RESPONSE TO THE
HOUSE OF LORDS
SCIENCE AND TECHNOLOGY SELECT COMMITTEE

INQUIRY INTO
THE PRACTICALITIES OF DEVELOPING RENEWABLE ENERGY

Memorandum submitted by
The Royal Academy of Engineering

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Executive Summary

The Royal Academy of Engineering is pleased to submit evidence to the House of Lords Science and Technology Committee's Inquiry into "The Practicalities of Developing Renewable Energy". The Academy welcomed the publication of the White Paper "Our Energy Future – Creating a Low Carbon Economy", but cautioned that the targets for renewables, reduction in emissions and energy efficiency were all economically and technologically demanding. The Academy has previously pointed out the immense engineering challenges of meeting these targets most notably in "An Engineering Review of the Performance and Innovation Unit's Energy Review" prepared for the Minister of State for Energy and Industry.

- Without subsidies, there are currently no cost effective renewable energy technologies. Over the next ten years, some predict that wind energy will become competitive and this will be the mainstay of efforts to help meet the Government's aim that, by 2010, 10% of electricity should come from renewable sources. When realistic discount rates, financial risk, intermittency and displacement costs are taken into consideration, the potential for large-scale development of any renewable technology is severely diminished, but a number of actions might be taken to help their development.

- The Government must look again at the Renewable Obligation Certificates (ROCs) arrangements. Uncertainty in the price of ROCs, as they are traded as a market commodity, means that investors could lose money if their value drops below a threshold. This threshold will differ for each technology and will vary over time, adding to investor uncertainty. Should this happen, investors will become sceptical of entering the market and may consider withdrawing. Bearing in mind that all new wind farms currently under construction in the UK are being built by large companies on their own balance sheets, this could have a significant impact in the City where traders are already sceptical about the power industry after the collapse of Enron.

- The planning process should be speeded up but without damaging the local democratic process. The Academy acknowledges that the Government has tried to speed up planning decisions for renewable energy projects, but much still needs to be done. Even at the earliest stage, there is a financial risk involved in preparing to apply for planning permission and investors need to see a reasonable success rate. It has been noted that the Ministry of Defence is a common objector to wind farm planning permissions, and although the Ministry has agreed to be more constructive in its approach, again, much remains to be done.

- Distribution network operators need better financial incentives to connect generators utilising renewable sources to their systems. At present, there are none. Network operators are generally wary of connecting large volumes of renewable generation to their systems as the added complexity of the large number of small and embedded generators has an impact on reliability, supply quality and fault levels. The forthcoming Distribution Network Operators (DNOs) price review by Ofgem in 2004/5 will be the only opportunity to address this before 2010.

- The high voltage transmission network needs to be extended and updated in areas, as the geographical pattern of generation and usage is likely to change. For example, it is expected that large amounts of wind-generated electricity in the North of Scotland will need to be transmitted to the south. There is already a general flow of power from North, to South in the grid, and this flow will be increased with further development of renewables, particularly in Scotland.

- The random intermittency of electrical power supplied from many renewable sources, most notably wind, requires a high level of conventional back-up generating capacity to ensure security of supply. As the penetration of intermittent generators increases and becomes a significant proportion of the total, the extra system requirements and costs could pose serious problems. Although the causes of recent well-publicised blackouts have been due to other reasons, intermittency will exacerbate the potential for cascade failure.

- The Academy recommends that, given the critical importance of a reliable electricity supply to our national economic and social well-being, and the large number of people and organisations engaged in the debate over renewable energy, including the general public, the Government should produce an Annual Report on progress towards the 10% target for renewable electricity by 2010 along with reasons for exceeding or falling short of intermediate targets. The same report should also make clear additional costs and benefits that arise from renewable energy, including the costs of standby generation and improvements to the electrical power supply infrastructure.

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1. Introduction

1.1. There are many different sources and many still unproven technologies considered under the umbrella of Renewable Energy. At present, established technologies exist to enable hydro, wind and waste combustion to make significant contributions to alternative energy supplies in the short to medium term, but for large-scale power generation the picture for other technologies is unclear. No renewable energy technologies are currently commercially viable in the marketplace without financial support.

