demonstration funding schemes. The European Commission provides funding for the "innovative" aspects of energy sector projects under its THERMIE programme. Selected projects fall into a number of different categories including rational use of energy, renewable energy, and fossil fuel technologies. Over the eight years to the end of 1997, the UK's share of the total THERMIE funds allocated was 15%. However, the UK's proportion of funds allocated for renewable energy was only 11%.[79] One of the reasons for this is the absence of integration between the NFFO process and the EU funding process. Disjunctures in the timing of the two application processes, and the absence of specific correlations between the award of NFFO contracts and the award of THERMIE funding have left some contracted NFFO projects unfunded, and some "funded" THERMIE projects uncontracted.[80]

In an effort to improve the rate of take-up of renewables under the NFFO, the later orders were constructed via a two-stage process in which the total capacity awarded included expectations about the likely completion rate. In other words, the total capacity awarded was calculated by dividing the desired capacity by the expected completion rate for each technology. In NFFO 4, the overall expected completion rate was 60%, while the expected completion rates for wind energy and waste-to-energy options were 50%. By contrast, the actual completion rate (to date) from the first three orders is only about 35% (Tables 4 and 5). Completion rates for wind energy and waste-to-energy were even lower at 34% and 25% respectively. Three years after the third NFFO order was announced, the completion rates for these technologies (under the 3rd Order) were 14% and 11% respectively.

These figures seem to suggest the expected completion rates are over-ambitious in the current regulatory and planning environment. If this is true, it will have implications for the expected additional 3% contribution from renewable energy by 2002/3, and a knock on effect on the feasibility of meeting the 10% target by 2010. Approximately 0.7% of UK electricity demand is currently generated under the NFFO. Extrapolating the current implementation rate into the future suggests that by 2010 the total contribution from NFFO sources will only reach 2%. Taking into account an additional 2% from large-scale hydro, the contribution from renewable energy will still only be 4%, less than half of the government's target.

A closer examination of the funding of renewable energy projects under the EU's THERMIE scheme highlights another critical aspect of the NFFO. Almost all (93%) of the funding for renewable energy projects in the UK was dedicated to wind, biomass, and hydro – the technologies favoured by the NFFO. The UK's representation in solar, geothermal and renewable energy in buildings was less than 2% of the total EU funding in these areas. In other words, by imposing narrow criteria of commercial competitiveness on the NFFO process, the UK may have selected itself out of development funds for more speculative technologies.

The recently announced fifth NFFO is the last of the planned renewable orders under the existing schedule. The future of an appropriate support mechanism for renewable energy – integrated both into planning processes and with potential funding sources – must be a priority if the impetus generated by the NFFO is not to be lost.

3.2 The EU White Paper on Renewables

The publication, last November, of the European Commission's White Paper – *Energy for the Future: renewable sources of energy* – marked the culmination of an extensive period of research work and public consultation by the Commission aimed at identifying the potential for an increased contribution from renewables in the EU. The main thrust of the paper was to confirm a target of doubling the contribution from renewables from 6% of energy consumption to 12% by the year 2010, and to set out a detailed action plan for reaching this goal.

The principal factors that have contributed to a progressive view of renewables by the Commission are:

- the environmental benefits associated with renewables – in particular in terms of reducing greenhouse gas emissions;
- a reduced reliance on imported fuels with benefits in terms of security of supply; and
- the stimulation of technology export markets, with knock-on benefits in terms of increased employment.

The European Union took a progressive negotiating position to the Kyoto summit (see Section 3.3 below) in which they sought a commitment to reduce greenhouse gas emissions by 15% from 1990 levels. In a recent Communication, the Commission analysed the consequences of the Kyoto negotiating position, and concluded that major policy decisions should be taken to increase the uptake of low carbon energy sources, including renewables.[81] The EU has also tended to take a proactive stance in negotiations to reduce other energy-related atmospheric emissions such as sulphur dioxide, and nitrogen oxides.

Current dependency on imported fuels in the EU is very high – around 50%. Dependency is particularly high for oil and gas, which are increasingly likely to come from greater distances outside the Union. This dependency is projected to rise to 70% by 2010 in the absence of specific policy measures to reduce it, and is seen as a potential threat to future security of supply. Renewables provide inherently local sources of supply, which would reduce the geopolitical risks involved in the energy market.

The worldwide annual turnover in sales of new, renewable energy technologies (excluding large-scale hydro) is estimated at ECU 5 billion. The EU currently has more than a one-third share of this market, and is at the forefront of development in several technical areas, including wind power, photovoltaics, and biomass gasification. As the White Paper remarks, "the leading position of the European renewable energy industry world-wide can only be maintained and strengthened on the basis of a significant and growing home market".

As a first step towards a renewable energy strategy for the EU, the Commission adopted a Green Paper in November 1996, in which the target for doubling the contribution from renewables from 6% to 12% was first proposed.[82] During the consultation period that followed, the Green Paper elicited a variety of responses from Member States, community institutions, agencies, and lobby groups. The response was described as "overwhelmingly positive", although there was some opposition. For example, the energy lobby group Eurelectric felt that the target was unrealistic, and would place a disproportionately high cost burden on the electricity industry because some renewables would still not be commercially competitive by 2010.[83] However, the European Parliament itself proposed a higher target (15%) than the one suggested in the Green Paper.[84] In confirming the target, the White Paper argued that an indicative target is "a good policy tool, giving a clear political signal and impetus to action", and declared that the goal of achieving a 12% penetration of renewables in the Union by 2010 is "an ambitious but realistic objective".

Table 6: Current and Projected Renewable Energy Consumption (mtoe)
(Source: EC 1997, Table 2)

Type of energy	Current (1995)	Projected (2010)	% increase
Wind	0.35	6.9	1871%
Hydro	26.4	30.55	16%
Large-scale	(23.2)	25.8	11%
Small-scale	(3.2)	4.75	48%
Photovoltaics	0.002	0.26	12900%
Biomass	44.8	135	201%
Geothermal	2.5	5.2	108%
Solar Thermal	0.26	4	1438%
Total Renewable Energies	74.3	182	145%
Passive Solar		35	

The predicted contributions to the target from individual technologies are set out in Table 6 together with the contributions from each technology in 1995.[85] The Table shows that the total contribution from renewables in 1995 was 74.3 mtoe, or 5.44% of total energy consumption in the EU. By 2010 the projected consumption from supply technologies will be 182 mtoe with a further 35 mtoe coming from passive solar design. The biggest absolute increase comes from biomass. An additional 90 mtoe is predicted from this source, of which about half will come from energy crops, and the rest from wastes and residues. Fifteen to twenty-fold increases are envisaged for wind and solar thermal. The installed wind capacity in 2010 would be 40 GW, providing the second largest contribution from new, renewable sources. Solar photovoltaics is set to increase almost one hundred and thirty-fold, although the contribution in 2010 remains relatively small at 0.26 mtoe, still only 0.02% of total energy consumption.

It is estimated that doubling the contribution from renewables by 2010 would require an increase of approximately 30% in energy sector investment, but could create 500,000 to 900,000 new jobs,[86] save 3 billion ECU annually in fuel costs, reduce imported fuels by 17.4% and save 402 million tonnes of carbon dioxide annually. In addition, a 17 billion ECU annual export market is projected for 2010, creating perhaps an additional 350,000 jobs.

The White Paper elaborates a detailed action plan for reaching the 12% target, and also sets out a "campaign for take-off" designed to seed the implementation of technologies in specific areas. The action plan suggests a number of policy measures and institutional initiatives for ensuring that the potential for renewable energy is realised. These include:

- ensuring fair access for renewables to the electricity market;

- the use of fiscal and finance measures – such as green tariffs, start-up subsidies, tax exemptions, flexible depreciation of renewable energy investments, green funds, soft loans, and public renewable energy funds;
- a new bioenergy initiative for liquid fuels in the transport sector;
- promotion of renewable energy technologies in the building sector – in conjunction with energy efficiency measures;
- standardisation in renewable energy products and services; and
- the provision of information and consumer advice.

Consideration is given to the development of research, development and demonstration, to the integration of renewable energy policy into regional policy, and in particular to the role of the Common Agricultural Policy and rural development policies in promoting energy crops.

The "campaign for take-off" sets out a number of "key actions" designed to promote specific technologies. These include targets for the implementation of:

- 1 million photovoltaic systems, comprising 500,000 roof and facade systems within the EU, and an export initiative for 500,000 village PV systems in developing countries;
- 10,000 MW of large wind farms, representing 25% of the feasible wind energy penetration shown in Table 5;
- 10,000 MW (thermal) of biomass installations, in particular in combined heat and power applications;
- integration of renewable energy in 100 communities, including a number of pilot communities where the aim would be to provide 100% power supply from renewables.

