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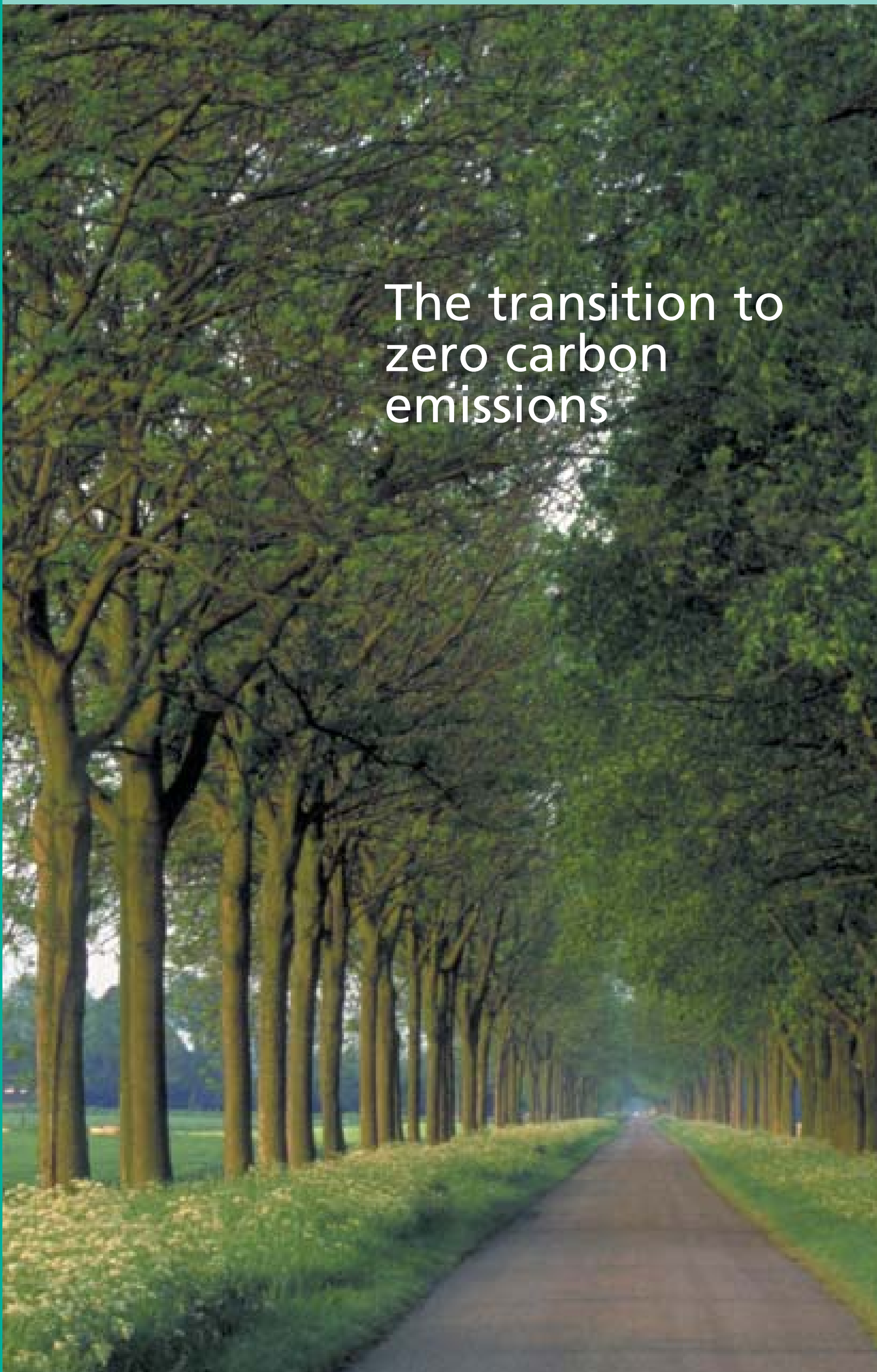

The transition to zero carbon emissions

A technology strategy for power generation from fossil fuels, biomass and waste

Advanced Power Generation Task Force

An Associate Programme of UK Foresight

The transition to zero carbon emissions

A Technology Strategy for Power Generation from Fossil Fuels, Biomass and Waste

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An Associate Programme of UK Energy and Natural Environment Foresight

July 2001

Michael Meacher Minister for the Environment taking an interest in Clean Coal Technology, Wakefield UK March 01

Front row: Nigel Yaxley, UK Coal; Mick Clapham, MP; Rt Hon Michael Meacher, MP, Minister for the Environment. Middle row: David Bowe, MEP; Alec Galoway, UK Coal. Back row: Gary Foreman, NACODS; Pat Carragher, BACM.