1.2. The Government must look again at the Renewable Obligation Certificates (ROCs) arrangements. Uncertainty in the price of ROCs, as they are traded as a market commodity, means that investors could lose money if their value drops below a threshold. This threshold will differ for each technology and will vary over time, adding to investor uncertainty. Should this happen, investors will become sceptical of entering the market and may consider withdrawing. Bearing in mind that all new wind farms currently under construction in the UK are being built by large companies on their own balance sheets, this could have a significant impact in the City where traders are already sceptical about the power industry after the collapse of Enron.

1.3. Specific risks associated with ROCs include:

- The importation of bulk biomass as a co-firing fuel, which lowers the value of ROCs.
- Uncertainty concerning the implementation of emissions trading from 2005. If emissions trading becomes a more commercially advantageous method of meeting obligations, less money will be available to subsidise renewables.
- The lack of firm renewable targets beyond 2010 does not give a long enough timeframe for many renewable projects. Many investors will be looking for repayment periods of 20 years or more on projects. Targets for renewable should therefore be set beyond 2010.

- The ROC system can be prone to certain distortions. For example, the fines incurred by TXU for missing renewable targets should have been ploughed back into the ROC system, but since the company failed, those fines have not been paid, robbing genuine renewable generators of support.

1.4. Chapter 2 of the White Paper[1] sets a target of saving 3-5mtC by 2020 by increasing renewables. For the purposes of this response it is assumed that the increase in renewables is to be manifested most strongly in the supply of electrical energy rather than in heat. Before considering the different renewable options it is useful, therefore, to look at the overall perspective of electricity supply in the UK and the emissions arising thereby. The contributions of the various energy sources to the generation of electricity in the UK in the year 2002 is shown in Table 1[2] along with the projected mix of plant in 2010 and 2020 as found in the DTI paper EP68[3]. Here it is supposed that the Government target of 10% of electrical energy to be supplied by renewables by 2010 will be met, but no allowance is made for further growth in renewables to 2020. The high-energy price scenario (CH) is shown in Table 1, which favours coal versus gas, i.e. results in the highest carbon dioxide emissions.

	Energy			**Emissions**		
	2002 TWh	**EP68 CH 2010 TWh**	**EP68 CH 2020 TWh**	**2002 mtC**	**EP68 CH 2010 mtC**	**EP68 CH 2020 mtC**
Coal	**119**	**83**	**49**	**27**	**19**	**11**
Oil	**4**	**0**	**0**	**1**	**0**	**0**
Gas	**149**	**173**	**264**	**15**	**18**	**27**
Nuclear	**81**	**66**	**27**			
Renewables	**11**	**41**	**41**			
Other sources	**6**	**8**	**6**			
TOTALS	**370**	**371**	**387**	**43**	**37**	**38**

Table 1 Generation supplied (gross) and emissions by fuel type

1.5. It should be noted that Table 1 does not include "large hydro" i.e. plant above 10MW, under renewables, as this falls outside the definition for renewables for the purposes of the Renewables Obligation.

[1] The Energy White Paper, *Our energy future – creating a low carbon economy* (DTI, 2003) www.dti.gov.uk/energy/whitepaper/index.shtml
[2] "Digest of United Kingdom Energy Statistics 2003", DTI, London, The Stationery Office.
[3] DTI (2000). *"Energy Projections in the UK",* Energy Paper 68, The Stationery Office. http://www.dti.gov.uk/energy/ep68_final.pdf

1.6. Future supplies are characterised by increasing contributions from gas and renewables balancing the decreasing contributions of coal and nuclear. With emissions from nuclear and renewables being counted as zero and coal emissions being more than twice those of gas per TWh generated, the net change in emissions is negative in both 2010 and 2020. This suggests that the 10% target for renewable generation, along with increased use of gas displacing coal, is capable of meeting the White Paper goal of 3-5mtC saving by 2020.

1.7. From a different viewpoint, any further increase in renewables beyond 2010 would be of added benefit, but it is the gas replacing coal that is the main reason for the decline in emissions shown. This option more or less ceases beyond 2020.