The Commission envisages that these initiatives will be funded by up to 25% from public sources, with the rest of the funding coming from the private sector. Public money will come partly from EU funds, such as ALTENER II – the only EU funding mechanism exclusively dedicated to funding renewable energies, and now targeted specifically at achieving the aims of the White Paper.[87] But as Patrick Lambert, head of the unit in DGXVII responsible for the White Paper pointed out, "we are not talking about suitcases full of money here".[88] The balance of the financial contributions towards the aims of the White Paper must come from Member States.

Generally speaking, success in meeting the indicative target relies crucially on the support of Member States, the European Parliament, and internal European bodies such as the Economic and Social Committee and the Council of the Regions. Initial responses to the White Paper from within the EU have been positive. An inter-parliamentary meeting on renewable energy in the EU held in Canarias in January 1998 pledged high-level support for the actions and proposals in the White Paper.[89] The Committee on Research, Technology Development, and Energy has drafted a proposal for an EU Directive on network access for electricity from renewables.[90] But the process of achieving the indicative targets set out in the White Paper is likely to require a committed effort on the part of EU institutions and Member States over the next decade. In particular, the need to integrate the demands of the White Paper with EU policy in areas such as the Common Agricultural Policy, the Directive on the Internal Market for Electricity, and trade policies, will be paramount.

3.3 The Kyoto Protocol

One of the motivating factors behind the EU's increasingly proactive stance on renewable energy has been the declared aim of reducing greenhouse gas emissions such as carbon dioxide, methane and nitrous oxide, many of which arise from energy sector activities. The implementation of the EU's 12% target would lead to carbon dioxide emission reductions of approximately 400 million tonnes, equivalent to a 5% reduction over 1990 levels, by 2010.[91] Although this reduction is relatively small, renewables are seen in the longer term as an important part of an on-going strategy to reduce greenhouse gas emissions.

In the spirit of this approach, the EU negotiating position at the Kyoto conference in December 1997 called for industrialised nations to adopt a target to reduce greenhouse gas emissions by 15% over 1990 levels by the year 2010. About half the necessary emission reductions were to have been delivered by the renewables target, with the rest coming from energy efficiency and energy saving measures. Within the EU itself, these reductions were to have been achieved by apportioning the overall reduction burden differently amongst the Member States. In this way, countries that could more easily achieve reductions undertook a greater commitment than those that would find emission reductions more difficult. The UK's contribution to this burden sharing approach was to have been a reduction of 10% over 1990 levels, somewhat lower than the average.[92]

In the event, the Kyoto negotiations settled on reductions varying between 6 and 8% levels of a basket of six greenhouse gases by the period 2008-2012. It is not yet clear what effect this will have on EU policy. It is possible, for instance, that the EU could still aim unilaterally for the 15% reduction favoured in the pre-Kyoto negotiating position. Were the EU to settle for the allocated 8% target, there remains the question of whether and how the overall figure would be allocated between Member States. The implications for the UK are uncertain.

In any event, the political incentive to increase contributions from low-carbon sources (such as renewables) must be seen to have diminished slightly as a result of the Kyoto negotiations. This is partly because the targets agreed at Kyoto were lower than those proposed by the EU prior to the negotiations, and partly as a result of the establishment of extensive "emission trading" arrangements within the Protocol. In principle, the EU could satisfy its Kyoto commitments relatively easily, by investing in low-cost energy efficiency improvements in the Central and Eastern European "economies in transition", without any extensive recourse to domestic measures such as increased contributions from renewable energy.

As far as the UK is concerned, the Kyoto emission reduction commitments fall considerably short of the government's own declared target of a 20% reduction in carbon emissions by 2010. Indeed, current projections indicate that a 4-8% reduction in carbon dioxide emissions is likely to be achieved by 2000 anyway, even without policy intervention. Even though business-as-usual emissions may begin to rise again slightly in the early years of the next century, the likelihood that the Kyoto target will bring significant pressure to bear on UK energy policy is low.

At the time of writing it is still not known whether the EU or the UK will continue to commit unilaterally to their earlier targets. If they do so, then meeting 2010 targets could exert a significant pressure to invest in renewable energy technologies. A 10% contribution to electricity supply from renewables could reduce carbon dioxide emissions by approximately 14 million tonnes, a modest but nonetheless valuable contribution in an electricity supply system, which may by that time already have an extensive contribution from low-carbon fuels like gas.

3.4 Commercial Initiatives

The increasing political interest in renewable energy has produced an upsurge in commercial activity from energy companies, and technology manufacturers. Typical of this kind of activity is the recent expansion of interest in renewables by Shell, the largest oil company in the world. In 1997, they announced the formation of a new business – Shell International Renewables – as a fifth core business to sit alongside the traditional oil exploration, production, products, chemicals, and gas and coal sectors. The company's first PV production plant began operation in Helmond, the Netherlands, in September. Shell plans to invest $500 million in renewables – mainly photovoltaics and biomass – in the next five years with the aim of capturing 10% of the solar PV market by 2005.[93]

The reason for Shell's growing involvement in renewables is simple: it believes that certain renewable energy technologies will achieve profitability if the price of oil remains at $15 per barrel or above over the next twenty years or so. Assuming that the technologies traverse similar learning curves to those witnessed by other technologies over the past 100 years, then Shell believes that renewables will begin to make a significant contribution by 2020-2030, and by the middle of next century could be contributing 50% of the world's energy supply.[94]

This level of expansion would lead to very substantial technology markets. Shell estimates that by 2020 the renewables market will be worth close to $250 billion, with biomass and PVs accounting for $90 billion and $25 billion respectively. The wind energy market is also predicted to expand rapidly, with turnover reaching $25 billion by 2010, and $133 billion by 2020. At its launch last year, the new company indicated that it could capture between 5% and 10% of this expanding market for wind, but had no immediate plans for investment. Shell has subsequently joined the European Wind Energy Association, and formed a task force to identify investment opportunities in wind.[95]

Shell International's initiatives in 1997 were perhaps the most surprising, and the most extensive, of the developments amongst investors in renewable energy. But they were by no means unique. Late in 1996, oil giant BP announced its withdrawal from the Global Climate Coalition, a US-based industry group which lobbies extensively against greenhouse gas emission reductions. In May 1997, BP announced a significant boost in investment in their solar power business, BP Solar, with the aim of increasing sales from current levels of $100 million to $1 billion over the next decade.[96] Major expansions in PV production capacity were announced in Germany, which has declared its aim of establishing world leadership in solar production. Shell Germany and Pilkington Solar International are to build a new 25 MW capacity manufacturing plant at Gelsenkirchen. Another German company, Angewandte Solarenergie, is to expand the capacity of its plant in Alzenau from 1 MW to 13 MW by 1999.[97]

This burst of activity on the supply side could be construed as wishful thinking, or perhaps even poor investment, were it not for two factors: firstly, that it is being led by major international energy supply companies; and secondly, that policy decisions on renewable energy are clearly in the process of generating huge demand side increases. Government (and EU) targets for the implementation of PVs alone (see section 2.5 above), would suggest that Shell's estimate of the PV market in 2020 may already be an underestimate. PV sales are already growing, and investments are expanding in size. The biggest PV plant in Europe, covering 25,000 square metres, is now under construction at the US Ford motor company plant in Bridgend, Wales. The total value of the investment is around $2.2 million.

3.5 Implications for the UK

To summarise: the institutional and policy context for renewables is one which has been changing rapidly in a very short space of time, and particularly so within the last twelve to eighteen months. In spite of the fact that the commitments emerging from the Kyoto Protocol were relatively weak, there are clear signs of a shift in thinking towards renewables at the European level, at the level of individual governments, and within commercial companies.

During the late 1970s and early 1980s, Britain was at the forefront of development in renewable energy technologies. By the end of the 1980s, a limited domestic manufacturing sector in wind energy had more or less collapsed, and much of the research and commercial impetus was lost to other countries. The introduction of the NFFO in the 1989 Electricity Act was an innovative piece of policy-making with the potential to make a significant impact on renewables in the UK. But as Tables 4 and 5 have shown, completion rates have so far been relatively low, and – perhaps more worryingly – very little has been done to advance technologies not included in the NFFO which have significant potential for either domestic power production or vigorous export markets.