Courtesy of UK Coal plc

Members of Advanced Power Generation Task Force

Mr Nick Otter
ALSTOM Power - Chairman

Dr Edward Clarke/Dr Larry Atwood
EPSRC

Dr John Cockaday/Dr Jeremy Rogers
Foresight Directorate
Office of Science and Technology

Mr Mike Evans/Mr Martin O'Connor
Innogy

Dr J Mike Farley/Mr Graham Welford
Mitsui Babcock Energy Ltd

Mr Ian Freeman/Dr Debbie Brown
Advantica Technologies Ltd

Mr R Paul Greaves/Mr Darren Watson
Rolls-Royce plc

Dr Alan Heyes/Dr David Crockford
Department of Trade and Industry
Sustainable Energy Policy Unit, Energy Group

Dr Allan Jones/Mr Richard Tabberer
Powergen plc

Mr John E Oakey
Cranfield University

Mr Brian E Ricketts
Technical Manager - COALPRO

Mr Paul Setchfield
M E Engineering Ltd

Dr Martin Mordecai
Secretary to APGTF

Dr Tony Oliver
K-S Tech - Rapporteur to APGTF

The views expressed in this document do not necessarily reflect those of the organisations represented and have been developed with substantial consultation throughout the whole Energy/Power Generation sector within the UK.

Introduction

The UK Foresight Energy and Natural Environment (ENE) Panel has identified 'Low and Close-to-zero Emission Power Generation' as a priority area for future Research and Development within the UK.(1) Developments in this area would meet the four objectives that the ENE Panel has adopted for sustainable development:

- Effective protection of the environment
- Prudent use of natural resources
- Maintenance of high and stable levels of economic growth and employment
- Social progress which recognises the needs of everyone.

The Advanced Power Generation Task Force (APGTF), which is an Associate Programme of the Foresight ENE Panel, has taken this priority area and produced a R&D strategy (looking out to 2030) for power generation from fossil fuels, biomass and waste. It should be noted that throughout this document, the term R&D refers to the whole range of Research, Technology Development and Demonstration.

In developing this strategy, the APGTF has consulted extensively with UK industry, academia and Government. The strategy aims to:

- Provide UK industry with global market opportunities out to 2030
- Contribute significantly to UK wealth creation
- Ensure that the UK contributes to improved quality of life through reduced environmental impact, both nationally and globally.

Fig 1

A Modern Cogeneration Power Plant

Courtesy of Rolls Royce

Future energy scene

The International Energy Agency (IEA), in its World Energy Outlook 2000[2], predicts that global electricity generation will need to grow by 2.7% per annum from 1997 to 2020 to meet the rapidly growing electricity demand. This projection means that nearly 3000 GW of new generating capacity will need to be installed, worldwide, over this period. About one fifth of this capacity will replace existing installations; the rest is to meet new demand. Figure 2 shows the world installed capacity of power plant by age and illustrates the need for replacement over the next two decades and more.

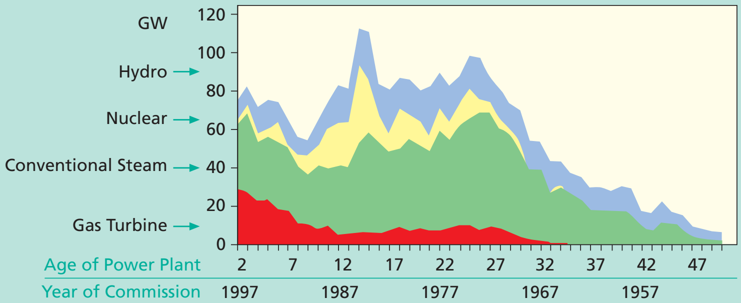
More than half of the projected new capacity to 2020 will be installed in developing countries, with Asia seeing the most rapid growth. In the EU average growth out to 2020 is predicted at 2% per annum[3] while in the UK[3], growth in electricity demand is predicted to average at 2.6% out to 2010 and then drop to 1.5% to 2020. Alternative figures for the UK in the DTI Energy Paper 68[4] gives a lower growth figure of about 1% to 2010, then less than 0.5% to 2020. Figure 3 illustrates the contribution of different fuels[2].

Coal is likely to maintain its position as the world's largest single source of electricity production over this period, although its importance will decline in OECD countries (in the UK [4], coal fired electricity production is predicted to be less than 50% of current levels). However, electricity production from coal could triple in developing countries by 2020[2].

Fig 2

World Installed Capacity of Power Plants by Age

Courtesy of ALSTOM Power



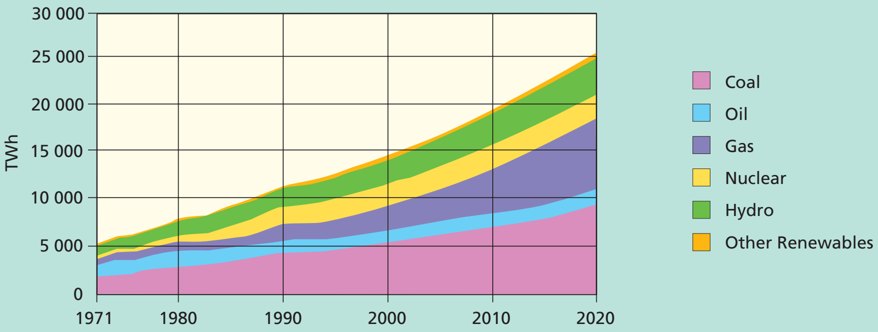
World natural gas fired power generation is projected to increase by three-and-a half times and it is expected to be the world's second largest source of power generation.

Oil accounts for about 9% of electricity generation globally, and its use in power generation has fallen steadily since the first oil shock. Its share is projected to continue falling to about 6% by 2020.

Non-hydro renewable energy accounts for a small but growing percentage of global electricity. In 1997, it was about 1.5% and it is projected to rise to about 2.3% by 2020. However, in OECD countries the growth in non-hydro renewables is expected to be more rapid, reaching 4% in 2020. Wind, biomass and waste are projected to dominate the non-hydro renewables with combustible biomass and waste being the largest contributor.