1.8. One anomaly not shown in Table 1 concerns the rapid loss of nuclear capacity in the period 2008 to 2014. These plant retirements will mean a substantial loss of emission free output associated with present base load supply. This will have to be replaced. To have developed compensating renewables capacity in time is not an option, so depending on the mix of conventional plant used to fill the gap, this plant would add 2-5 mtC to the emissions by 2012 and 4-8 mtC by 2014. These additions, whatever their magnitude, do not change the net equilibrium state foreseen for 2020 by the DTI EP 68 paper in Table 1, but do have a temporal significance. Any life extension of the present nuclear capacity at current levels would clearly reduce greenhouse gas emissions and reduce a potential over dependence on gas fired capacity, predicted to be almost 70% by 2020.

1.9. The UK has a Kyoto Protocol commitment to reduce greenhouse gas emissions by 12.5% below 1990 levels by 2008-12, i.e. a savings target of 20.6mtC. From 1990 to 2001 overall national carbon dioxide emissions decreased by 10.1 mtC due mainly to the contribution from gas fired electrical power generation of 10.4 mtC. By 2010 the saving from electrical power generation might have reached 17.1 mtC, well on the way to meeting the national target of 20.6mtC. The retirement of nuclear plant in the period before 2012 and the replacement by fossil fuelled plant for baseload supply could seriously jeopardise the achievement of the Kyoto target.

2. Renewable energy technologies

2.1.1. Renewable electricity generation contributes only 2.9% to the national demand at present with biofuel energy sources and existing hydro contributing nearly half each of the present total. The White Paper notes (para 4.9) that, "To hit the 10% target we will need to install approximately 10,000MW of renewables capacity by 2010, an annual build rate of over 1250MW."

2.1.2. With the exception of wind the opportunities renewables offer to make significant additional contributions to electrical energy supply by 2010 seem to be severely limited for practical reasons. In the longer term to 2020, however, with the subsidies and possible rewards available through the Renewable Obligation Certificate scheme considerable progress should occur both with established and newly emerging technologies. These will be considered in turn.

2.2. Biofuels

2.2.1. Biofuels make the largest contribution to renewable energy supplies in the EU, mainly through heat rather than electrical energy. In electrical power generation in the UK the potential contributions of these resources can be gauged from the following evidence supplied by the various Trade Associations to the House of Commons Trade and Industry Committee in January 1998: [4]

2.2.1.1. (British BioGen) Energy crops are seen as a major resource where if 10% of the farmed area in the UK were to be planted with willows for short rotation coppicing (SRC), ultimately 9000 MW could be supported, but by 2010 only between 1000 and 2000 MW could be achieved, i.e. 6.1 - 12.2 TWh of electrical energy produced.[5]

2.2.1.2. Biomass in the form of landfill gas (Landfill Gas Association) and waste combustion (Energy from Waste Association) are limited resources, but might contribute together some 11 – 12 TWh eventually.

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[4] *"Energy Policy",* Trade and Industry Committee, Fifth Report, HC471-II, 2 June, 1998

[5] (*Miscanthus* varieties, *sometimes* known as elephant grass, are probably the most promising energy crop. This is a fast-growing perennial grass that can be grown in poor soil and a wide range of climatic conditions. Its energy ratio turns out to be excellent at 25:1, much better than SRC at 10:1).

2.2.2. With regard to electricity costs, estimates have been made of the future costs of production of electricity from various biomass processes[6]. Electricity from such systems is likely to cost 4 to 5 p/kWh at 20MW plant sizes, after substantial learning effects are taken into consideration and improvements in overall system efficiencies have been achieved. Biomass in the form of landfill gas might contribute up to 850MW at prices less than 4p/kWh, or 6.7 TWh pa, and waste combustion 760 MW, or approximately 4.7 TWh pa.

2.2.3. Although there is the technical potential for significant contributions from energy crops to electricity supplies in the UK the recent history of the prototype ARBRE scheme is not encouraging. This was an 8MW plant (gross output 10MW with 8MW to the grid) using Integrated Gasification-Combined Cycle (IGCC) plant, the favoured technology for biomass. Conventional forestry residues comprised most of the fuel initially with SRC willow to take over the major role (70%) with crop maturity. By May 2000 some 500 hectares had been planted with a further 625 hectares to be established within the year. Many difficulties were noted, e.g. reluctance of farmers to grow willow for various reasons and difficulties to overcome in harvesting where fuel costs are especially significant. At the end of May 2003, Yorkshire Water, the owners and instigators of the ARBRE project sold the company, with some other assets, to a company which had no intention of continuing the project.