The new government has shown signs of remedying this situation – announcing a major review (which is due to report this year) to assess the feasibility of a 10% target for renewables by 2010. Environment Minister Michael Meacher has indicated that this review may increase support for technologies such as offshore wind, and wave, where the UK is particularly well endowed. On the other hand, increased wind capacity would rely – as existing wind capacity does – on imported technology, and the government appears to have rejected pleas to support domestic manufacturing in the solar sector.[98]

The situation in the UK contrasts sharply with certain other European countries, most notably Germany and Denmark. Germany has initiated a number of programmes in renewable energy, and achieved impressive implementation rates in particular technologies such as photovoltaics and wind energy. They have supported, and pledged further support, to domestic manufacturing industries that already command a significant market share in some of these technologies. Danish wind energy manufacturers dominate the world market. Wind energy already contributes 5% to

Denmark's electricity supply, and under the government's Energy 21 action plan, it will contribute almost 10% to electricity generation by 2005, and could contribute 50% by 2030.[99]

In a world where political, institutional, economic and technological parameters are all changing rapidly, it is difficult make appropriate technological decisions. There are risks involved, and trade-offs to be made. However, it is becoming increasingly clear that to prioritise technology choice and policy frameworks solely on the basis of what is commercially competitive with today's energy sources could be damaging to our long-term interests in the energy sector. If the UK fails to commit itself to appropriate support for renewable energy, it risks falling behind its European competitors, and losing out in multi-billion pound technology markets.

4. Critical Policy Issues

The discussions in the previous two sections highlight a number of important policy issues. Two, in particular, stand out. Firstly, the developments occurring in renewable energy involve technologies which are maturing very fast, which offer distinct advantages in terms of lower environmental emissions, reduced dependency on imported fuel supplies, and increased export markets, but which are, in many cases, still not commercially competitive with conventional sources of energy. This situation raises the problem of devising an appropriate pricing policy for renewables. Secondly, it is clear from experience under the NFFO that, in the UK at least, one of the most important obstacles to implementation of renewables is the issue of public acceptability. In the following subsections, we discuss each of these issues in more detail.

4.1 Pricing Policy

Vigorous growth in the renewables sector could have tangible economic benefits in terms of lower environmental emissions, higher employment, an improved balance of trade, rural development, and increased security of supply. The trouble is that these economic benefits are external to the existing market framework in which commercial choices are made about energy supply. Some of the benefits still lie in the future, and depend on appropriate technological developments. Others are more immediate, but are simply not reflected in existing pricing structures. One of the key issues in pricing renewable energy is therefore the question of devising appropriate mechanisms for internalising the external costs and benefits of different energy sources.

Internalisation of Externalities

The external social and environmental costs of conventional energy consumption have attracted increasing attention within the last decade, and a number of attempts have been made to quantify these costs in economic terms.[100] Hohmeyer, for example, identifies the following categories in which external costs might arise from conventional fuels:[101]

- impacts on human health:
    - short-term impacts such as work-related injuries;

    - long-term impacts such as cancer or breathing-related diseases;
    - intergenerational impacts due to genetic damage;
- environmental damage:
    - flora;
    - fauna;
    - global climate;
    - materials;
- long-term costs of resource depletion;
- structural macroeconomic impacts such as unemployment;
- subsidies arising from R&D expenditure, investment or operation subsidies, and subsidies in kind – eg for evacuation and emergency services;
- relocation costs due to construction or accidents;
- costs of international conflict through:
    - securing energy resources (eg Gulf War);
    - proliferation of nuclear capabilities;
- costs of radioactive contamination after accidents;
- psycho-social costs of serious illness and death.

Monetary estimates of these external costs vary, in some cases widely. Table 7 illustrates some of the values that have been calculated for the external costs of different energy technologies.[102] Typically, the external costs ascribed to conventional sources of power are considerably higher than those ascribed to the renewable technologies, reflecting the general advantages which renewables offer in environmental and social terms. The higher range of estimates for conventional fuels indicates that internalising the external costs of electricity generation could double delivered electricity prices to consumers.

Table 7: Estimates of the External Costs of Electricity Generation (1994USc/kWh)

Fuel Cycle	Source of estimate			
	EC 1995	Hohmeyer 1988	Ottinger 1990	Pearce 1995
Coal	0.89 to 2.17	3.96 to 9.03	6.74	1.98 to 8.39
Oil	1.71	3.96 to 9.03	3.14 to 7.79	9.32
Gas	0.104	3.96 to 9.03	1.4	0.64
Nuclear	0.014 to 0.36	9.96 to 21.3	3.37	0.08 to 0.5
Hydro	0.33	NA	NA	0.07
Wind	0.16-0.33	- 5.74 to - 2.6[103]	0 to 0.12	0.07

However, there are considerable differences in the estimates calculated by different studies, in part as a result of variations in the external costs included, and in part due to differences in the methodologies employed in calculating the costs. This variation in external cost estimates confronts the policy-maker with considerable difficulty in formulating appropriate pricing and taxation policies. On the one hand, it is clear that there are environmental and social costs involved in consuming conventional fuels, and in some cases these costs may be significant in relation to the market price of the fuels. On the other hand, the nature of these costs and the difficulties inherent in estimating them lead to considerable uncertainty about the exact level of external costs, and the appropriate internalisation of them.

Generally speaking, policy-makers have tended to make two main pragmatic responses to this difficulty. The first response has been to propose environmental taxation at levels which are at least partly influenced by estimates of environmental cost; but are also determined by factors such as the price elasticity of energy demand, the cross-price elasticity of fuel substitution, and the social impacts of energy price changes. The second response has been to use externality "adders" as a decision-making input to integrated resource planning for energy supply investments, without attempting to change market price structures.

The first of these responses is exemplified by the development of carbon taxation as a response to the long-term costs of global warming. The "perfect" market solution to the problem of global warming would be to internalise the (present value of the) future costs associated with global warming by adding a marginal social cost per tonne of carbon emitted to the price of fuels consumed today.[104] In principle, a carbon tax calculated from this marginal social cost could both compensate future generations for the damages caused by today's energy consumption, and provide an incentive for consumers to switch from carbon intensive fuels to renewables (for example) or reduce energy consumption through improved energy efficiency.

In reality, there is too much uncertainty associated with future costs and too great a demand on public funds for any but the most risk-averse nation to contemplate setting aside substantial sums of money against estimated future damages. Rather, carbon taxes have been set (or proposed) at levels determined partly by the desired macroeconomic effect and partly by considerations of social and political acceptability. The revenues from such taxes, rather than being set aside as compensation to future generations are either used to offset taxes elsewhere in the economy (so-called ecological tax reform) or else "hypothecated" as special funds to promote energy efficiency or renewable energy investments.

Several countries, most notably the Netherlands and the Scandinavian countries, have now implemented carbon taxes on this sort of basis ranging from around $30 per tonne of carbon to over $170 per tonne of carbon, depending on country, sector, and fuel.[105] Proposals in the United States and in the EU for similar taxes have so far been unsuccessful, mainly because of political and industrial opposition.

One of the difficulties of introducing energy taxation is that it tends to be socially regressive, hitting households with lower incomes harder than those with higher incomes. This is because lower income households spend a much greater proportion of their disposable income on fuel and electricity than higher income households do. There are in principle a number of ways of tackling this problem, for instance by taxing consumption above a certain level, by reducing income tax in low income brackets, by providing compensation mechanisms for low-income households or by devising support programmes to combat fuel poverty.

In general, however, the extent of the problem depends on the level at which energy taxes are raised. If energy taxes have to achieve the work of reducing energy demand and promoting renewables through price effect alone, the evidence suggests that tax levels will have to be rather high.[106] Much lower levels of taxation can be effective at reducing carbon intensity if tax revenues are hypothecated for the promotion of specific technologies. The UK's fossil fuel levy and NFFO (Section 3.1) is an example of exactly this kind of arrangement. The level of tax on fossil fuels is very low: the renewables component of the levy is currently running at around 1%. But the NFFO mechanism targets the revenues specifically for the implementation of renewable energy technologies. It is perhaps ironical that a government committed to energy market liberalisation, and vehemently opposed to hypothecation, should have established, albeit by accident, a mechanism such as the NFFO. Nevertheless, the operating principles of a hypothecation mechanism have distinct advantages in reducing the potentially regressive impacts of high energy taxes.