Fig 3

World Electricity Generation 1971-2020[2]



Carbon Dioxide emissions

According to the Intergovernmental Panel on Climate Change[5], "emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate". The major contributor is carbon dioxide (CO_2), which arises mainly from the use of fossil fuels. Current projections[2] give an average increase in global CO_2 emissions of 2.1% per annum and currently electricity generation produces approximately 35% of the total CO_2 emissions resulting from human activities. CO_2 emissions from the transport sector will grow by 3.3% per annum to 2020, when it will contribute up to 25% of global emissions.

In power generation from fossil fuels, two approaches are currently being used to reduce CO_2 emissions

- Switching to lower carbon content fuels
- Increasing efficiency of conversion from fuel to energy

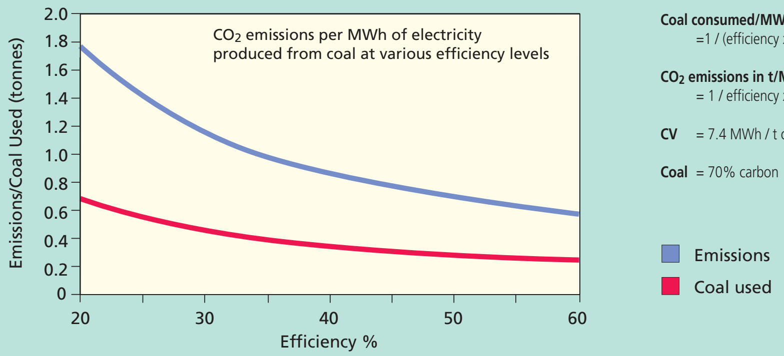
The push for increasing efficiency is also raising the profile of Combined Heat and Power (CHP) both at small scale and large scale. Additional opportunities also arise where heat can be used in absorption chilling to deliver cooling in industry, commerce and the public sector.

Technologies for cost effective sequestration are now being actively considered. These include pre and post combustion technologies.

Of the major fossil fuels (coal, oil and natural gas), natural gas has the lower carbon content. Comparison of fuels gives the following typical values for CO_2 emissions per unit of energy produced[6] - Coal 88, Oil 70 and Natural Gas 51 gm per M Joule - indicate that fuel switching alone could contribute significantly to the reduction of CO_2.

Fig 4

Emissions vs Efficiency for Coal [7]



Coal consumed/MWh
=1 / (efficiency x CV)

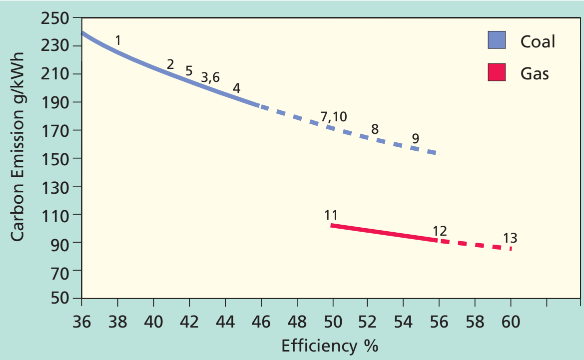
CO_2 emissions in t/MWh
= 1 / efficiency x 44 / 12 x %C in fuel x 1 / CV

CV = 7.4 MWh / t of coal

Coal = 70% carbon

Fig 5

Efficiency Improvements and Impact on CO_2 Emissions[8]



Plant Type	Efficiency with cooling tower (%)	Source
1 Subcritical pf with FGD	38	typical
2 Subcritical pf with FGD	41	best available
3 Supercritical pf with FGD	43	typical
4 Supercritical pf with FGD	45	best available
5 PFBC	42	demonstration
6 IGCC	43	demonstration
7 PFBC (2010)	50	*
8 IGCC (2010)	53	*
9 Supercritical pf (2010)	55	*
10 ABGC (2010)	50	**
11 CCGT (early)	50	typical
12 CCGT (current)	56	typical
13 CCGT (2005)	60	***

* Energy World, March 1997
** Private communication
*** Power Generation, 10 October 1997

Also considerable efforts are being made by power plant developers and operators to improve the efficiency of the power generating process in order to reduce CO_2. Figure 4[7] shows how emissions from coal use are reduced by increasing efficiency.

Figure 5[8] shows efficiency improvements achieved to date for some power generation technologies, together with predictions for the medium term and the resultant reductions in CO_2 emissions.

Electricity production from biomass and waste uses the same technology as fossil fuel power generation. This is leading to cofiring of biomass or waste with fossil fuels as an alternative means of reducing CO_2 emissions whilst utilising fossil fuels. The same technologies are also being used for combustion or gasification of 100% biomass or waste. Plant sizes are dictated by the local availability and commercial price of the fuel, together with the economics of the overall system.

Clearly, power generation and the production of electricity is critical in meeting the needs of current and future generations. Future developments of technology will be essential to support the growing energy demand but must be done with acceptable impact on the environment as a whole.

Fig 6

ARBRE Biomass IGCC Plant Yorkshire UK

Courtesy of First Renewables

The future market

The Global Market
Over the next 25 years, the global business for new generating plant is expected to be in excess of £2000 billion.