2.2.4. The Government is right to encourage the development of this industry, deploying proven advanced gasification and turbine technology fuelled by energy crops or forestry residues which otherwise would go to landfill sites. However, with the average size of power station being small, 40 to 70 MW, the infrastructure problems and costs of building and connecting large numbers of new plants would reduce this option to a fraction of that theoretically possible.

2.2.5. Another significant use of biomass is in co-firing, a technology where a proportion of biomass is used to fire a conventional fossil fuel boiler. The Academy has been made aware of some generators claiming ROCs for the use of bulk-imported biomass (hazel nut husks) from Turkey. While the use of

[6] Toft, A.J. and Bridgwater, A.V., "How fast pyrolysis competes in the electricity generation market", in Biomass Gasification and Pyrolysis - State of the Art and Future Prospects, Kaltschmidt, M and Bridgwater, A.V. (eds), CPL Press, 1997, pp504-515.

biomass is nominally carbon neutral, if long distance transport is taken into account, it is not. Thus, as the number of ROCs in circulation is limited, support could have been denied to another genuine renewable project. The importation of bulk biomass fuel for co-firing also raises questions of security of supply and additionally means that no benefit is derived by the UK farmers.

2.2.6. Biofuels might enter the picture in the longer term, especially in the transport sector through bioethanol and biodiesel fuels, but while biofuels have the advantages of being made domestically and less environmentally damaging, they remain expensive to produce. The European Commission calculates the additional cost of biodiesel over conventional oil-based diesel at about €300 ($270) per 1,000 litres, with an oil price of $25 a barrel. The EU has plans to include 5.75% of biofuel in transport fuels (excluding aviation fuel) by 2010. Although this is a laudable target, some estimates of the amount of land that would be required to grow the energy crops are staggering. If all of the UK's current set aside land was used, it could only supply about 2% of the requirement, and while nominally carbon neutral, if biofuels have to be imported over long distances, the benefit is reduced.

2.3. Marine

2.3.1. The Energy Technology Support Unit (ETSU) estimated that practicably (as at 1999) the marine energy that could be obtained from around the UK was:

- offshore wave - 50 TWh/year;
- near shore wave (closer that 20 miles to the coast) - 2.1 TWh/year; and
- tidal energy (at the 10 most promising sites only) - 36 TWh/year.

2.3.2. After many years where marine renewable energy received little if any support, the possibilities are now being pursued with renewed Government interest. Several wave and tidal stream developments are now in the prototype stages. A list of some of the higher profile projects with a summary of their current and predicted future costs is as follows.

Wave		*Pence/kWh*
	Limpet-Shoreline wave energy device (500kW Oscillating Water Column)	
	Current contract	5.95
	Predicted unit cost	4.50
	Osprey-near shore wave energy device	
	Today's unit cost	5.40
	Predicted future unit cost	4.25
	Hydra-floating near and offshore wave energy device	
	Today's unit cost	4.0
	Predicted unit cost:	
	- 5 years	3.2
	- 10 years	2.7
	Pelamis floating offshore device	
	Today's unit cost	6.5
	Predicted unit cost:	
	- 5 years	4.7
	- 10 years	2.4 - 3.4
Tidal stream		
	Today's unit cost (single prototype systems)	12 to 22
	Predicted unit cost:	
	- 5 years (20 MW projects)	4 – 6
	- 10 years (100 MW projects)	3 - 4
	- longer term (GW projects)	2

Table 2 Cost estimates of various wave and tidal stream technologies [7]

2.3.3. Developers in the field believe that given success with progressing the technology to use this high intensity energy resource beyond the targets that can be envisaged at this early stage, then even better cost-effectiveness than the above may be envisaged.

2.4. Tidal barrages

2.4.1. A purely commercial case has yet to be made for a large tidal barrier such as the Severn Project but, as a renewable source, this would avoid approximately 4.6mtC emissions per annum and contribute 17TWh of renewable electricity annually, or approximately 6% of UK demand. A number of other smaller sites have been identified for tidal schemes such as the Humber and the Mersey, but again are not under serious consideration at present. Tidal barrages could in the

[7] House of Commons, Session 2000-2001, Science and Technology Committee, Seventh Report, *"Wave and Tidal Energy"*, 30 April 2001, HC 291

future be incorporated into flood defences, such as an upstream replacement for the Thames Barrier, thus subsidising their development costs.

