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Power without Pollution - An R&D Strategy for Electricity Generation with Near to Zero Emissions

Foresight Energy and Natural Environment Panel:
Report of the ZEPG Group

5th September 2001

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Contents

1 Introduction

Near to Zero Emission Power Generation (ZEPG) refers to a range of technologies that are capable of producing electricity with minimal emissions to the environment, taking account of their full fuel cycles. They fall into three broad groups, classified by fuel type:

- Fossil fuel
- Nuclear power
- Renewable energy

These technologies are strategically important because they open up the option of supplying electricity with near to zero carbon dioxide emissions. They also reduce other atmospheric pollution, and contribute to diversity and security of power supply. With electricity accounting for an increasing share of world energy consumption, the development of ZEPG plant will be crucial in achieving the major reduction in greenhouse gas (GHG) emissions, which is generally agreed to be needed beyond 2020 if climate change is to be contained within tolerable limits[3,4]. Indeed the availability of cost-effective ZEPG plant could be crucial in facilitating international agreement on more stringent GHG abatement.

The significance of ZEPG technology, and the large commercial opportunity it presents, has been recognised in other countries with strong power engineering sectors by the initiation of R&D[5] programmes such as the USA's Vision 21 Programme, and Japan's New Sunshine Programme. If the UK power engineering industry is to retain and grow its world market, it too needs to be at the forefront in the development of these technologies.

The UK Foresight Energy and Natural Environment Panel (ENE Panel) identified "low and close to zero emission power generation" as a priority area for future R&D, and supported two associate programmes to advise on key areas for action with the fossil and nuclear technology groups. Together with the DTI's work on renewable energy technologies[6], these programmes have produced reports[7,8,]setting out prioritised plans that aim to build on the UK's existing strengths with these technologies. The reports revealed a broad range of R&D themes and requirements that are common to the three technology groups, and which would benefit from co-ordinated implementation. It is also clear that, at this pre-commercial stage, other non-technical actions are needed to support development, which again are common to the three technology groups. The ENE Panel set up the Zero Emissions Power Generation (ZEPG) group to draw together the recommendations into an

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[3] IPCC Report - The Science of Climate Change, Cambridge University Press, 1996.
[4] Royal Commission on Environmental Pollution, 21st Report, Energy - The Changing Climate, HMSO.
[5] Throughout this document the term R&D will be used as shorthand to represent basic research, technical development, pilot and demonstration activities.
[6] Technology Status Reports produced by the DTI's New and Renewable Energy Programme.
[7] A Technology Strategy for Power Generation from Fossil Fuels, Biomass and Waste (produced by the Advanced Power Generation Task Force)
[8] Technologies and Skills for the Future, (produced by the British Nuclear Industries Forum Foresight Programme)

integrated strategy. This report presents the conclusions of this group, and aims to provide high-level decision makers in government and industry with a clear agenda for action.

Near to Zero Emission Power Generation refers to a range of technologies that are capable of producing electricity with carbon dioxide emissions that are of the order of 10% of those from conventional plant. Their development is vital for achieving major (50-60%) long-term reductions in greenhouse gas emissions

2 Near to Zero Emission Power Generation Technologies

The Introduction defined near to zero emission power generation as the production of electricity with minimal emissions to all elements of the environment (the atmosphere, water and land). However, what makes these technologies strategically important is that they produce near to zero emissions of CO_2; the principal gas responsible for climate change. Of the three classes of technology capable of being developed as ZEPG plant, renewable energy sources and nuclear power are inherently low in CO_2 emissions (the main emissions are those associated with their manufacture, fuel processing/transportation and final decommissioning). In contrast technologies using fossil fuels require engineered systems to separate, capture and dispose of the carbon in the fuels either before or after combustion (e.g. during gasification of coal, or by taking CO_2 out of flue gases).

Each of the above technology classes draws on a range of devices and processes, together with enabling technologies (e.g. materials, control systems, structural integrity analysis, etc.). In some cases the same devices are common to more than one class of technology. Important examples are gas turbines, boilers and steam turbines, which are used in fossil and biomass plant as well as in a range of nuclear reactor designs. Another is fuel cells, which are likely to be crucial to achieving high conversion efficiencies with both fossil, with CO_2 capture, and biomass power generation.

Fossil Fuel systems involve the oxidation of carboniferous material and conversion of the energy released to electrical power through high efficiency devices such as gas turbines, fuel cells, gasifiers, boilers and steam turbines. Technologies are already available to give considerable reductions in the emissions of pollutants such as NOx and SOx, and the industry is constantly striving to maximise fuel efficiency through technical advances and greater deployment of combined heat and power systems. However, whilst these represent important intermediate steps towards near to zero emissions, such developments are not the complete answer. Capture and disposal of CO_2 is a key element of plant designed for near to zero greenhouse gas emissions. This introduces the need for new developments and know-how (e.g. CO_2 separation methods, geological disposal of CO_2) lying well beyond the tradition capabilities used in the manufacture of thermal power plant.