For the next 15 years, the large central power station is still seen as being dominant for new build with coal and gas remaining as the two major fuel sources. Over this period, the dominant technology for coal is likely to remain as Pulverised Fuel (pf). The projected worth of the global market for clean coal plant for the period 1997-2020 (23 years) has been estimated by the International Energy Agency to be £460 billion(2). For gas, Gas Turbines (GTs) are expected to continue to be the technology of choice with large GTs remaining dominant; however there will be a growing market for micro, small and mid-size GTs. The predicted worth of the GT new plant market over this period is around £160-200 billion(2,10).

The key drivers that will determine which particular power plant technologies will enter into the market place in the future have been identified by the APGTF as:

- Cost (eg capital, through-life, fuel, infrastructure)
- Regulation (eg environmental, government policy, public opinion)
- Resources (eg fuel, fuel flexibility, security of supply)
- Business/Market Dynamics (eg plant ownership, electricity/emissions trading)

Over the next 20 years some of these drivers are expected to lead to the gradual growth of Distributed Generation (DG), where electricity and possibly heat is produced close to the load centre. This would lead to some displacement of the conventional large power plant. Predictions for global electricity production from DG range from 10-20% over the next 20 years; in the EU(3) predictions are for up to 20% by 2020.

Longer term, these drivers are likely to produce substantial changes in power plant technology mix, particularly if there is continued commitment to reduce greenhouse gases. Post 2020, renewables could start to make a major impact. In the EU, partly because of the decommissioning of existing nuclear plant, predictions(3) show that other technologies may also start to contribute. These could include: clean fossil technologies; hydrogen based technologies; renewables; fuel cells; new nuclear; and wider use of combined heat and power (CHP).

For fossil-fuel technologies, CO_2 capture is a future possibility. The UK's Royal Commission on Environmental Pollution[11] in looking to the future, comments that if CO_2 removal can be done safely and cost-effectively then a substantial proportion of electricity requirement for the UK could continue to be produced by fossil fuels whilst still meeting reductions in CO_2 release to the atmosphere. If achieved, this statement would be applicable to many other countries in the world.

The UK's Position in the Market

The UK's share of the global market for new power plant has recently been in the region of 11-12.5%[12]. In 1995, the UK power engineering industry had a turnover of £13.6 billion and employed 150000 staff[10]. The industry is therefore an important one for the UK in terms of employment and contribution to GDP.

Considering the current major power plant technologies, the UK has strengths in the specific areas of clean coal technology, small and medium sized GTs, specialist components for large GTs (>150MW). It also has a high level of expertise in the supply of turnkey plant, research and development, design and operation, including consultancy expertise in all these fields. In an earlier Foresight Task Force[9] an estimate was made for the UK share of the future clean coal plant market, including the provision of spares and repairs. Based on an assumed 10% share of the market, the value over the next 15 years is predicted to be £35.3 billion. A similar estimate has been made for the GT power plant market and the corresponding GT sales are estimated at £15.7 billion[13].

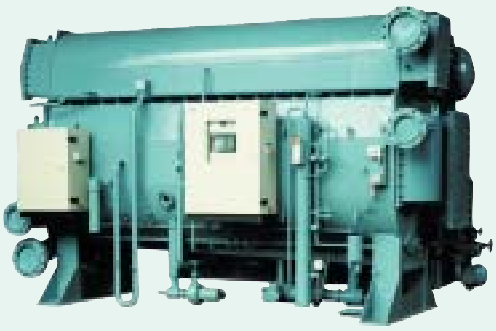


Fig 7

Absorption Chiller for Cogeneration Plant

Courtesy of M E Engineering

Fig 8

Biogas Gas Turbine at ARBRE Plant

Courtesy of ALSTOM Power

The Nature of the Competition

Governments in other countries are making significant investments in power plant technology development for the longer term, typically 2015 and beyond, to ensure that their industries remain competitive. In particular the USA has its new 'Vision 21' programme and Japan has its 'New Sunshine' programme (Table 1). This factor, combined with the preference of the US, Japan and certain European countries for installing indigenous plant and plus the existence of a more open UK power plant market, will result in UK industry being at a significant relative disadvantage. To counteract this, the UK needs to have, or be part of, a similar strategic research, development and demonstration (R,D&D) programme to maintain its position in the future UK and global markets.

Table 1

Strategic Development Programmes in the USA and Japan

Programme	Aims		Costs
US Department of Energy Fossil Power R&D (includes Vision 21 programme)	Efficiencies (in electricity)	>60% on coal >75% on gas	**£220m** (2001 budget)
	Overall thermal efficiency	85%-90%	
	Near zero pollutant emissions		
	Cost effective management of carbon emissions		
	Lower cost of electricity than today		
Japan New Sunshine Programme	Clean coal technology		**£360m** (1999 budget)
	Gas turbine efficiency	> 70%	
	Commercial, cost effective hydrogen technology		

Benefits of a thriving UK power plant industry
Maintaining a thriving UK power generation/equipment supply industry embracing fossil fuel technologies will have major benefits:

- High technology, high value products will be available for large power plant, distributed generation and cogeneration/chp applications
- Improved technology performance will reduce harmful emissions while increasing electricity output. This will have UK and global environmental benefits
- The academic base that underpins the technology will benefit the national economy through technology development and the supply of appropriately trained/skilled people
- The sector will support around 150000 jobs with a large supply chain of small and medium sized enterprises (SMEs)

Technology aim points

In order to be competitive with the US and Japan out to 2030, a UK based R&D programme must have a set of comparable targets. Taking account of the key drivers detailed above, particularly the need for commercially cost effective, low emission plant, the APGTF has proposed the following aim points for commercially available plant by 2030:

• Electrical Efficiency	> 60% on coal
	> 70-75% on gas
• Thermal efficiency	> 85-90%
• Near zero pollutant emissions	

plus:

- Cost-effective management of CO_2 emissions
- Cost-effective hydrogen technologies

Other plant performance parameters such as Reliability, Availability and Maintainability will also need to be better than present values.