2.5. Wind

2.5.1. In the decade to 2020 there may well be some significant contributions from marine generation projects as technologies mature, but the major contribution to electricity generation from renewable energy sources over the next few years will undoubtedly come from wind. As a result of much government subsidy worldwide over the years (£10 billion has been estimated[8]) it is now a well developed industry backed by much scientific and engineering knowledge and experience[9]. The true amount of subsidies received is immaterial, but the extent indicates that new renewable technologies must receive substantial and continued financial support before being able to compete successfully with conventional sources.

2.5.2. In the 2002 data (Table 1) showing 11.1TWh contributed by renewables, 5TWh came from biofuels, 4.8TWh from hydro (natural flow) and only 1.3TWh from wind, wave and solar technologies. With the potential increase in contributions from thermal and hydro sources being somewhat limited before 2010, wind will have to supply most of the additional renewable energy to meet the Government targets by 2010.

2.5.3. Assuming a 2010 target of 37 - 40TWh this means wind generation producing, say, approximately an extra 20TWh. The load overall load factors[10] for onshore wind generation over the last five years has varied between 26.4% and 30.7%.[11] Presumably with larger wind turbines with higher hub heights these figures will be improved upon, especially as the better wind sites in Scotland are developed. Using higher load factor estimates of 30 – 35% this additional energy requirement translates into new wind turbine capacity requirements of approximately 7000 MW. Viewed differently, some five thousand 1.5MW

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[8] House of Commons, Session 2000-2001, Science and Technology Committee, Seventh Report, *"Wave and Tidal Energy"*, 30 April 2001, HC 291

[9] http://winddata.mek.dtu.dk

[10] The overall energy load factor is the generation output as a percentage of the theoretical maximum output based on plant rating accounting for the wind variability, plant availability and sundry energy losses

[11] "Digest of United Kingdom Energy Statistics 2003", DTI, London, The Stationery Office.

turbines wind turbines need to be installed along with the necessary network modifications over the next seven years, proportionately fewer if larger machines are used. The feasibility of this task has not yet been proven in the UK, especially as the greater proportion of these turbines would be built offshore with their longer construction times.

2.5.4. Although already a well-developed industry, the IEA Wind Executive Committee [12] notes that continued medium and long-term research is needed. The large-scale implementation of wind energy requires a continued cost reduction. The technology of turbines, wind power stations, grid connection and grid control, the social acceptability and the economy of wind power in a liberalized market, all have to be improved in order to provide a reliable and sustainable contribution to the energy supply. It is for these reasons that there is a need for sustained R&D, partly funded by the industry but also by the Government.

2.5.5. The total exploitable wind resource in the UK is hard to assess with any certainty. The Central Electricity Generating Board did an appreciable amount of research into probable costs of wind power and availability of sites within England and Wales. Results were published in their evidence to the Hinkley 'C' Public Inquiry.[13] Preliminary resource estimates are shown in table 3 for 30 m heights, which is a tower height typical of medium size machines. The variation of energy yield with wind speed is given in terms of the energy load factor that varies as the cube of the average wind speed.

2.5.6. It must be emphasised that this study was based on the total land area available in England and Wales; the actual usable areas are likely to be considerably less than this. Areas of high wind speed are mainly found at high elevations and therefore tend to lie in scenic regions including areas of outstanding natural beauty and national parks. The practical land area that could be used is uncertain. If 10% of the areas given in the table could be developed with a typical planting density of 4MW per square km the total wind energy capacity

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[12] http://www.afm.dtu.dk/wind/iea/pdfs/Final%20IEA%20R&D.pdf

[13] "Renewable Energy Sources", Watt Committee on Energy Report Number 22, (Ed. Michael A.Laughton),Elsevier Applied Science,1990.

of these regions would be about 3000 MW, with up to 1000 MW available at wind speeds of 8.4m/s and above."