Nuclear Power is a stand alone fuel cycle that starts from primary fuel (mainly uranium) extraction, through reactor fuel production, power plant operation, spent fuel management, plant decommissioning, waste management and disposal. This embraces a wide range of technologies and skills some of which are not directly associated with power generation.

Nuclear power generates comparatively low CO_2 emissions. The main goals for future development are improved economy, higher safety margins, reduced waste production, and for advances in the "back end" of the fuel cycle that produce safe and socially acceptable methods for radioactive waste management and disposal. This requires inputs from the geology, hydrology and biology as well as engineering. Nuclear fusion offers an alternative method for power production, but was considered too far from commercial deployment for consideration in this strategy.

Renewable Energy covers a range of devices that capture different sources of energy present in nature and converts them mainly to electricity. It includes wind, wave and tidal power, solar energy, and sources of biomass for combustion including energy crops, waste and landfill gas. These technologies already have near to zero emission characteristics, but their sustained commercial deployment depends on further reductions in cost and increased capture efficiencies. Biomass combustion will benefit from many of the developments with fossil fuel systems. Other technological developments include new and improved devices, and also methods for siting and ensuring the reliability of the devices, which are often placed in hostile environments. Additionally, the intermittent nature of some sources places importance on the electricity distribution system, including economic and reliable methods for electricity storage.

- The key feature of near to zero emissions power plant is that it offers an approach for achieving major cuts in CO_2 emissions from power generation.
- Near to zero emission power plant can be derived from fossil systems, nuclear power and renewable energy sources.
- Nuclear power and renewable energy are inherently low in CO_2 emissions, but fossil fuel systems require CO_2 sequestration and disposal.
- Each near to zero emissions power system consists of a chain of devices, processes and enabling technologies, which need to be developed in an integrated manner to achieve commercial deployment.
- Several of the devices are common to more than one type of near to zero emission system (e.g. gas turbines, gasifiers, fuels cells, boilers, steam turbines) and therefore their development will have broader benefits.

3 Demand for the Technologies

In formulating a strategy for the development of ZEPG plant it is important to consider how the market for such plant will develop in the future.

Most forecasts agree that the demand for electricity will continue to grow both in the industrialised nations and the developing world. For example the International Energy Agency (IEA), in its World Energy Outlook 2000[9], estimates that global electricity generation will expand by 2.7% per annum from 1997 to 2020. This equates to a requirement for new generating capacity totalling about 3000 GW over the next 20 years,

[9] International Energy Agency, World Energy Outlook 2000, ISBN 92-64-18513-5

or over £2000 billion of sales, with more than half located in developing countries. The IEA's forecast is for a "business as usual" future, and it is arguable that demands for electricity could be greater. For example, a drive to reduce carbon dioxide emissions from transport could result in the deployment of electric or hydrogen fuelled vehicles, which could in turn create additional demand for electricity. Forecasts looking beyond 2020, such as those from the Inter -governmental Panel on Climate Change (IPCC)[10] and the World Energy Council[11], see growth continuing into the second half of the century, driven in particular by demands for electrification and industrialisation in developing countries. With the UK presently holding about 10% of the world market for power plant this represents a major opportunity for the creation of wealth and jobs.

Whilst there is general agreement amongst forecasters on the growth in demand for new power plant, it is less certain what the future holds for ZEPG technologies.

Fossil Fuel systems currently account for the bulk of global power generation (~70%) and most projections expect this to be maintained at least to 2020 (e.g. IEA World Energy Outlook). Therefore a large part of the future power plant market will be for advanced fossil fuel systems. Moreover, a combination of market liberalisation, competition and environmental regulations will drive the development of high performance and low cost plant with low pollution emissions. However, under current policy and market conditions there is no driver for the adoption of ZEPG plant involving CO_2 separation and disposal. Consequently the market for this technology seems likely to be limited to demonstration projects plus niche market applications in which the separated CO_2 has commercial value, such as its utilisation for enhanced oil recovery.

Nuclear Power is commercially deployed, accounting for about 17% of world electricity generation, but this is expected to decline over the next two decades as plant is retired. With current policies the prospect for new build is limited because of the high cost combined with problems over public acceptability. Concern is growing over long-term security of electricity supply, particularly in regions with a growing dependence on imported natural gas, but it is not clear if this issue alone will be sufficient to renew interest in nuclear technology.

Renewable Energy sources currently account for about 11% of world electricity generation, with roughly two thirds of this coming from large hydro-electric schemes. The non-hydro technologies have achieved remarkable growth in deployment over the last 20 years, particularly in the advanced economies, which have taken a variety of measures to support their commercialisation. This action has been taken because renewable sources are recognised as contributing to security of supply as well as reducing pollution. However, as their deployment increases there are indications of growing public concern, stemming from perceived impacts on natural amenities, which may slow further expansion.

As well as achieving growth in deployment the support measures have also been successful in reducing the cost of the renewable technologies to the extent that some are approaching competitiveness with fossil fuel systems. However, it seems unlikely that they will gain a

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[10] IPCC Special Report on Emissions Scenarios (2000)
[11] WEC/IIASA, Global Energy Perspectives to 2050 and Beyond (1995)

market share comparable with fossil fuels unless there is a major drive to reduce GHG emissions.