Future plant technologies

There are several power plant technologies for fossil fuels, biomass and wastes that are in various stages of research or development that may have the potential to meet the aim points in a cost-effective way within the specified time frame. Table 2 lists those which the APGTF has identified as relevant and describes their current status.
The APGTF has assessed each of these plant technologies and looked at their future potential, particularly with regard to their ability to achieve the Technology Aim Points and the risks involved. In this assessment, future energy and power generation scenarios have been considered and weighting has been given to those plant technologies where the UK has a technology strength compared to other competing countries. In carrying out this assessment, the APGTF has consulted extensively with UK industry, academia and Government.

The results of the assessment suggest that the following will be the key, longer-term power plant technologies for UK R&D to focus on:

- **Gas Turbines** - from micro to mainframe, for distributed generation (DG) and main plant; complex cycles (eg wet cycles/intercooled recuperated cycles) are also expected to become important
- **Fuel Cells** - a strong contender for DG; could also become integrated with other technologies such as gas turbines and gasification
- **Gasification** - a key plant technology for fuels such as coal, wastes and biomass; currently integrated with GTs, could also be integrated with fuel cells or ‘Novel Cycles’
- **Novel Cycles** - the UK has a strong position in the development of novel cycles based on existing technology; support for this should be continued

Table 2

Current Status of Plant Types

Technology	Status	Capital £/kW$_e$ Costs ($/kW$_e$)	Performance	Issues
Pulverised Coal	Commercial, strong position, supercritical	600-670 (900-1000)	up to ~45% eff. Needs fgd	Leading, proven technology
IGCC	High efficiency plant at commercial demo stage	730-800 (1100-1200)	Depends a lot on GT. Up to ~45%	Perceived as clean. Complex
Fluid Bed Combustion	Commercial, niche market for poor fuels	690-800 (1000-1200)	up to 40% eff.	Competitive for low grade fuels
Pressurised Fluid Bed Combustion	Commercial demo stage. Niche market	N/a	up to 45% eff	Targeting low grade fuels
Air Blown Gasification+FB	Designs for commercial demo	N/a	up to 45% eff	Niche market with certain coal types
Pressurised Combustion	Pilot demo	N/a	up to 50%	Can be direct to GT or to heat exchanger
Fuel Cells	Some are commercial. Small types at commercial demo	>1700 (>2500)	40 - 60% eff, depending on type	Still developing, costs falling. Could be significant for DG
GTs	Commercial, strong position	330-470 (500-700) for >1MW$_e$	Small ~ 33% Mid ~ 42% CCGT ~ 60%	Mid-size and micros currently niche
ICEs	Commercial, strong position for DG	270-400 (400-600)	up to 50% for large ICEs	Leading, proven technology for up to ~20MW
Hydrogen Fuelled	Pilot scale demos	N/a	Unknown (zero CO_2 from plant)	Could need new infrastructure
Novel Cycles	Demo	N/a	Targeting 50-70%	Several cycles eg Kalina, CO_2 recycling, recuperation

N/a - denotes no commercial plant
FB - Fluid Beds
ICEs - Internal Combustion Engines
IGCC - Integrated Gasification Combined Cycle.

Internal Combustion Engines did well in the assessment, particularly where costs are concerned and they are expected to remain competitive for the medium term. **Pulverised Coal** is likely to remain the dominant technology for large coal plant in the medium term, with the main drive being towards higher supercritical conditions.

Hydrogen Fuelled power generation could be turned into a priority by political or social pressures. Although there are R&D issues for power technology, the main issues are: hydrogen production; hydrogen storage; transmission infrastructure.

Fig 9

Industrial Trent Gas Turbine

Courtesy of Rolls Royce

Fig 10

Meri-Pori Advanced Supercritical Coal Plant, Finland

Courtesy of Mitsui Babcock Energy Ltd

Fig 11

500MW Gas Turbine Combined Cycle Deeside UK

Courtesy of ALSTOM Power

The transition to zero carbon emissions

The chosen aim points have significantly higher efficiency targets than can be achieved by current plant. The chosen, key long term power plant technologies all have the potential to achieve the aim points and this will result in significant reductions in CO_2 emissions from future fossil fuelled power plant. For example, from Table 2, the highest efficiency for current commercially available coal plant has an efficiency of up to ~45%. From Figure 3, it can be seen that if future coal plant can achieve the aim point of 60% efficiency, it will result in reductions in CO_2 emissions of 20-25%; similar sized reductions will be achieved with gas compared to today's most efficient gas-fuelled plant.