Annual wind speed at 30m height (m/s)	*Land area with wind speed (sq km cumulative)*	*Energy load factor*
9.0+	500	42%
8.4+	2500	35%
8.0+	7500	30%

Table 3 Estimated land areas and energy load factors with high average wind speeds

2.5.7. There are several points of interest here. With modern, larger wind turbines having hub heights up to 100m and beyond, wind speeds are higher and so these land areas would also be larger, especially if those of Scotland are included where there are better wind regimes. In addition with larger turbines the Scottish Executive have adopted a figure of 9MW / km^2 for onshore sites (10MW/ km^2 for offshore wind energy in areas such as the more northerly UK west coast)

2.5.8. The areas with the best wind resources, however, are a fraction of all of those that are commercially viable, less than 5% in the above table. More importantly it is suggested that only 10% of all of these areas could be planted with wind farms. This indicates that public acceptance will form an essential constituent in the future density of wind turbines in the landscape.

2.5.9. The present-day installed cost for onshore wind in the UK is quoted as £650/kW, and for offshore around £1000/kW. [14] For offshore wind this figure includes around £100/kW for the farm to shore connection and £150/kW for inter-turbine cabling. These figures can vary considerably depending on site and in the extreme cases will approach the cost of developing the resource.[15] The extent of cost reductions that can be achieved in this industry is a matter of speculation and figures produced from a number of studies should not be taken as accurate, especially those based on unreal learning curve optimism. Offshore prices should show a bigger drop, partly due to maturation of the industry and

[14] DTI, 2002. Future offshore. A strategic framework for the offshore wind industry.
[15] "Concept Study – Western Offshore Transmission Grid", Report by PB Power to ETSU, February 2002.

partly due to the moves towards much larger wind farms. Onshore and offshore windfarms will benefit as well from manufacturing cost savings with the advent of larger turbines, but the potential for savings from the Civil Engineering work is not so great. Some 30% of the present cost of onshore windfarms can be attributed to site infrastructure.

2.5.10. Using the above capital costs, nevertheless, the present generation costs based on a 10% real rate of return, 20 years plant life, 3-4% annual operating and maintenance costs, 95% availability and, importantly, the published average overall load factors (not nominal load factors) gives total average generating costs for onshore windfarms of approximately £37/MWh. This cost applies, however, only to the relatively limited areas having the best wind speeds with nominal load factors of 35%. For offshore windfarms a preliminary basic cost of £55/MWh results although further costing needs to be carried out to reflect experience gained and also anticipated reductions in this new industry.

3. Intermittency

3.1. One of the main drawbacks of renewables is that while able to supply a certain amount of energy over a year with reasonable assurance, they are intermittent, and some randomly so. All except biofuels, and to some extent hydro, are therefore unable to supply power on demand and are limited in their contributions to security of supply. Such variations in power output can cause problems for a power system if the resources penetrate the system on a large scale. This problem has been studied extensively, based on security of supply considerations using reliability theory and known plant operational data, to determine how much conventional plant capacity can be displaced by wind in particular. Table 4 shows the levels of conventional capacity that must be retained according to National Grid calculations to preserve the present levels of security of supply. Less conventional capacity would be needed if more new peak load plant were installed, open-cycle gas turbines, for example.

Installed wind capacity MW	Conventional capacity MW	Spare capacity MW
500	59,000	9,500
7,500 (approx 2010 target)	57,000	14,500
25,000(approx 2020 target)	55,000	30,000

Table 4 Capacities required to meet a 50,000 MW peak load 90 winters per century based on historic conventional plant forced outage rates with increasing wind penetration

3.2. What the commercial arrangements would be to ensure the continued availability of so much spare capacity, i.e. standby plant, is not clear. Certainly very high marginal prices would have to be charged to cover the fixed costs of so much idle plant. Various attempts have been made to quantify the system costs of additional renewables in, say, 2020. None, however, are satisfactory mostly because of the necessity of making gross simplifying assumptions, imprecise data or through defects in methodology. Balancing costs, regardless of their amount, when spread over 400 TWh of demand are reduced to small numbers so accuracy is somewhat immaterial. An extra £2 billion pounds, for example would be reflected by an increased in unit costs of only 0.5 p/kWh.