In conclusion the markets for all three groups of ZEPG plant are likely to be limited under present policies and market conditions. However, this position would change dramatically if more radical targets are adopted for reducing global GHG emissions. Electricity generation presently accounts for about one third of global energy related CO_2 emissions, and since electricity demand is expected to grow faster than total energy demand this share should grow. The IPCC[12] has estimated that, for atmospheric CO_2 concentrations to be stabilised at 550 ppm, about double pre-industrial levels and representative of the concentration thought necessary to avoid "dangerous anthroprogenic climate change", annual emissions will need to be reduced globally by about 50% from 1990 levels by 2050. The Royal Commission on Environmental Pollution in its recent report "Energy- the Changing Climate"[13] concurred with this view and suggested a reduction target of 60% for the UK by 2050.

The technical specification of ZEPG plant will be affected by future market and policy developments. At first any drive for radical reductions in greenhouse gas emissions is likely to emphasise energy efficiency both in production and end-use. In the long term the result in the power generation sector is likely to be a drive for greater integration of power and heat production to extract the maximum useful energy from primary sources. This could involve expansion of combined heat and power to small and even "micro" applications (1 -50 kWe). This has major implications for both the type of ZEPG technologies that would be needed (e.g. micro-gas turbines, fuel cell systems) and the fuels they would use. It is unlikely to be feasible to separate and dispose of CO_2 from a large number of small generators, and therefore such plant would need to operate with fuels that have low or zero carbon contents such as hydrogen.

Increasing the deployment of renewable energy sources would also favour a change from almost total dependence on large centralised generation plant to a greater proportion of distributed generation. A recent workshop for the power industry[14] estimated that up to 20% of generation capacity could be based on distributed plant by 2020. This would have profound effects on the structure and operation of power systems, facilitating closer linkages between supply and demand. It is also likely to increase the need for back-up plant and novel methods for electricity storage. It should be stressed ,however, that although the share taken by distributed generation is expected to grow, large centralised plant is expected to continue its dominance of power production.

Finally it is worth noting that, whilst the market for ZEPG plant is dependent on global action for major reductions in GHG emissions, agreement on such abatement measures may well depend on the availability of cost-effective methods to achieve the targets.

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[12] IPPC Report (Reference 1)
[13] Royal Commission on Environmental Pollution, 21st Report, Energy - The Changing Climate, available from HMSO
[14] CETI workshop "Cleaner Energy Technologies for the 21st Century" a report of a workshop held in Brussels, December 2000 (www.ceti-fossil.com).

Therefore paradoxically the development of ZEPG technologies may well be an essential prerequisite to attaining a global agreement for radical action on climate change.

- Market forecasts agree that electricity generation will grow substantially producing a large global market for new plant with a value of about £2000 billion over the next 20 years alone.
- The UK has a significant share of the present world market for power engineering (about 10%) and will need to develop advanced systems to maintain and grow its share.
- Electricity generation is responsible for about one third of CO_2 emissions, and will be a key target if major reductions in emissions are to be achieved beyond 2020.
- Global agreement for major reductions in CO_2 emissions is the key to producing a large commercial market for near to zero emission power plant.
- Paradoxically the availability of cost-effective CO_2 abatement technologies, such as ZEPG plant, could well be essential for gaining global agreement for more severe cuts in GHG emissions.
- Demand for near to zero emissions power plant will be divided between large centralised facilities and smaller distributed generation plant.
- Although the share taken by distributed generation is expected to grow, large centralised plant is expected to continue its dominance of power production.
- To have these technologies ready for commercial deployment beyond 2020 requires development work to be started now.

4 Status of UK Power Engineering Industries

The development of a strategy for R&D into near to zero emissions power plant needs to take account of the industrial structure available to exploit potential developments. Major changes have happened over the last decade that have affected the technology areas in different ways and therefore they need to be considered separately.

4.1 Fossil Power Plant

The UK's fossil power engineering industry, worth over £13Bn/yr, presently holds roughly 10% of the global market and has about 150,000 direct employees. Globalisation in power engineering has seen some UK based firms extending their manufacturing activities to other countries, whilst others have been absorbed into multi-national corporations. Nonetheless, the UK industry has retained a strong production capability, particularly in small/medium gas turbines, key components for large gas turbines, combustion systems, boilers, steam turbines and clean coal technologies. The UK is also an acknowledged leader in systems design, environmental assessment, and in the overall technical and financial management of power plant construction projects. It is also significant that the multi-nationals maintain a substantial R&D effort in the UK

Looking to the future, the UK has strength in the new technologies and capabilities needed to produce fossil fuel near to zero emission plant. For example in gasification, gas separation, gas storage, pipeline transportation and the use of CO_2 in enhanced oil recovery. The UK is also strong in the geological and marine sciences needed to develop safe and effective options for CO_2 disposal.