The second pragmatic response to the problems of internalising the external costs of conventional fuels has been the adoption by utilities, mainly in the US, of so-called externality "adders" in an integrated resource planning (IRP) framework. The idea of IRP – also referred to in Europe as least-cost planning – is to optimise the allocation of utility financial resources, by investing in both supply and demand side technologies on an equal basis. In this way, the consumer demand for electricity can be met at the lowest social cost.[107] Investment decisions are made by adjusting conventional generation costs using an externality "adder" which reflects the external costs of individual fuels and technologies. Thus, an IRP decision would tend to favour installing renewables over conventional fuels, even where the renewable technology was more expensive, provided that the estimated "adder" was greater than the difference between the (market) cost of the two technologies.

One of the difficulties of IRP is that it presupposes a utility framework in which investors are capable of making a comparative assessment of the complete range of investment options. However, this works most obviously in the context of a retail monopoly. Its relevance in competitive, liberalised markets is far less clear.[108] In fact, both of the pragmatic policy responses to the internalisation of externalities rely on interventions in the energy market which are increasingly at odds with what is arguably the single most significant energy policy trend across Europe: energy market liberalisation.

Renewables in a Liberalised Energy Market

A decade ago, the electricity sector throughout Europe was dominated by large, public sector utilities building large, centralised power stations, usually fired by coal which was supplied – in the case of the UK at least – from a heavily-subsidised coal industry. Today, this picture has changed almost beyond recognition. For a variety of reasons, some of them political in the narrowest sense of the word, large public sector utilities with captive monopoly markets are being systematically dismantled. In their place is being established an increasingly competitive market, in which suppliers compete for consumers across a wide range of markets from very big industrial users to individual households. Similar changes are occurring in the gas market.

The UK has led the way on this process in Europe. The Electricity Act of 1989 simultaneously dismantled the former Central Electricity Generating Board, and created in its place a market in which independent generators could compete to supply power to the Regional Electricity Companies, and to large industrial consumers. Subsequent legislation has further extended the liberalisation process. As from 1998, the domestic electricity and gas markets are open to full competition in supply.

The implications of these changes for renewable energy have been profound, but not altogether straightforward to unravel. In the first place, it is clear that the old, monopolistic, public sector, energy supply industries would not – at least without significant restructuring – have provided a sympathetic environment for the development of renewables. This was partly because the thinking which dominated those industries saw electricity supply in terms of large, centralised coal-fired (and later nuclear) plant and very little else; and partly because the institutional framework encouraged them to think in that way. Even when renewable energy became a technical possibility, it tended to be considered mainly in terms of its ability to substitute directly for conventional plant – as the unrealistic 2 GW design concept for wave energy illustrates. It was only the break-up of the electricity supply monopoly, which has allowed the new, renewable energy technologies to gain a toehold in the UK supply system. The NFFO was originally set up with the aim of protecting the nuclear industry during the privatisation process. But the support provided for renewables is increasingly seen as one of its major benefits.

On the other hand, the declared aim of liberalisation is to drive down the costs of electricity and gas supply to the consumer, and there is good evidence that it has been successful in achieving this aim in the UK. Electricity prices fell in real terms in the years following the 1989 Electricity Act, and the cost of energy to consumers is currently falling in most sectors of the market.[109] The problem is that these cost reductions will delay the time at which renewables are able to compete with conventional energy sources, unless it is possible to find some mechanism for introducing renewables into the liberalised market at premium prices.

Of course, there are a number of ways of achieving this. The NFFO is one such mechanism. Essentially, it operates by creating a "ring-fence" around particular technologies, placing an obligation on the market to purchase a certain quantity of electricity from the chosen technologies, and funding the additional costs of this, by way of a levy on conventional sources. The logic here has three distinct components to it. Firstly, renewable energy confers benefits not captured in the exchange market, a fact that justifies a protective stance towards them. Secondly, conventional sources incur hidden costs not captured in exchange prices. The fossil fuel levy is a way of (loosely) internalising those external costs. Finally, the money raised from the levy allows the RECs to offer a guaranteed premium buyback price to renewable developers; and this financial transfer from the technology with the lower market price (but hidden costs) to the technology with the higher market price (but hidden benefits) allows renewable energy developers to achieve financial viability in a competitive investment market.

In principle, it would have been possible to impose the protective "ring-fence" without a corresponding financial mechanism. Equally, it would have been possible to impose a levy without establishing the protective ring-fence. In the first case, however, there would have been little transparency about the costs of the mechanism, and a degree of haphazardness about where those costs fell. In the second case, the mechanism would have been considerably more expensive, and not necessarily effective: little commercial activity could have been expected at all until the price of conventional sources (as a whole) exceeded the costs of renewable sources; and even once this occurred, market penetration could have been hindered by structural or institutional factors.

As we have hinted in previous sections, the NFFO is by no means a perfect mechanism. The problem of low completion rates highlights the fact that the mechanism is not in itself sufficient to ensure implementation. Projected into the future, NFFO type implementation rates will not achieve the 10% target. The problem of technological exclusion – the fact that certain very promising technologies have been left out in the cold by close adherence to criteria of commercial maturity – will have to be addressed. The lack of direct interaction with the planning process needs to be remedied. Support of domestic manufacturing capabilities needs to be established. In spite of these difficulties, the NFFO has turned out, almost by accident, to be a relatively sophisticated way of establishing commercial investment opportunities for renewable technologies in a liberalised energy market. The continuation of an improved version of the mechanism is likely to be a necessary (if not sufficient) condition for the success of the government's 10% target.

Supplementary mechanisms should certainly be considered. In Sweden, the USA, Germany, Denmark and the Netherlands, for example, it has been common to offer tax credits as an incentive to invest in renewables, and these have certainly played a part in promoting technological development and market penetration. The arguments for a more general reform of the tax system to shift the burden of taxation away from labour and capital and onto the consumption of material and energy resources are also strong.[110]

In addition, recent attention has been paid to the stimulation of a consumer demand for renewable energy, and the establishment of so-called "green pricing" structures for renewable energy which allow consumers to buy renewable electricity at a premium price.

Green Pricing

In principle, the idea of establishing green tariffs and pricing structures lies close to the philosophical heart of market liberalisation, because it places on the consumer the burden of choosing "green" electricity, and it provides electricity suppliers with a means of differentiating their product on environmental grounds. In practice, experience with such schemes has delivered only mixed success. Moreover, a closer examination reveals that the concept itself appears to be flawed because the burden of additional costs lies in the wrong place.

Much of the early experience in the setting up of green pricing schemes for renewables has been gained in the United States, where a number of such initiatives are under development. The first of these was established in 1996 in New Hampshire where three of the fifteen supply companies offering services in the area drew attention to the source of their power. In Minnesota, the Dakota Electric Association has recently sought state permission to offer their consumers wind-generated electricity at a premium tariff, following a survey carried out during 1996: 65% of the respondents indicated a desire to buy renewable energy, while 39% expressed a willingness to pay more for it.[111] Similar schemes exist in Europe. In the Netherlands, all six utilities now offer a green energy scheme.

In the UK, a number of schemes have recently been established. The Renewable Energy Company, established in 1995, was "the first company in Europe to be dedicated to the supply of electricity from renewables". The aim of the company – which has so far been selling power only to large industrial customers – is to act as a broker between consumers who are prepared to pay a premium price for environmentally-friendly power, and generators who require a premium price for their product. In October 1997, Eastern Electricity launched their Ecopower initiative, the first to offer domestic consumers the opportunity to support renewables. The scheme enables customers to pay an additional 5 to 10 per cent supplement to their electricity bill to "contribute directly to the future growth of 'greener' electricity in Britain". The customer contributions will be matched pound for pound by Eastern Electricity and the collected funds will be set aside in an independent charitable trust. The aim of the trust is to support new renewable electricity projects such as wind, solar and wave and to further research in renewable energy sources.[112]

It is really too early to say how successful such schemes will turn out to be. Evidence from the United States suggests that there is a disparity between what consumers say they want, and what they are actually prepared to pay for. Market research shows that around 40-70% of utility customers expressed a willingness to pay additional premiums for renewable energy. But the actual take-up in such schemes is typically under 3% of electricity consumers.[113] In a recent communication in response to the EU Green Paper, the electricity lobby group Eurelectric pointed out that "public expectations are divided between environmental concerns, low prices as promised by the internal market, quality and security of supply, and acceptance of the renewable plants", and expressed little confidence that consumer behaviour alone would generate a market for premium-priced renewables.[114]

Such pessimism may turn out to be unfounded. The idea of allowing consumers to choose the source of their electricity is eminently defensible. Equally, suppliers should be encouraged to differentiate their products on the basis of environmental characteristics – at least in so far as these characteristics can be reliably established. But there is a certain confusion inherent in relying on consumers to pay premium payments for renewable energy. The marginal benefits which renewable energy delivers (over and above its value as a source of power) are essentially public goods: environmental benefits, increased employment, improved balance of trade and so on. There is something perverse about a market system in which people who choose renewable electricity – thus generating hidden benefits to the rest of society – pay more for the privilege than those who consume dirty electricity – thus imposing costs on the rest of society. A market system in which the altruistic are led to subsidise the selfish would appear to be missing the mark somewhere.