3.3. The main issue may not be cost, but in ensuring sufficient capacity is always available to provide security of power supply. Capacity that is necessary although apparently spare for large parts of the year still requires full remuneration to be an economically efficient investment. This depends on prices rising much higher than running costs. If a generator suitable for peak usage (i.e. up to 1000 hours per year on average) had an annual fixed cost (i.e. investment cost plus fixed operating costs) of about £20,000 per MW of installed capacity,[16] then a premium over running costs must apply of £20/MWh for 1000 hours of operation, £200/MWh for 100 hours, £2000/MWh for 10 hours, etc. To retain such investments either prices must rise very high or else electricity consumers must become very responsive to short-term (i.e. half-

[16] "Persuading the private sector to meet the aims of energy policy", NERA report for Powergen, 17 December 2002.

hourly) “price spikes” with all of the consequences and problems posed by possible government or regulatory intervention in the market.

3.4. From wind data records covering the whole of mainland UK, there is a sizeable probability of little or no wind blowing across the entire country, regardless of the capacity installed. Figure 1 illustrates the situation where a hypothetical wind power capacity of 7,300 MW installed throughout the country is correlated with actual Met Office wind data. The most likely power output nationally is seen to be less than 200 MW[17]. This graph illustrates what is effectively a common mode failure of supply. These results have been confirmed recently[18] from a study of hourly demand data and simulated wind generation data covering ten years. The results show that there are significant periods in an average year when demand is high and wind output is low, for example, 1642 hours when wind output is less than 10% of maximum, including 450 hours when demand is between 70 - 100% of peak demand. Attention is drawn to previous evidence presented to the Minister by the Academy on this matter[19].

3.5. Large weather systems, particularly high-pressure windless systems, can cover most of the country as seen during the January 2003 cold spell for several days and again during the subsequent July heat wave. At such times the contributions from any wind and wave generation are severely curtailed. This implies the need for conventional backup capacity appropriate for the risks assumed regarding the acceptability of loss of supply.[20]

3.6. Unlike Denmark the UK, despite future interconnector arrangements, is essentially an island system. The high penetration of wind power in Denmark is possible because Denmark is stabilised by the connections to Norway, Sweden and Germany. On the assumption that the mainland UK system continues to be essentially “stand-alone” all such large-scale alternative reserve balancing and backup capacity would have to be installed in the UK. It should also be noted that the Danish system is vulnerable to the loss of these interconnectors as

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[17] National Grid PIU Supplementary Submission, 28 Sept 2001

[18] “The non-market value of generation technologies”, OXERA, June 2003

[19] “An Engineering Appraisal of the Performance and Innovation Unit’s Energy Review, Memorandum prepared by The Royal Academy of Engineering for Mr B. Wilson MP, Minister of State for Energy and Industry, August 2002

[20] Laughton,M.A., “Renewables and the UK Electricity Grid supply infrastructure” Platts Power in Europe, Issue 383, 9 September 2002, pp 9-11.

happened on 23rd September 2003 causing substantial power cuts in Copenhagen and Zeeland.

3.7. A further problem that has not received much attention regarding the contributions from wind to be expected over the years to 2020 concerns the significant changes in mean annual wind speeds. A study of climatic variability in northern Europe shows that variations in wind energy of up to 30% can be expected from one decade to another. Again this uncertainty has to be reflected in the planning for sufficient conventional or other forms of capacity.

3.8. With small levels of penetration, these reservations would be of minor importance, but for large levels of wind capacity as considered by the Government over the next two decades these extra system requirements and costs could pose serious problems. The importance of the development of renewable energy supplies for electricity generation is not to be denied, although these remarks may appear to be somewhat negative, but targets and aspirations need further and continuous careful engineering appraisal to anticipate and to solve the technical problems before they arise.