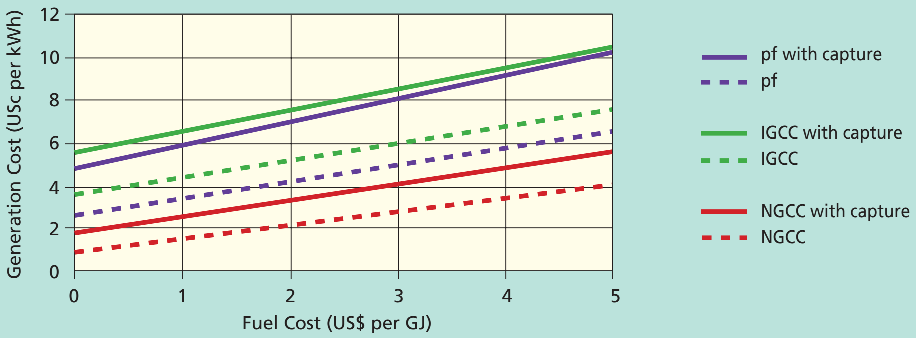
Power production from biomass fuels approaches CO_2 neutrality, however large amounts of biomass are needed to meet power generation needs. Using current plant technology and current biomass stock, to produce 10MW requires approximately 4000ha of biomass planting, corresponding to an efficiency of 35%. Achieving the aim point of 60% efficiency for solid fuels would result in a reduction of this acreage by approximately 40%; or from the same acreage, it would produce approximately 70% more CO_2 neutral power.

The future technologies for distributed generation from fossil fuels, biomass or waste are also expected to come from the chosen key technologies. They can be used in CHP mode, or to provide cooling, where the aim point for thermal efficiency will ensure low CO_2 emissions. The combination of a high electrical efficiency will ensure that if such plant has to operate in electric power production only mode, as is necessary at times in most CHP applications, CO_2 emissions will still be reduced. The final option for fossil fuels is to capture CO_2 from combustion of fossil fuels and store it in reservoirs. According to a recent US Department of Energy report(14), 'Scientific experts are optimistic that (large scale) CO_2 capture and sequestration could be implemented on a scale that would mitigate climate change – and if successfully developed could allow the continued use of fossil fuels in the presence of carbon emission constraints'. CO_2 capture and storage can be done using technologies that have been developed and proved in other applications; details of these technologies, storage and utilisation options are given in(15).

The acceptance of such technologies will certainly depend upon their economics and the fact that CO_2 has a value, be it associated with a tax or from commercial application. There will therefore be a continuing drive to identify the most effective ways of capture and sequestration as there will always be some sort of efficiency or financial penalty from their inclusion in the cycle. To give an idea, estimated costs of electricity generation with and without CO_2 capture, including the costs of compression of CO_2 ready for transport and storage, for a range of fuel prices are shown in Figure 12(15).

Fig 12

Costs of Electricity Generation with and without CO_2 Capture(15)



CO_2 capture in large GTs increases the cost of electricity generation by about 1cent/kWhr (about 0.7p/kWhr). For large coal plant the generation costs are increased by approximately 2.5cent/kWhr (about 1.7p/kWhr). The additional costs for transport and storage should be low compared to the costs of capture (and compression). Other costs that go to make up the price of electricity for the consumer, such as transmission, should remain unchanged. These costs compare very favourably with the costs of other options for avoiding CO_2 emissions in power generation, such as renewables or nuclear.

However, there are some outstanding issues with CO_2 capture and storage. The technologies must be demonstrated at a larger scale as required by a fossil-fuelled power plant; the environmental impacts and degree of reliability of storage need to be addressed. Research to reduce the costs and to improve the removal efficiencies will be essential.

Themes for research, development and demonstration

The Foresight ENE Panel[1] is highlighting the need for a long term, step change in the way in which energy is created and used, with a medium term transitional phase that leads into the step change. This is consistent with the step change in technology mix that is referred to above for power generation which is expected post 2020. The ENE Panel is calling for R&D to be undertaken now to ensure that these technologies are available in time; this is particularly true for power generation given the typical long 'lead times' of such technologies.

An indication of how the key longer term, power plant technologies fit in with these timescales can be shown by a matrix of technology options, Table 3:

Table 3

Matrix of Options

Short term	Medium term	Long term
Pulverised coal	Pulverised coal (USC)	Gasification
FBC/PFBC	FBC/PFBC	Fuel cells
GTs	GTs	GTs/GT hybrids
ICEs	ICEs Gasification (niche) Fuel cells (niche) GT hybrids (niche)	CO_2 capture & storage Hydrogen fuelled

USC - ultra supercritical
Niche - limited market penetration

A R&D programme for the long-term power plant technologies needs to be formulated now. In addition a programme is needed for the supporting technologies and underpinning sciences that will be required to deliver the power plant technologies.

Supporting Technologies
The power plants of the future are likely to be more complex than those of today and consequently with more integration of different supporting technologies. This means that any R&D programme needs to not only consider the individual technologies, but also their integration.