Green pricing is one mechanism that at least allows consumers to choose the environmental impact of the product they consume. It also encourages suppliers to differentiate their product on environmental grounds. However, green pricing initiatives cannot, and should not, be seen as a substitute for appropriate intervention in the market.

4.2 Public Perception and Social Acceptability

Generally speaking, the public attitude towards renewable energy is positive. The main reason for this is that renewables are perceived as clean, safe, good for the environment, and beneficial in terms of long-term energy security. In reality, a substantial increase in renewable energy in the UK might be expected to have some impact on employment in conventional energy supply sectors, and thus to generate some resistance from within these industries. However, present (and presently envisaged) contributions are rather small by comparison with other structural effects in the UK energy sector – such as the substitution of gas for coal, and of imported coal for domestic coal. Moreover, the studies on renewable energy implementation in Europe indicate that increasing the contribution from renewables could generate significant net increases in employment (Section 3.2).

Yet in spite of these perceived social and environmental benefits, it is becoming increasingly difficult to site and build renewable energy plants in the UK and elsewhere in Europe, because of public opposition. To a large extent, this problem arises from local opposition to specific projects, although there are occasions on which a wider opposition lobby is mobilised, for instance against development in areas considered wild or unspoilt. It is not, however, sufficient simply to dismiss this opposition as NIMBYISM: the impacts of local opposition are too significant to be ignored.

To take a specific example, we recall from Section 3.1 that the completion rate for wind power from the first three NFFO orders is currently only 35%. Approximately 65% of all wind turbine projects that have gained an NFFO contract have failed to gain planning permission – largely due to public opposition. The opposition toward the siting and operating of wind turbines in the UK is generated by local public opinion, some environmental pressure groups (most notably local CPRE organisations and the Country Guardian) and some well connected anti-wind landowners.

This opposition is focused on three key issues:

- the destruction of pristine landscapes through the building of wind turbines in high windspeed uplands in Wales and Scotland;
- the noise that wind turbines make and how this noise will lead to decreasing property values, disruptions of sleep patterns and so on; and
- the effects that wind turbines have on television transmissions.

There are now manuals produced on how to site wind and other renewable energy plants.[115] However, there is increasing evidence that the problems involved in siting and building wind power plants are not related in a simple fashion to physical impacts; they are also related to whether the utilities or developers who are proposing the plants can be believed, and whether the siting of the plants is perceived as *fair*. This section seeks to explain why public opposition to the siting of any type of renewable energy plant has increased, despite the emergence of general public concern for the environment and trends toward green consumerism.

The Role of Trust

One of the main reasons for public hostility to the siting and building of renewable energy plants is the lack of trust toward the proposer of the plant.[116] In these cases the public perceive the risks of such developments to outweigh the benefits and hence they will oppose it. If trust cannot be established, any risk communication programme put in place to convince or persuade the public of the merits of a proposed project is virtually meaningless.[117]

The issue of trust has grown in importance, as the public today – especially in the UK – are increasingly distrustful of local and national government policy makers, industry and other public bodies, and see environmental NGOs and other pressure groups as more trustworthy.[118] Several authors have explained this in terms of a growing alienation of the public and a belief that industry puts profits far above the common good along with scepticism about the virtues of modern democracy as a whole.[119]

The growing lack of public trust stems from past experience of government and industrial actions. Factors such as perceived incompetence of officials, "sleaze", and corruption that have also been evident in cover-ups of hazardous/potentially hazardous incidents have all decreased public trust in authority. As these issues are reported more and more frequently in the press, public distrust toward policy makers and industry tends to increase.[120]

In sum, no matter how environmentally aware the members of an affected community actually are, they are still likely to oppose the siting and building of "environmentally-friendly" renewable energy schemes if the developers of the schemes are perceived as being untrustworthy.

Fairness and Equity

Research in the risk area has shown that the public's perception of fairness and equity plays an important role in determining whether a proposed facility receives planning permission or not.[121] In cases where the public perceive that they have been treated inequitably and where they are not compensated adequately, they tend to oppose the siting of the facility. Renewable energy plants represent a good example of this at work. In many cases the affected local community only sees the costs and not the benefits.

In the case of wind power, the costs involved are local noise, and local visual intrusion on areas of natural beauty, while the benefits (in terms of electricity or profits from the scheme) are often delivered outside the immediate locality. Additionally, the manufacturing of the turbines (to a large degree imported from Denmark) leads to few local jobs or benefits for the local economy.

There is more likelihood of perceived fairness within a local community with biomass-to-energy plants. The benefits derived by the local community from these plants can include: monetary value for locally produced biomass that would otherwise be treated as waste (eg sawdust, straw, wood residues); local labour demand for transporting feedstocks to plant; and job creation in the plant itself. However, costs are still seen by local residents as significant. People, particularly in rural towns and villages, are concerned about local traffic increases associated with transporting feedstocks to the plants; possible noxious emissions from the plants; declining property values in the vicinity of the plants; and a perception that the already well off in the community (eg the large landowners) are benefiting disproportionately.[122]

Overall this suggests that if the impact of a proposed renewable plant is perceived as being unfair or inequitable, chances are that the public will oppose it.

Inappropriate Communication Techniques

Top-down risk communication strategies have been unsuccessful when used to try to help site industrial facilities.[123] That is to say, rather than treating the public as an equal partner and engaging them in dialogue on a siting issue, "experts" try to persuade the public that their concerns are unfounded. This type of communication strategy has virtually always failed, while developing a dialogue where the developers/regulators are seen as partners has been more successful.[124]

However, often a developer trying to communicate a risk is not aware of the types of siting strategies available. This is illustrated by the case of Elm Energy, a subsidiary of a large US-based utility, which has tried to site and build waste tyre incinerators in several towns, most notably Guildford and Wolverhampton. In Wolverhampton, Elm's approach was to set up discussions with the general public and concerned parties and through this process succeeded in siting and building the incinerator without too much opposition from local policy makers and the public. However, in Guildford, where this approach was not followed, public opposition prevented the company siting a waste tyre incinerator.[125]

Overall, the evidence from the evaluative research suggests that dialogue risk communication strategies are more successful in achieving the siting of renewable energy facilities.[126]

Successful Siting Strategy

The building of a large biomass-to-energy facility in Växjö, Sweden provides an example of a successful siting strategy.[127] The plant originally built in 1970 has a thermal capacity of 210 MW and is one of the largest biomass-to-energy plants in Sweden. In comparison to the difficulty faced by UK developers in siting renewable energy plants, the siting and building of the Växjö plant was rather easy. There are several reasons for this:

- It was viewed as something positive. The public believed that the biomass district heating plant would lead to a cleaner environment. In other words, the public viewed the siting and building of the plant as fair and equitable.
- The company that owned and operated the plant was owned by the municipality itself (in other words the residents of the community), not by shareholders requiring high returns on an investment. Therefore, the public believed not only that the municipal utility could be trusted, but that it would act in their best interest.
- All local policy makers, even from opposing sides of the political spectrum, believed that the investment was the right one.
- Environmental NGOs took the view that the local policy makers acted extremely pro-actively (eg building an environmentally friendly heating and electricity generating plant) before there even was a concern for the protection of the environment.

Generally speaking, developers of renewable energy schemes will in the future have to take into consideration issues of trust, fairness and proper dialogue forms of risk communication. Conflicts need to be avoided as much as possible, if the UK is to be able to increase the generation of renewable electricity production to 10 per cent by the year 2010. Developers need to realise that in any given situation they are likely to be coming in at a disadvantage. Public attitudes toward them will either be neutral or distrustful and the developers have to actively seek to gain public trust. There are a number of factors that can help in gaining this trust. These include:

- early announcement of the planned project;
- open communication of plans, rather than revelation through leaks to the local media;
- early engagement with local policy makers regarding both the risks and virtues of the proposed project;
- empowerment of the local population by engaging with them on an equal basis;
- consideration of schemes which allow local residents to become involved as part owners or shareholders in the scheme.