Overall UK based industry has the capability to design, project manage, and build innovative ZEPG technologies. However, it is more realistic to view the industry within a global system in which specialist centres for design and manufacture supply components and devices to be incorporated into a generation plant. In some cases the UK may lead on the design and project management of the complete system, buying components from an international set of suppliers. In other cases the UK may supply specific components to a project led by a foreign organisation. Within this framework it is important for UK systems designers, manufacturers and project managers to retain their position at the forefront of development. This position will not be assured through support for R&D alone (see Section 5).

4.2 Nuclear Power

The international industry now has four or five centres of power reactor technology. The UK's nuclear power industry has also undergone substantial change since building its own first and second generation plant. Key aspects for the UK industry are:

- The lack of new orders since the 1980's has substantially reduced the capability to design and manufacture new reactor systems.
- The recent acquisition of the US PWR technology companies and of ABB Atom, plus a stake in the South African Pebble Bed (PBMR) project puts British industry in a position of strength in world reactor technology.
- Development of advanced systems has effectively ceased with the closure of the Fast Reactor programme.
- Technical development of power reactors is now focussed on safety and reliability engineering and life-time extension of existing plant.
- The UK is a strong player in fuel reprocessing, but the future of this market is uncertain.
- A strong capability has been established in decommissioning.
- A strong capability has been established in the treatment, management and development of disposal options for decommissioning and reprocessing wastes.

The overall effect of these trends is that the UK nuclear industry is now dominated by the electricity and fuel supply companies with a relatively weak plant manufacturing sector. The remainder of the industry consists of a range of smaller organisations that specialise in supporting some aspect of reactor operations, fuel processing or waste management, many of which are part of multi-national groups servicing the global industry. Overall the UK industry is geared towards gaining the maximum economic benefit from existing facilities and undertaking the decommissioning of retired plant.

Looking to the future, and the possible construction of new power systems, it seems likely that the main UK actors will see their role as informed buyers of technology, rather than developers of new UK based designs. Other parts of the industry are small and will probably concentrate on providing specialist services to plant operators.

4.3 Renewable Energy

The renewable energy industry is extremely diverse, covering energy capture and conversion devices ranging from wave power to photo-voltaic electricity to energy crops. Moreover, it is often the case that the main conversion device is only a fraction of the cost and manufacturing input associated with a renewable system. For example the balance of system elements to photo-voltaic power are roughly of equal value to the PV panels themselves. System costs are also important to off-shore wind energy (e.g. foundations, off shore maintenance) and energy crops (e.g. growing and harvesting). Consequently it is misleading to draw a generalised picture of the status of the industry for exploiting new innovations.

Wind energy is one of the more mature renewable technologies, but the UK does not have a manufacturer of turbines. Instead the industry has become concentrated on specialist areas, for example blade production, installation, project and commercial management. The move to off-shore location is attracting interest from the UK's strong off-shore engineering sector, which hitherto has had little involvement in renewable energy, but could take a lead in installation and maintenance.

Biomass is another important renewable energy source for the UK, which offers considerable new business opportunities for both the agriculture and power engineering industries. The UK is strong in specialist technical areas including bio-engineering, gasification, pyrolysis and co-firing. It also has strength in financial services and in putting together turn-key packages. In addition the need to increase the efficiency of power production from biomass may draw on many of the developments in fossil fuel generation plant.

In contrast other renewable technologies are only at the design and development stage, and the field is open for organisations to gain a dominant position. This applies for example to Tidal Stream and Wave energy devices where the UK leads in innovative design, and is rich in the natural energy sources to be exploited.

A further consideration with renewable energy is the size of the devices, which in general are smaller and more modular in nature than fossil or nuclear power plant. As a consequence the demonstration of devices is less costly to implement at a national level. Overall these near to zero emission technologies continue to offer opportunities for innovation and its exploitation by UK industry. However, unlike fossil and nuclear power, the industry is fragmented and less well established and it is more difficult to bridge the gap between basic research/innovation and the commercialisation of promising developments.

- The UK has a strong capability for the overall design, civil engineering and construction of power plant of all types. It is also strong in the management and operation of power stations, both in the UK and overseas.

- Most of the UK's power engineering industry is involved with the production of fossil power generation plant. Globalisation has seen some UK based firms extending their manufacturing activities to other countries, whilst others have been absorbed into multi-national corporations. UK industry has retained a substantial production capability, and is also an acknowledged leader in systems design, environmental assessment, and in the overall technical and financial management of power plant construction projects.
- While the development of fossil fuelled near to zero emissions plant will be an international activity, UK industry has the strength to lead in a number of key areas including systems design, environmental assessment and overall project management. It could also lead in the development and manufacture of key components, including gas turbines, combustion/gasification systems, boilers, steam turbines and clean coal technology, together with CO_2 separation and its utilisation/disposal.
- The lack of orders, and the planned closure of most existing nuclear capacity over the next 20 years, means that the UK's capability to design and produce complete nuclear power plant is much reduced. It is likely that any future orders will be sourced from international consortia, with UK generators acting as informed buyers.
- The UK nuclear industry is strong in certain specialist areas such as fuel processing, plant life-time extension, waste management and the assessment of disposal options, and is likely to focus more strongly on such niche areas in the future.
- The renewable energy industry is relatively new, and covers a broad range of devices and supporting industries. In some of the more mature areas (e.g. wind energy) rationalisation has occurred and the UK industry is focussed on specialist component and service provision rather than complete manufacture of devices. However, other areas such as biomass offer considerable opportunities for UK agricultural and power engineering industries, while tidal and wave energy are still at the conceptual stage and there is the opportunity for a UK lead.
- The relatively small and modular nature of renewable energy devices makes demonstration less costly to implement at a national level. The UK has strong industry sectors, which up to now have not been strongly linked to renewable energy (e.g. off-shore engineering), but which could make a major contribution to new developments.