The APGTF has assessed the key, longer term power plant technologies and identified the following supporting technology areas that need further R,D&D:

- Combustion technology - for gas turbines
- Fuel flexible gasification - for the process of gasification with either coal, biomass or waste fuels; optimisation of integration
- Cofuelling with biomass - technologies for dealing with biomass together with fossil fuels
- Hot gas cleanup - pollutant removal from higher temperature gas streams
- High temperature heat exchangers - heat exchangers for plant operating at higher temperatures

- Hybrid or novel cycles - development of existing technologies that will make up the cycle, systems integration, novel heating (or cooling) cycles for CHP (or chilling)
- Reformers and fuelling - for fuel cells
- Electrochemical processes - for fuel cells
- Membranes - for fuel cells
- Component integrity - for components operating at more extreme conditions
- Control systems - for increased performance, reduced emissions, increased safety etc
- Power electronics - for integration and control of distributed generation
- Plant manufacture - for advanced manufacturing methods giving high quality components at lower cost
- Carbon management - for reducing CO_2 emissions from power plant, such as CO_2 capture from flue gases

Fig 13

Combustion System Development

Courtesy of ALSTOM Power

The power plant technologies and the supporting technologies need to be evaluated, tested and demonstrated at component and full scale to ensure that the new technologies are successful in getting into the market place. For large complex power plant, this is expensive and time consuming. An alternative for the future is to develop sufficiently accurate plant computer models, 'Virtual Plant Demonstration Models', so that the need for full scale testing and demonstration is reduced and so that more accurate evaluation of the plant is possible. Thus the final supporting technology area is:

- Virtual Plant Demonstration Models

Underpinning Sciences

In order to develop the supporting technologies and to deliver the future power plant to market, R&D is required in certain underpinning sciences.

The APGTF has considered the science developments required by the key, longer-term power plant technologies. In doing so it has consulted with UK academia and industry and it has identified the relevant sciences that will need supporting in the future; these are listed in Table 4.

Table 4

Underpinning Sciences

Technology	Com	Mat	ECh	Cat	Mem	C&I	FSc	Man	Mod	CLI	Ele	Car	Aer
Gasification	–	●	–	●	–	●	●	●	●	●	–	–	–
Fuel Cells	–	●	●	●	●	●	–	●	–	●	●	●	–
GTs	●	●	–	●	–	●	–	●	●	●	●	–	●
Novel Cycles	●	●	●	●	●	●	●	●	–	●	–	–	–
Carbon Management	–	–	–	●	●	–	●	–	–	–	–	–	–
Plant Modelling	●	●	●	–	–	–	●	–	●	●	–	–	–

The main topics for the underpinning sciences listed in Table 4 are defined as : -

Combustion (Com)	modelling, flame stability, pollutant production, cofiring with biomass, diagnostic techniques
Materials (Mat)	high temperature materials, crack growth, corrosion, fatigue, materials processing
Electrochemistry (ECh)	fuel cells
Catalysts (Cat)	fuel cells, combustion, pollutant removal, gas separation, fuel processing
Membranes (Mem)	fuel cells, gas separation
Control and instrumentation (C&I)	intelligent, 'wireless' for harsh conditions
Fuel science (FSc)	hydrogen production from fossil fuels, decarbonisation of fossil fuels, gasification
Manufacturing methods (Man)	advanced materials, thin films, membranes, low cost processes
Mathematical modelling (Mod)	fluid flow, heat transfer, interactions with chemistry
Component life integrity (CLI)	lifing studies, creep, fatigue
Electronics (Ele)	electrical systems integration
Carbon clean-up (Car)	preparation, including reforming, of fuels for fuel cells
Aero-dynamics (Aer)	turbines, compressors

The way forward

The R & D Programme
In order to move the strategic programme forward, initiatives are required from the policy makers as well as from the R and D community.

Governments have objectives, both national and international, which will not be achieved by market forces alone (the Global Climate Change issues associated with the Kyoto Protocol being one example). To meet these objectives the UK Government must provide leadership to integrate 'UK plc' resources. The following initiatives are suggested for the policymakers :-

1) Set long-term policies consistent with export opportunities and emerging legislation
2) Organise funding for pre-competitive R and D in a programme which is market oriented, coordinated and followed through to demonstration and deployment of new power generation products and services
3) Establish mechanisms to drive forward the implementation of new power generation technologies that meet the long-term objectives of the government.

The role of industry is seen as :-

1) Invest in R and D
2) Industry, government and academia should work together to develop and implement their strategy

Fig 14

Cogeneration Plant, Grimsby UK

Courtesy of ALSTOM Power

Foresight has identified the need for a strategic initiative on 'Low to Near Zero Emission Power Plant'. Three approaches are identified for achieving this:-

- Switching to lower carbon content fuels (which should include biomass)
- Increasing efficiency of conversion from fuel to energy
- Carbon dioxide capture and storage

Each of these approaches should be pursued in conjunction with the prioritised power plant technologies. To do this, consideration should be given to a few 'managed programmes' focusing on the key technologies and key sciences for the medium to longer term with the 'Aim Points' being regarded as targets for these programmes.

The Advanced Power Generation Task Force has considered these points and discussed them extensively with representatives from government, industry and academia. The Task Force has concluded that the following areas are key components of a strategic initiative on 'Low to Near-Zero Emission Power Plant'

1) Gas Turbine systems up to ~100MW size including distributed generation application
2) Cleaner coal systems to focus on the drive to lower emissions and higher efficiency power generation particularly for pulverised coal
3) Gasification systems to include fossil fuels, waste and biomass
4) Fuel cell systems, including hybrids and advanced cycles
5) Zero or Near Zero Emission Power Plant including sequestration
6) Virtual Plant Demonstration leading to component and plant/system demonstration
7) Science base programme focusing on key science areas; co-funding of an institute or an integrated network should be considered

Fig 15

Control Systems for Advanced Power Generation Plant, Shajiao, China

Courtesy of ALSTOM

The Advanced Power Generation Task Force recommends that strategic, managed programmes be developed which encompass all of these different areas. These Research and Development programmes should go through to and include Demonstration where appropriate.