In general terms, the complex demands associated with siting renewable energy require developers to be as flexible as possible and even allow the option of withdrawing from the project. These proposed measures are especially important in situations where the best places for the siting of various renewable projects (such as windy areas for wind plants) have been fully exploited. In these situations, it will always be more difficult to site and build renewable plants as has been seen with the planning of wind power schemes in Denmark.[128]

5. Renewables in the UK – options for the future

5.1 A Summary of the Issues

Renewable energy sources offer, in principle, the prospect of cleaner, more sustainable ways of meeting the demand for electricity, heat and transport fuels than conventional fuels. The physical resource base is enormous. At the global level, the recoverable resource exceeds the demand for commercial energy by a factor of more than 100 (Table 1). Direct insolation rates in the UK are lower than in many other European nations. Even so, direct solar conversion technologies could supply enough electricity to meet present levels of demand using less than 3% of the UK's land area. The accessible wind resource alone could generate twice the current level of electricity demand. Biomass – mainly from energy crops – could supply more than 75% of the UK's demand for electricity, or contribute substantially to the demand for transport fuels.

Technologies for converting renewable energy flows into useful forms of commercial energy are manifold and diverse. The engineering bases for different kinds of renewable energy often have little or nothing in common with one another. The use of some form of turbine for generating rotational motion – and hence electrical power – is common to most (but not all) of the renewable energy technologies. But upstream and downstream elements of the different technologies, and the operating conditions of different generation cycles all vary widely between renewable technology types.

This technological diversity may be one of the reasons why, historically at least, renewable energy has found it difficult to establish a significant niche in the energy market. The lobbying power of disparate technological groups is always likely to be lower than that of a unified lobby. The clamour of voices speaking very different technical languages is more likely to obscure than to clarify the problem of allocating scarce resources to technologies which are at different stages of technical development, different levels of commercial maturity, offer different prospects for employment and export, and impose different institutional structures and social considerations.

Faced with this kind of complexity, policy-makers in the UK (and elsewhere to a lesser extent) have tended to adopt a kind of "commercial league table" approach (Section 2.8) in choosing which technologies to support. In particular, short-listed technologies have often been those which offer the best short-term prospects of commercial competitiveness, under conventional financial assessments. So for instance, onshore wind energy, small-scale hydro, and biomass (mainly from waste) have been favoured by the UK's NFFO. These technologies have also taken the lion's share of important innovation and demonstration funds such as those available under the European Commission's THERMIE programme. As a result, there is no doubt that important operational experience has been gained, the chosen technologies have improved, and delivered renewable energy costs have fallen.

At the same time, certain other renewable energy technologies – such as solar PVs, offshore wind energy, tidal power, energy crops and wave energy – stand in danger of losing out in the UK. Certainly, some technologies are closer to commercial maturity than others. But these technologies are not necessarily the ones with the biggest long-term resource potential, the greatest opportunity for generating employment and export markets, or the best long-term social and environmental prospects. A few examples – drawn from experience in the UK and elsewhere – may help to illustrate the dangers of a short-term, narrowly focused, commercial assessment:

- onshore wind energy can now compete fully with conventional sources of energy in specific locations; but the low NFFO completion rate is a witness to the problems of social acceptability which may constrain substantial onshore developments in the future;
- offshore wind was more or less dismissed during the 1994 ETSU study for the DTI; but the prospects for offshore resources have improved considerably in the intervening four years, mainly as a result of the commitment of countries like Denmark who have now gained valuable operating experience of the offshore technology;
- small-scale hydro can sometimes offer competitive, locally-based electricity generation with minimal environmental impacts; but the long-term potential is extremely limited in comparison to UK capacity needs;
- solar conversion technologies have received little support in the UK, mainly because the solar resource is weaker than in Southern European nations, and the UK has virtually no domestic manufacturing capability; but an increasing number of energy experts agree that solar PVs will be one of the backstop

energy technologies of the future; the rate of expansion in sales is approaching 20% per annum, and the export market is already worth billions of pounds;
- waste-to-energy technologies are extremely competitive with conventional electricity generation in many cases, and offer positive environmental benefits in some cases over conventional waste disposal routes; but competition for sources and increasing public opposition are already limiting implementation levels, and an extensive waste-to-energy sector could discourage effective waste prevention strategies;
- the economics of energy crops are variable; but the development of an agro-energy industry could revive the flagging fortunes of the agricultural sector and create desperately needed jobs in rural areas;
- the proposed Severn tidal barrage was clearly uneconomical on the basis of delivered energy costs using conventional financial appraisal; but the project would have provided valuable secondary benefits (such as a second Severn crossing – subsequently built using private funds) and virtually free electricity for up to a century after the initial capital was paid off;
- the development of offshore technologies (wind and wave, in particular) may still suffer from technical and financial uncertainties; but the UK has the best physical resources in Europe and a marine construction industry currently facing an even more uncertain future.

One of the difficulties in devising appropriate policies for renewable energy is the sheer speed at which change is occurring in the renewable energy market. Overall, technological efficiencies are improving fast; and costs are falling rapidly for particular technologies. Several technologies – most notably PVs – offer the promise of significant further reductions, mainly through increases in production scale. The result is that technologies that were dismissed only a few years ago as being too uncertain or too expensive are now being developed, semi-commercially, in other countries.

Moreover, this technological change is occurring in a rapidly changing institutional and commercial context. As Section 3 has detailed, the institutional forces driving towards an increasing contribution from renewables are identifiable at a number of different levels: the EU's White Paper on renewable energy (Section 3.2); the Kyoto Protocol on greenhouse gas emission reductions (Section 3.3); a flurry of activity on the commercial market (Section 3.4); increased investment by multi-national energy companies; and the rush by certain European nations to support domestic renewable technology industries (Section 3.5). Clearly, these institutional and commercial initiatives are closely related, and feed from one another in quite specific ways, as the following scenario illustrates:

Driven by concerns about fuel security and the need to support domestic industries, the EU promotes a doubling of the contribution from renewables from 6% to 12% of energy consumption by the year 2010. This requires setting specific targets for the implementation of individual technologies – such as the White Paper's "million roofs" programme (Section 3.2). It also requires active policy measures to reduce the obstacles to implementation. Specific targets inevitably increase the demand for conversion devices – eg PV cells – and better network access increases the incentives for renewable energy developers in the market. Manufacturing interests respond by increasing both production investments, and research budgets (Section 3.4). The increasing scale of production brings about cost reductions (Table 2) which – together with the technical improvements flowing from more research – increases the commercial feasibility of the technology. As the technology moves closer to commercial maturity, the gains which are to be achieved from aggressive policy intervention multiply, prompting further action and support both at the EU level and at the level of individual Member States, particularly those with domestic manufacturing capabilities.

Perhaps as little as two or three years ago, this sort of scenario might have stretched the bounds of credibility in energy policy. Nonetheless, it is a pretty accurate description of what has actually happened in the last twelve to eighteen months, and an increasingly likely scenario for the continued development of renewable energy policy within the next decade.

The UK is poised precariously in this rapidly changing context. The country's physical resource is very large. During the late 1970s and early 1980s we were at the leading edge of renewable energy research. But this research base has now declined, and domestic manufacturing interests have suffered considerably by comparison with those of other European (and non-European) nations. At the end of the 1990s, it is fair to say that the UK has slipped behind in the race to develop, to implement and to market renewable energy and renewable energy technologies.

In a world where political, institutional, economic and technological parameters are all changing rapidly, it is difficult to make appropriate technological decisions. There are risks involved, and trade-offs to be made. However, it is becoming increasingly clear that to prioritise technology choice and policy frameworks solely on the basis of what is commercially competitive with today's energy sources could be damaging to our long-term interests in the energy sector. Tomorrow's energy system will not consist purely of technologies that are *competitive* today, but of technologies that are *supported* today, because of the longer-term environmental and social benefits that they offer.

In the medium to long term, renewable energy could contribute more than 50% of total global energy supply. Failure to develop a domestic manufacturing industry would put the UK at a serious disadvantage in such a system, with potentially severe consequences for employment and the balance of trade. If the UK fails to commit itself to appropriate support for renewable energy, it risks falling behind its European competitors, and losing out in a global market which by 2020 is projected to be worth $250 billion.