5 R&D Needs of Near Zero Emission Power Plant

The Foresight ENE Panel has supported two Associate Programmes, that together with DTI studies have examined the R&D needs of the three classes of ZEPG technology; fossil fuel, nuclear power and renewable sources. These programmes have produced detailed reports setting out priorities for the research, development, demonstration and implementation of plant, component devices and underpinning technologies needed to advance these systems to commercial availability. This section of the report draws together the key findings from these studies to identify the most important themes to be included in an integrated programme for developing ZEPG plant.

An important conclusion from all three studies is that R&D needs to be considered within an overall system for development, demonstration and deployment. This conclusion has also been supported by the ENE's Energy Futures Task Force[15] and in the Panel's report on sustainability issues[16]. Figure 1 illustrates such a system in which the key elements are R&D, policies and measures (to support a market for the technologies) and action to win social acceptance.

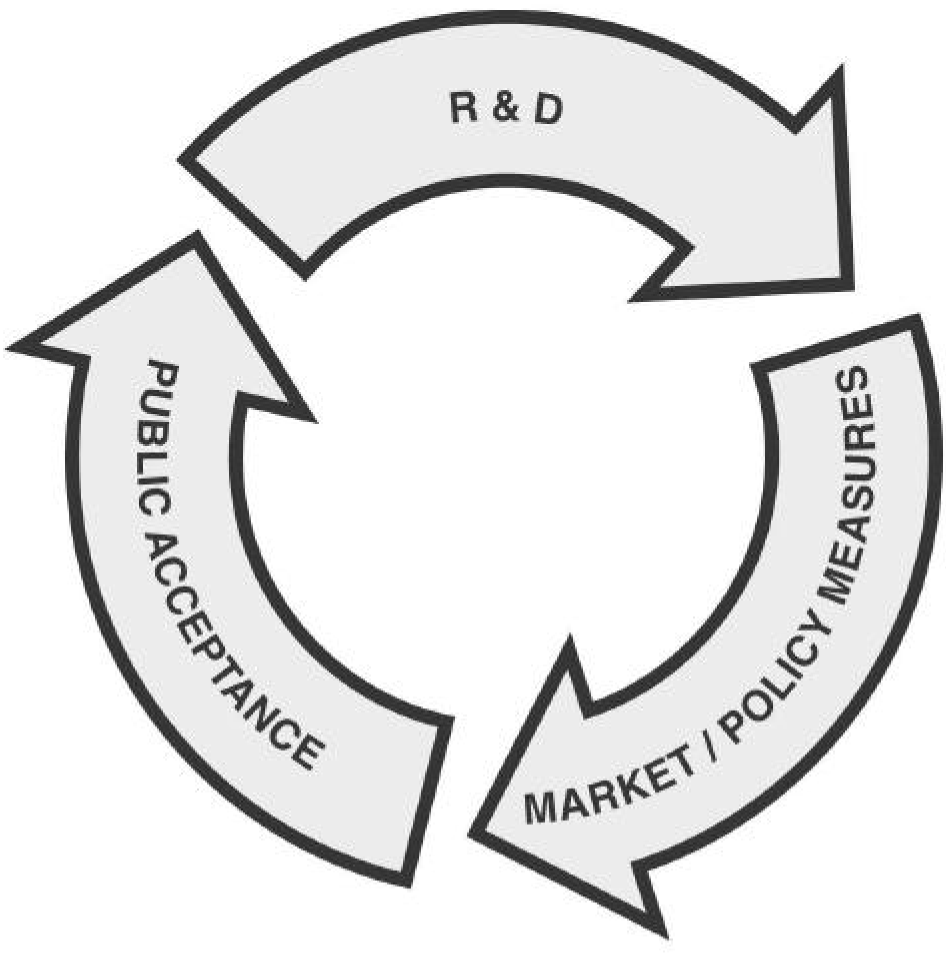

Figure 1 An Overall System for Development of ZEPG Plant

The system is not linear, all three elements need to be addressed together with feedback and interaction between them. For example it is doubtful whether the necessary R&D

[15] Powering the Future, September 2001.
[16] Stepping Stones to Sustainability, December 2000

investment will be made by industry without policy and market measures being taken to stimulate a potential market for the technologies. Also the deployment of ZEPG plant needs to be managed within a regulatory framework that is tailored to the characteristics of the technologies, and does not impose unnecessary costs and delays. However, even if the R&D is undertaken, and the policies, market measures and regulatory systems are put in place, there are significant uncertainties about the deployment of the technologies unless this is approached in a way that is socially acceptable.