Estimate of Funding Requirement
In order to obtain an accurate estimate of the costs of the recommended managed programmes, it is necessary to look in detail at the developments that are required in each underpinning science and technology and also to identify what large scale demonstration activities are required to prove the technology. This is a crucial next step in developing the strategic programmes.

However, it is possible to get an estimate of the programme costs by considering the accurate costings that have been carried out for current UK power generation R&D programmes. Costings for short to medium term R&D programmes have been determined for GTs[13] and for Cleaner Coal[9]. The costings vary between £50m-200m with the higher costs coinciding with the need for more large-scale demonstration. Based on these figures it is anticipated that the total cost of the R&D programme for all the proposed strategic, managed programmes will be approximately £1000m in the early part of the 21st Century.

It is clear that in order to meet the predicted requirements of the global market, these programmes would have to be completed in the next 10 or so years.

Cost Benefit Analysis
A cost benefit analysis for the proposed, strategic R&D programme is summarised in Table 5

Table 5

Cost Benefit Analysis

Cost Benefit Analysis	
Total global market for new plant over next 25 years	£2000 billion
UK market share based on current performance	11 - 12.5%
Income to UK over next 25 years	£220 - 250 billion
Average income to UK per annum	£8.8 - 10 billion/year
Strategic R&D programme	£100 million/year (average)
Strategic R&D investment rate	1.0% (approximately)

The current value of UK market share has been used to evaluate the income to the UK as the aim of the strategic programme is to maintain, or grow, this market share in the global market.

The cost benefit is expressed as an investment rate that is obtained by dividing the R&D investment by the average income to the UK. The benefit is in terms of the retention or growth of the UK's market share.

It is estimated that current levels of R and D annual funding in the UK for this sector are below this required figure, probably at approximately £75m per year. This is a difficult figure to identify as there is no explicit category for power generation in many of the public funded programmes and many of them are not directed at enhancing fossil and associated fuel technologies per se. In addition industry is often sensitive about releasing figures for specific technology areas. However it is estimated that the industrial figure is in excess of 50% of the total for fossil oriented R&D.

Possible Funding Sources

The 1% figure for investment rate needs to be considered within the perspective of current net incomes. Business in the power plant sector is very competitive and company net income rarely exceeds 3%. Furthermore, only a fraction of this is from new plant sales, the remainder arising out of service and maintenance activities.

It is also important to note that the changes in the Energy Market through greater deregulation, privatisation and liberalisation have increasingly placed the onus for setting the future technical agenda on the suppliers of the products and services - hence the need to invest more. This comes just at a time when there are greater pressures on commercial margins arising from the severe competition in the market, especially from overseas organisations that benefit from a more favourable level of support.

This means that contributions to R&D from public funds are especially important, particularly when consideration is given to the level of government support enjoyed by UK principal competitors in other countries.

Funding sources for the strategic R&D programme have been identified as coming from four main areas:-

- UK industry (50%)
- UK Government, for example through DTI and associated programmes (20%)
- EPSRC (10%)
- European Commissions programmes (20%)

In deriving these percentages, the generally accepted principle of public support for most UK and European R&D programmes not exceeding 50% of their total cost, has been assumed.

It needs to be noted that in the UK there are a number of new or recently established initiatives targeting sustainable energy technologies and their promotion. These include the Carbon Trust and the expanded Renewable Energy Programme. The APGTF are firmly of the opinion that there needs to be true balance to the development of power generation technologies and that these should include the cleaner use of fossil and associated fuels. It is clear that, although the use of new and renewable technologies will grow, there will remain a major reliance on coal and gas as fuels to generate electricity for many decades to come. It will therefore be essential to continue to develop technologies for their clean, reliable and cost effective use.

Recommendations

The following recommendations are addressed to government, industry and academia

- The proposed managed programmes should be adopted as the UK's strategic R&D programme for cleaner power generation from fossil and associated fuels. As such they should be an integral part of the thrust towards the accepted desire for a sustainable energy economy.

- Funding mechanisms should be identified and proposals put together for funding. This includes ensuring that the priorities of existing and new R&D initiatives encompass the technologies identified in this document.

- Plans should be developed for how best to co-ordinate all the R&D managed programmes targeting sustainable power generation to ensure maximum synergy between them. This includes making sure that there is the progression of new technologies through to component and plant demonstration.

- Working groups should be set up for each of the managed programmes to further define the R&D programmes and to take them through to initiation

- Detailed R&D programmes, including costs and timescales, should be defined for the underpinning technologies and sciences in each of the managed programmes

- An understanding should be developed of the industry's education and training needs and consideration of how these can be met

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For further information please contact:

Nick Otter
ALSTOM Power Technology Centre
Cambridge Road
Whetstone
Leicester LE8 6LH

Martin Mordecai
Secretary to APGTF
5 Langdon Road
Cheltenham
Gloucester GL53 7NZ

John Cockaday
Energy & Natural Environment Panel
Office of Science and Technology
1 Victoria Street
London SW1H 0ET
ene@dti.gsi.gov.uk

http://www.foresight.gov.uk
http://www.dti.gov.uk

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