Almost by accident, the UK has stumbled on a mechanism that, in principle, offers a relatively sophisticated route towards semi-commercial implementation of renewables. The NFFO has been successful in establishing a limited, protected market for renewable energy within an increasingly liberalised electricity supply system. However, there are a number of problems with the mechanism. It has been inadequately integrated with the planning process; it supports only a limited number of technologies, mainly in electricity supply, leaving certain other technologies and end-uses out in the cold; and completion rates for contracted capacity have been much lower than expected. At current rates of implementation, the contribution to electricity supply from renewables by 2010 is not likely to exceed 4% (including large-scale hydro).

5.2 Critical Policy Questions

These considerations suggest several important conclusions, and lead to a number of critical questions (identified in ***emphasised*** text below) which might form the basis for further investigation.

In general terms, the diversity of technologies, and the complexity of technical, economic, institutional and social issues which arise from this diversity, suggest a far more eclectic approach to renewable energy than the one which has dominated renewable energy policy decisions in the UK over the last decade. In particular, renewable energy demands a broad policy focus – capable of assessing secondary and tertiary benefits of technological development – and a long-term view. It also requires an integrated approach, involving at least agricultural policy, employment policy, transport policy, regional development policy, overseas trade policy and fiscal policy. All of these policy areas have an impact on the development of renewables, and without consideration of them, some at least of the longer-term benefits of renewables are likely to remain invisible.

- ***What are the operational parameters of a comprehensive, long-term policy framework for renewable energy?***

Next, there are a number of good reasons to support the setting of an ambitious target for the implementation of renewable energy. In principle, this target need not, and in the longer term should not, be restricted to electricity supply. Moreover, these targets should probably not be restricted to the relatively short time-frame indicated by the current government. The speed at which markets in renewable energy are expanding, the extent of the environmental advantages which renewables offer, and the scope of the potential contribution from renewables in the middle of next century, indicate that it might be appropriate to set short, medium and long-term targets for implementation.

- ***What level of target contributions from renewables to the three main end-uses (electricity, heat and transport fuels) should be set in the UK for the short term (2010), the medium term (2025) and the longer term (2050)?***

Importantly, increasing the contribution from renewables to the UK energy supply is likely to require a number of government interventions in key policy areas. These might include:

- appropriate mechanisms to stimulate a broadly-based, research and development community in the UK;
- support to enable renewable technology researchers and renewable energy developers to access sources of public (eg EU) and private finance;
- a fiscal framework which reflects the external costs of conventional fuels, and the latent benefits of renewable energy;
- fiscal incentives for the development of domestic renewable energy manufacturing capabilities;

- a regulatory framework which promotes fair – and perhaps premium – access by renewables to the relevant energy supply and distribution systems;
- support for renewables in government procurement programmes;
- planning policies which allow for and promote environmentally and socially sensitive renewable energy developments;
- industrial training programmes which re-orient and re-employ existing industrial capacity, particularly in hard-hit areas such as rural agriculture, the marine construction industry, and the coal-mining community;
- the encouragement of appropriate funding institutions (eg soft loans, green or golden funds) to support local community investment in indigenous renewable energy sources.
- ***What policies and support mechanisms should be put in place to maximise the chances of success in meeting renewable energy targets in the UK?***

In particular, it is clear that some means must be found to build upon and improve the NFFO as a mechanism for integrating renewables into the liberalised energy market. This mechanism will need to build on the experiences gained through the first five NFFO orders. It will also need to improve upon the existing framework in certain key respects. Critically, it will need to:

- find ways of increasing current completion rates;
- incorporate a broader basket of technologies, and in particular find support for those technologies with a significant long-term potential or demonstrable secondary benefits;
- improve the integration of renewable energy development into the local planning processes;
- improve the integration of innovative renewable energy development with sources of EU funding;
- encourage sensible and environmentally sensitive development over time-frames that are consistent with the engineering life of the technology.

The indications from government are now that an extension of this mechanism at least in some form is likely,[129] and this would appear to be vital to the success of meeting the government's 2010 target. It is worth recalling here that the mechanism itself consists of several components. First, it comprises an obligation on the regional electricity companies to supply a certain quantity of electricity from renewables. Second, it establishes a tendering process which is competitive within specific technology bands, but allows renewable electricity generators to achieve a premium price for their electricity and thereby compete for finance in commercial markets. Third, it provides a financial mechanism in which the cost of this "ring-fence" is spread across electricity consumers as a whole.

In principle, as we noted earlier, it would be possible to implement a variety of mechanisms drawing on different combinations of these elements, or including additional elements. For example, a mechanism called the Renewables Portfolio Standard – first proposed by the American Wind Energy Association – essentially imposes an obligation on all suppliers to purchase a certain minimum percentage of the electricity they sell from renewables.[130] A "hands-off" method of reaching the 10% target might simply be to impose on all licensed electricity suppliers the obligation to secure 10% of the electricity they sell from renewable sources by 2010.

Flexibility could be added into the scheme by making these commitments tradable. The drawback would be that such a scheme would tend to promote least-cost technologies at the expense of technologies which are at the present time more expensive, but which offer longer-term advantages in terms of lower environmental impact, greater public acceptability, improved export earnings, and higher potential.

One of the mechanisms which has been employed in other European countries is to offer a guaranteed standard payment for renewable energy. This payment is usually made throughout the lifetime of the plant and is set in terms of a fixed percentage of the price which small consumers pay for electricity. In Denmark for instance, wind is paid 85% of the domestic consumer price, while hydro is paid 60%.[131] In Germany, this standard payment method has been one of the reasons for the rapid expansion of wind power in recent years. However, it has also led to disputes over who should bear the cost of this policy. Without a mechanism for distributing costs evenly over an appropriate consumer base, some individual utilities are liable to find themselves incurring higher costs than others, and in a competitive supply market would inevitably resist this.

- ***What kind of access mechanism should be set in place – based on the experiences of the NFFO – to ensure that renewables can develop within the liberalised energy market?***
- ***What is the appropriate role for green pricing initiatives, and how should these be integrated into other access mechanisms?***

There are clearly questions of principle involved in establishing mechanisms appropriate to the support of technologies which offer both private goods (electricity, heat and transport fuels) and public goods (a cleaner environment, improved security of supply, higher employment, improved balance of trade). In particular, the question of who should pay for public goods is central to the development of support mechanisms for renewables. Some attention should probably be given to the "polluter pays principle" in allocating the additional costs of achieving cleaner energy supplies. This, in essence, is the basis for the fossil fuel levy. On the other hand, some of the public goods delivered by renewables benefit a wider community and there may be grounds for funding such benefits from public sources.

- ***What mechanisms are appropriate to ensure an equitable distribution of social costs and benefits in a competitive energy market?***

The financing of certain renewable energy technologies raises questions about the conflict between long-term benefits and short-term commercial financing criteria. Renewables in particular, suffer from high capital intensity, which means that they tend to be penalised heavily under commercial capital financing conditions. High discount rates tend to favour projects with long-term costs streams, and to penalise technologies with long-term benefit streams. Some renewable energy technologies (such as tidal energy) could deliver useful energy for many decades after the capital amortisation period is over. By contrast, the same financing conditions will bias lenders in favour of conventional fossil-fuelled technologies, in spite of long-term environmental costs and increased commercial risk from fuel price rises.

- ***What mechanisms could be found to compensate for the unfavourable treatment of renewable energy technologies in capital markets?***
- ***What mechanisms could be found to re-orient capital lending markets towards more sustainable investment patterns?***

Finally, we have highlighted throughout this background paper the potential importance of the export market for renewable energy technologies. Imagine a world in which 50% of the energy supply is coming from renewables by 2050 – as envisaged for example by Shell (and others). The balance of geopolitical power in this world no longer rests with those who have indigenous fossil resources. It rests with those who have the technical capability to manufacture the capital equipment needed to capture ambient energy flows. Not to be well positioned in such a market could spell economic suicide.

- ***What mechanisms can be found to stimulate domestic manufacturing capabilities, and encourage a vigorous export market, in renewable energy technologies?***
- ***Would it be appropriate for government to set national targets for the development of domestic manufacturing capabilities in renewable energy?***

The government is currently engaged in a review of renewable energy with a view to extending the support mechanisms for renewables in the UK. It is expected that this review will report during 1998. In addressing questions such as those which have been raised above, the Royal Commission on Environmental Pollution could make an extremely valuable and timely contribution to a debate which may turn out to be critical for the UK's energy and economic future.

Endnotes

The full list of references follows these endnotes.

1 IPCC 1995.

2 WCED 1987.

3 UNCED 1992.

4 WEC 1993 and 1994.

5 EC 1997.

6 ENDS Daily, 21st May 1997.

7 Shell International News Release, 16th October 1997.

8 ENDS Daily, 5th November 1997.

9 Lloyds List International, 27th October 1997.

10 *Future for Renewables is bright, says John Battle*. DTI Press Release, 13th November 1997, eg.