The main themes for R&D drawn from the reports are:

- Basic Research
- Device Research
- Virtual Demonstration
- Physical Demonstration
- Condition Monitoring and Reliability Engineering
- Systems Analysis
- Social Research
- International Collaboration

Basic Research

This theme covers a broad range of activities including the study of basic processes such as combustion, fluid dynamics, electrochemistry. It also includes R&D into underpinning technologies that are incorporated into power generation plant and are crucial to its design and performance. One example is high temperature materials, which enable boilers and turbines to operate at higher temperatures and therefore greater efficiency. Another example is geological science, which will be central to the location and design of disposal systems for both nuclear waste and captured CO_2. Further examples are biological engineering for improved energy crops and surface chemistry for the advanced catalyst systems needed in fuel cells. Work of this type has traditionally been undertaken in universities and research establishment with input from industry.

The benefits of basic research are three fold. Firstly, generation of knowledge that diffuses into industry and can be integrated in the evolutionary development of existing systems. Secondly, a supply of more innovative ideas for devices and processes for development into new products for manufacture. Finally a sustained supply to industry of high quality engineers and scientists.

Device Research

This theme covers innovative design studies through to the manufacture of small scale prototypes. Examples could include novel methods for converting renewable energy into electricity, high efficiency processes for carbon separation from fossil fuels or flue gases, and modelling assessments of ways of combining conversion devices such as fuel cells, gas turbines and steam plant to maximise generation efficiency. Work of this type tends to be undertaken through collaboration between universities, research organisations and industry.

Once again the benefits are the development of new ideas and devices, combined with the training of high quality engineers and scientists for industry.

Virtual Demonstration

The costs and financial risks of building and operating demonstration plant have increased as designs have become more elaborate and push further towards technical limits. At the same time the liberalisation of energy markets has made the power generating industry more risk averse. Therefore there is a need to develop computer based systems that go beyond design to virtual demonstration. Such systems should make much more sophisticated and detailed plant simulations and thus reduce the need for, and remove some of the risks from, real demonstration projects.

Clearly the benefit from the development of such systems is reduced costs for demonstration. They also open up the potential to take a broader range of design concepts much further towards development before the selection of preferred systems needs to be made.

Physical Demonstration

Ultimately near to zero emission plant will need to be demonstrated at full scale, both to gain operational experience and to reduce the investment risks attaching to new untried designs. Demonstration is expensive, particularly with large fossil and nuclear plant, and it is unlikely that UK industry would be prepared to carry such costs on its own. Therefore there is a need for clear strategies to be developed for :

- Virtual demonstration
- Separate demonstration of key components (e.g. gas turbines, CO_2 separation)
- Promotion of demonstrations both nationally and abroad

These comments apply not only to the central power plant, but also to key elements of the fuel chain. For example the disposal of CO_2 in disused gas fields, nuclear waste conditioning and disposal and the anchorage of off-shore wind farms.

Hosting demonstration in the UK at all levels would provide a "shop window" for the export of UK technologies as well as ensuring that maximum benefit is gained in terms of operational and maintenance experience of novel plant that will feedback into more advanced designs. It will also benefit the UK's power plant operators by giving them experience with running advanced systems.

Condition Monitoring and Reliability Engineering

Liberalisation of the electricity generation industry has increased the commercial pressure to gain maximum benefit from deployed capital. This translates into having reliable plant with high availability and where possible extending its operating life. These pressures will apply to all three classes of near to zero emissions plant, with plant life extension being particularly important to nuclear plant.

Achieve such reliability requires advances in the design of key components and in new methods for monitoring and assessing their condition. In addition improved retrofitting methods are needed to support plant life extension.

Systems Analysis
Near to zero emissions technologies will need to be deployed into an evolving energy system. One topical issue affecting their deployment is the balance between large centralised and smaller distributed power generation. Other issues are the options for backing up, and storing the output from intermittent renewable energy sources, options for using energy crops (e.g. dedicated plant or co-firing of fossil fuel plant), and the potential future role of electricity in reducing carbon emissions from other energy consuming sectors such as transport.

Because of the wide range of options available and their potential impact on both the design and market size for near to zero emission plant, there is a need for systematic assessments. This also needs to examine how systems may evolve with time and how economies of scale and "learning by doing" can affect technology costs and performance both in manufacture and operation.

Social Research
Experience with the deployment of energy technologies has shown that public acceptance is crucial to their commercial success. However, the public appears to be reluctant to accept the building of many forms of energy plant despite their growing demand for energy related services. This is a key area for social science research in relation to the broad area of sustainable development. Research is needed into methods and approaches to engage the general public in the energy debate and to identify the technical and perception issues, which need to be addressed in order to make near to zero emission plant more acceptable.