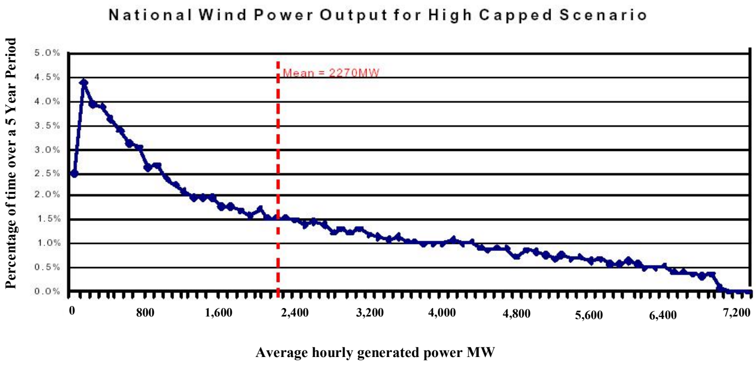

Figure 1 Hourly Power generated v Percentage of time over five years from a hypothetical GB wind power capacity of 7300 MW installed over the whole country

4. Transmission

4.1. With the implementation of more renewable generation within the UK distribution system, major changes in the way the transmission network has to behave will be imposed. The UK's 400kV transmission network was essentially designed to interconnect a small number of large, centralised generators for security reasons, but the new renewable generators tend to be small, widely distributed and require many new connections. A few renewable generators will be connected directly to the 400kV network, but the concentration of those connected at lower voltages will require significant developments and investments in the 275kV and 400kV networks throughout the UK to preserve security of supply.

4.2. The high voltage transmission network needs to be extended and updated in areas, as the geographical pattern of generation and usage is likely to change. For example, it is expected that large amounts of wind generation in the North of Scotland will need to transmit power to the South. There is already a general North, South flow of power in the grid, and this will be exacerbated with further development of renewables.

4.3. Distribution network operators need better financial incentives to connect renewable generators to their systems. At present, there are none. Network operators are generally wary of connecting large volumes of renewable generation to their systems as the added complexity of the embedded generators has an impact on reliability and fault levels. The forthcoming Distribution Network Operators (DNOs) price review by Ofgem in 2004/5 will be the only opportunity to address this before 2010.

5. Conclusions

5.1. There are very significant engineering challenges ahead of the UK if it is to meet the targets for renewables and emission reductions called for in the Energy White Paper. These range from the simple engineering effort involved in installing thousands of wind turbines or constructing tidal barrages to the management of the electricity grid in a regime of distributed and intermittent generators that were not envisaged when it was designed.

5.2. The main cost-effective technology available today for the generation of renewable power is wind energy. However, the cost of the power generated depends upon the methods used to calculate project costs and whether, as some argue, the full cost of intermittency should be taken into account. As has been argued above in para 7.3, high levels of intermittency would lead to increasingly high peak costs for balancing which should be taken into account when considering cost effectiveness within the system as a whole.

5.3. Other technologies that are currently available and cost-effective are hydro, sewage gas, landfill gas, biofuels and waste combustion (a proportion of which can be considered to be renewable). None of these currently has the capacity to make the same impact on supplies as wind energy, but they do not suffer from the same randon intermittency problems. It should be noted that due to the way in which renewables have been defined for the purposes of the Renewables Obligation the UK's large-scale hydro capacity has fallen by 4 per cent as some stations have been adapted to fall within the capacity limit of 10MW. [21]

5.4. The number of potential sites for renewable technologies has been studied in great detail and The Academy has little to offer in this respect except to observe that, as far as wind sites are concerned, the most favourable sites available will be developed first. This means that, while current load factors for wind turbines are around 30%, possibly rising to 35% for larger turbines, average load factors may be seen to fall over time as less favourable sites are developed. Although the Government has acted to streamline planning applications for wind

[21] "Digest of UK Energy Statistics 2003", DTI, London, The Stationery Office

generators, the MOD continues to object to development of some of the better sites, further compromising future load factors.

5.5. The logistics of providing stand-by capacity for intermittent sources is discussed in section 7. If, say 22,000MW of wind turbine capacity were installed, approximately 16,000 to 19,000 MW would have to be available in the form of conventional capacity in order to provide back-up power when wind is light or absent. This is in addition to the stand-by capacity required to cover for peak loads and conventional plant outages, giving a total figure around 30,000MW quoted in Table 4. The cost of providing this back-up capacity to cover wind intermittency would be in the order of £1billion.

5.6. The Academy recommends that, given the large number of people and organisations engaged in the debate over renewable energy, including the general public, that the Government produces an Annual Report on progress towards the 10% target for renewable electricity by 2010 along with reasons for exceeding or falling short of intermediate targets. The same report should also make clear additional costs and benefits that arise from renewable energy, including the costs standby generation and improving the electrical infrastructure.

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