11 1 TW = 1 terawatt = 1×10^{12} watts.

12 Estimating the recoverable resource from biomass is problematic. Vitousek *et al* (1986) estimate that humans already appropriate 40% of the total photosynthetic product, suggesting two things: firstly, that global estimates of commercial energy use considerably underestimate our reliance on biomass; and secondly that the

potential for further exploitation might be limited by concerns other than technological constraint.

13 For sources see Jackson 1993, pp256-257, Johansson *et al* 1993, and WEC 1994.

14 The biomass figure refers mostly to the traditional consumption of woodfuels in developing countries, although it is widely believed to exclude a significant contribution from non-commercial sources (Hall *et al* 1993 eg).

15 EC 1997.

16 DUKES 1997.

17 The technological descriptions in the following sections draw mainly on the following sources: DTI 1994, ETSU 1994, Grubb 1995, Grubb and Vigotti 1997, Hill *et al* 1995, Jackson 1993, Johansson *et al* 1993, Twidell and Weir 1986, and WEC 1993 & 1994.

18 WEC 1993 and 1994.

19 CEC 1994a and EC 1996b respectively.

20 DTI 1994 and ETSU 1994.

21 WEC 1994. Nepal obtains 95% of its energy from biomass, Malawi 94%, Kenya 75%, India 50%, Brazil 25%, Egypt and Morocco 20%.

22 Luengo and Cencig 1991.

23 Conventional power generation cycles have efficiencies in the region of 33-35%, but combined cycle power generation – fired by a gaseous fuel – can achieve efficiencies approaching 50%.

24 Holm 1995.

25 Cited in Debeir *et al* 1991, p 95.

26 US EPA, cited in WEC 1994.

27 WEC 1994.

28 Hall *et al* 1993.

29 EC 1997, Table 2.

30 At 10 p/kWh or less.

31 DTI 1994; low-head hydro is characterised as hydro where the height through which the water falls is less than 3m.

32 ETSU 1994.

33 Rodier 1992.

34 WEC 1986.

35 ETSU 1994.

36 DTI 1994.

37 Ie the fact that the technology could be installed in small, modular units rather than requiring massive capital installation.

38 EC 1996b.

39 Salter, cited in Grubb and Vigotti 1997.

40 ETSU 1991.

41 An angry account of these events is to be found in Ross 1995, for instance.

42 Thorpe 1992.

43 Ibid.

[44] Grubb and Vigotti 1997.
[45] OECD 1987.
[46] Georgescu-Roegen 1975.
[47] Hill *et al* 1995, eg.
[48] ETSU 1994.
[49] ETSU 1994.
[50] EC 1996b.
[51] EC 1996c.
[52] Wp = peak Watts: this term refers to the theoretical power output of a cell exposed to incident radiation of 1 kW/m^2 at a standard temperature of 25^{o}C.
[53] Table 5.3 in Grubb and Vigotti 1997.
[54] Oliver and Jackson 1997.
[55] Hill *et al* 1995.
[56] CEC 1994b.
[57] Grubb and Vigotti 1997.
[58] ETSU 1994.
[59] Hill *et al* 1995.
[60] Jackson 1997.
[61] As characterised by Grubb and Vigotti 1997.
[62] The capacity factor is the ratio of annual average output to peak output.
[63] Windpower Monthly, Vol 13(1), January 1997.
[64] ENDS Daily, 12th February 1998.
[65] ETSU 1994.
[66] DTI 1994.
[67] Grubb 1993.
[68] Ogden and Nitsch 1993.
[69] Poul-Erik Morthorst, Risø National Laboratory, Denmark, personal communication, January 1998.
[70] The Annex 1 countries include all OECD countries plus central and eastern European "economies in transition".
[71] The Minister for Science, Energy and Industry.
[72] In fact, the legislation places the requirement on public electricity suppliers, but only on those who are also regional electricity companies.
[73] DTI Press Release, 13 November 1997.
[74] Broadly speaking, the declared net capacity (DNC) is defined as the equivalent capacity of conventional baseload plant that would produce the same average annual output. For intermittent renewable energy sources, the declared capacity is calculated by multiplying the installed capacity by specified factors. For wind, for example, this factor is set at 43%.
[75] See, for example, Mitchell 1995 and 1996.
[76] OFFER 1997.
[77] Ibid.

[78] DTI Press Release, 25th November 1997.

[79] Figures provided by DG XVII.

[80] Enzo Millich, DG XVII, personal communication, February 1998.

[81] COM(97)481, Climate Change – the EU Approach for Kyoto.

[82] COM(96)576 of 20.11.96, "Energy for the Future: renewable sources of energy".

[83] Eurelectric 1997.

[84] PE 221/398.fin.

[85] This table shows the contributions using the Eurostat Convention counting inputs from primary electricity sources directly, rather than on a substitution basis.

[86] These are net of job losses due to reduced production in other energy sectors.

[87] Altener II brochure, final draft, DG XVII.

[88] Patrick Lambert, DG XVII, personal communication, February 1998.

[89] Declaration of Canarias, Canarias, January 16th-18th 1998.

[90] "Draft report drawing up a directive on network access for electricity from renewable sources of energy in the EU", Committee on Research, Technology Development and Energy, European Parliament, DOC_EN\PR\339\339181.

[91] Total carbon dioxide emissions in 1990 were 3,200 million tonnes, and these are forecast to rise to 3,459 million tonnes by 2010 - COM(97)481.

[92] Council Conclusions on Climate Change, 3rd March 1997.

[93] The Independent, 17th October 1997; Lloyds List International, 27th October 1997; ENDS Daily, 16th October 1997; Reuters, 16th October 1997.

[94] Jennings 1995 and 1997; Moody-Stewart 1996; Shell 1996; Herkstroter 1997.

[95] ENDS Daily, 8th January 1998.

[96] ENDS Daily, 21st May 1997.

[97] ENDS Daily, 5th November 1997.

[98] Financial Times, October 23rd 1997; Lloyd's List International, 14th November 1997.

[99] Morthorst 1998, eg.

[100] See, in particular, the pioneering work of Hohmeyer (Hohmeyer 1988, Hohmeyer *et al* 1997) and the Pace Institute (Ottinger *et al* 1990), and more recent studies including the joint US-European Commission study on fuel cycle externalities (EC 1995, ORNL 1994), and the Tellus Institute's EXMOD programme (Bernow *et al* 1997).

[101] Hohmeyer 1993.

[102] The values in this table are adapted from Table 2 in Lee 1997.

[103] The minus sign indicates external benefits from the technology.

[104] Fankhauser (1994) eg, suggests a marginal social cost of US $20.4 per tonne of carbon based on estimates of the future cost of global warming.

[105] See, eg, Table 1 in Muller 1997.

[106] Barker *et al* 1995, eg.

[107] See Thomas 1997 for an overview of some IRP programmes.

[108] This argument is reinforced by experiences on IRP gained through the European Commission's SAVE programme – see references 145-147 in Jackson 1997.

[109] Whether these reductions in cost are sustainable in the long-term is another matter.
[110] Jackson 1996, eg.
[111] GEC 1997.
[112] Eastern Press Release, 23rd October 1997.
[113] Wiser and Pickle 1997.
[114] Eurelectric 1997.
[115] ETSU 1996.
[116] Hargreaves 1996; Kunreuther *et al* 1993; Slovic 1993, eg.
[117] Slovic and MacGregor 1994.
[118] Löfstedt 1997; Marris *et al* 1995; Worcester 1995 and 1996.
[119] Giddens 1990, 1991 and 1994.
[120] Renn and Levine 1991; Slovic 1993; Nye *et al* 1997.
[121] Kunreuther *et al* 1993; Linnerooth-Bayer and Fitzgerald 1996; Renn *et al* 1996.
[122] Hargreaves 1996.
[123] Fischhoff 1995; Hargreaves 1996; Kunreuther *et al* 1993; National Research Council 1989.
[124] Fischhoff 1995; National Research Council 1989 and 1996; Slovic and MacGregor 1994.
[125] Löfstedt 1997.
[126] Löfstedt and Renn 1997.
[127] See Löfstedt 1995.
[128] Meyer 1995.
[129] John Battle, personal communication, December 1997.
[130] Actually, the proposal is formulated in terms of "renewable energy credits" which are tradeable on the market (see Mitchell 1996 eg).
[131] Cutts and Jackson 1998.

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