International Collaboration
International collaboration has already been mentioned in relation to plant demonstration. Benefits can also be gained from pre-competitive collaboration in the development of longer term technologies such as fuel cells, photo-voltaic and advanced nuclear systems (e.g. fusion). There is a range of opportunities open to the UK for such collaboration:

- European Union Programmes
- IEA Programmes
- One to one collaboration with other national programmes (e.g. the on going interaction with the USA on clean coal technologies)

International collaboration could potentially go beyond R&D and information exchange to the development of common standards for measuring and reporting technology performance and for measuring renewable energy resource. This would facilitate technology development, the transfer of technology to other markets and increase investor confidence through the existence of credible performance standards.

- R&D needs to considered within an overall system for development, demonstration and deployment. In this system the key elements are R&D, policies and measures to support a market for the near to zero emission power generation technologies and action to win social acceptance.
- The development system is not linear; all three of the above elements need to be

addressed together with feedback and interaction between them.
- Eight R&D themes have been identified which are common to the development of all three groups of near to zero power generation plant.

6 Supporting R&D on Near Zero Emission Power Plant

The ENE Panel's Associate Programmes also considered the support needed for R&D on ZEPG technologies. They concluded that it was unrealistic to expect industry to take the lead on ZEPG plant because of the current uncertainties concerning the future market for these technologies. Therefore public sector funding is essential if the UK is to take a prominent role in their development.

Some R&D related to ZEPG plant is already supported through the Research Councils, DTI programmes, the European Union Framework Programme and directly by industry. Additional funding will be available once the Carbon Trust's R&D programme is fully established, and further support for R&D on renewable energy may come from the extra £100M of funding recently announced by the Prime Minister for these technologies. However, present figures suggest that in total UK investment is small compared to our main competitors. For example IEA data show total R&D spending on coal technology in 2000 to be £83M in the USA, £61M in Japan, £12M in Germany and under £2M in the UK. Corresponding values for renewable energy are £145M USA, £116M Japan, £39M Germany and £5.5M UK. Although the IEA's data may have some inconsistencies linked to how countries define R&D, the basic message is beyond doubt; a significant increase in funding is needed if the UK is to be a leading player in this field.

However, adequate R&D funding is only part of the support needed for ZEPG technologies. As discussed in Section 5, the development of these technologies also requires policies and measures to stimulate a market to support their commercial deployment, and the engagement of the general public to win acceptance for their deployment. Key actions to be considered are:

- Inclusion of new-build ZEPG fossil fuel and nuclear power plant in existing and proposed policy measures designed to deliver reductions in CO_2 emissions (e.g. Climate Change Levy and Carbon Trading).
- Consideration of additional market based measures to encourage the commercial deployment of ZEPG plant that advance in step with the technical development of the technologies.
- Development of planning and regulatory frameworks that recognise the specific characteristics of ZEPG plant and do not impose unnecessary delays and costs on their deployment.
- Stimulation of a broader public debate on the need for ZEPG plant that will establish greater appreciation of the choices to be made.

The ENE Panel's Associate Programmes also noted that there was no single centre to examine technical options and to co-ordinate R&D on ZEPG technologies. Such a centre could play a key role in providing objective assessments of alternative ZEPG technologies and systems. It could also advise both government and industry on targeting R&D to gain maximum benefit from the UK's strengths in ZEPG technologies (Section 4).

- Because of present uncertainties regarding the future market for near to zero emission power plant public funding will be needed to support the development of these technologies over the next few years.
- Current levels of public funding are insufficient and are small compared to the UK's main competitors.
- Any expansion of R&D on near zero emission plant should be accompanied by policy measures designed to develop progressively a market for these technologies. Suitable actions could include the inclusion of new build ZEPG fossil fuel and nuclear power plant in existing and proposed policy measures designed to deliver reductions in CO_2 emissions (e.g. Climate Change Levy and Carbon Trading). Consideration should also be given to additional market based measures to encourage the commercial deployment of ZEPG plant that advance in step with the technical development of the technologies.
- Planning and regulatory frameworks are needed that recognise the specific characteristics of ZEPG plant and do not impose unnecessary delays and costs on their deployment.
- Action is also needed to raise the debate on climate change and sustainable energy sources so that the public is aware of the choices to be made regarding future energy supply and demand.
- An expanded R&D programme on near zero emission technology would benefit by co-ordination from a central unit.

7 Conclusion and Recommendations

Near to Zero Emission Power Generation (ZEPG) refers to a range of technologies that are capable of producing electricity with minimal emissions to the environment taking account of their full fuel cycles. They fall into three broad groups classified by fuel type; namely fossil fuel (with CO_2 capture), nuclear power and renewable energy. This report outlines an integrated strategy for the development of such plant in the UK. It considers the future demand for the technologies, the competitive position of UK industry, the R&D priorities and how future development should be organised and managed to gain maximum benefits from available resources.

There is a large and growing world market for power generation plant, but with present policies only a small fraction will be taken up by ZEPG technologies. However, models of climate change suggest that major reductions in CO_2 emissions, of the order of 50-60% by about 2050, are needed to avoid serious global warming. Concerted action to achieve such reductions will produce a large world market for ZEPG plant. Paradoxically the attainment of a global agreement for major cuts in CO_2 emissions may depend on the availability of cost-effective options for achieving such a reduction. Consequently it may be necessary to develop ZEPG plant in advance of market requirements.

Most of the UK's power engineering industry is involved with the production of fossil power generation plant in which it presently has a 10% share of the world market. Globalisation in power engineering has seen some UK based firms extending their manufacturing activities to other countries, whilst others have been absorbed into multi-national corporations. Nonetheless, UK industry has retained a strong production capability, and is also an acknowledged leader in systems design, environmental assessment, and in the overall technical and financial management of power plant construction projects. . Its is also significant that the multi-nationals maintain a substantial R&D effort in the UK

UK development of fossil fuelled ZEPG plant should be viewed within a global system in which a limited number of centres design and manufacture specialist components and devices to be incorporated into generation plant. UK manufacturing strengths lie in areas such as gas turbines, boilers, steam turbines, clean coal technology, CO_2 separation and its utilisation/disposal, materials, combustion science, catalysts and power systems engineering.

The lack of orders, and the planned closure of the majority of existing nuclear capacity over the next 20 years, means that the UK's capability to design and produce complete nuclear power plant is much reduced. It is likely that any future orders will be sourced from international consortia, with UK generators acting as informed buyers. The UK nuclear industry is strong in certain specialist areas such as plant life extension, waste management, fuel processing and the assessment of disposal options, and is likely to focus more strongly on such niche areas in the future.

The renewable energy industry is relatively new, and covers a broad range of devices and supporting industries. In some of the more mature areas (e.g. wind energy) rationalisation has occurred and the UK industry is focussed on specialist component and service provision rather than complete manufacture of devices. However, with other renewable sources such as biomass systems and off-shore wind, there is potential for major involvement through the UK's strengths in agriculture, power systems, off-shore engineering and in the overall financial/technical management of systems supply. Other systems such as tidal and wave energy are still at the conceptual stage and there is the opportunity for an UK lead. Furthermore, the relatively small and modular nature of renewable energy devices makes demonstration less costly to implement at a national level.

Associate Programmes supported by the Foresight ENE Panel and the DTI's renewable energy programme, have produced detailed recommendations on the R&D priorities needed to develop fossil fuel, nuclear and renewable energy power plant. These priorities can be grouped into eight areas for action that will benefit all three types of plant, namely:

- Basic Research
- Device Research
- Virtual Demonstration
- Physical Demonstration
- Condition Monitoring and Reliability Engineering
- Systems Analysis
- Social Research

- International Collaboration

However, R&D needs to considered within an overall system for development, demonstration and commercialisation of near to zero emissions technologies. In this system the key elements are R&D, policies and measures to support a market for the technologies and action to win social acceptance. The development system is not linear; all three elements need to be addressed together with feedback and interaction between them. In addition to R&D key actions could include:

- Inclusion of new build ZEPG fossil fuel and nuclear power plant in existing and proposed policy measures designed to deliver reductions in CO_2 emissions (e.g. Climate Change Levy and Carbon Trading).
- Additional market based measures to encourage the commercial deployment of ZEPG plant that advance in step with the technical development of the technologies.
- Planning and regulatory frameworks that recognise the specific characteristics of ZEPG plant and do not impose unnecessary delays and costs on their deployment.
- Action to raise the debate on climate change and sustainable energy sources so that the public is aware of the choices to be made regarding future energy supply and demand.

Because of present uncertainties regarding the future market for ZEPG plant, public funding will be needed to support the development of these technologies over the next few years. Current levels of public funding are insufficient and are small compared to the UK's main competitors.

In addition to supporting work on the above themes it is important to organise and co-ordinate the UK's national research effort to gain maximum benefit from the resources available. In order to achieve this the following actions are recommended:

Establish a Government Chief Scientist for the Energy Sector
The UK lacks an authoritative centre for examining the technical options available for tackling policy issues relating to energy supply and demand. Because of this there is no recognised authority to lead on the objective assessment of alternative options, the level of investment needed to bring them to the market and the role of the UK in such developments. This requirement would be most effectively covered by a Chief Scientist for Energy, who could advise government on energy technology policy and act as the main link between government and industry.

Sustainable Energy Centre

Support for UK energy research is fragmented between the research councils, DTI, the Carbon Trust and industry. There is a need for a single unit to steer and co-ordinate these activities and to advise all actors of R&D opportunities and priorities. Specific tasks for this centre could be:

- Assessment of technology prospects
- Providing a panorama on international developments
- Advising on priorities and opportunities
- Acting as a broker for setting up collaborative programmes between industry, government and the research community

International Collaboration

International collaboration on pre-competitive R&D and demonstration activities should be encouraged and supported. Government could help facilitate this by supporting such initiatives within the EU, through organisations such as the International Energy Agency and with bi-lateral agreements with other national programmes.