A suggestion for meeting the UK Government's renewable energy target because the adopted use of windfarms cannot meet it

by

Richard S Courtney

SPPI Reprint Series

SPPI
Science & Public Policy Institute
"science based policy for a better world."

The 2006 Annual Prestigious Lecture to

The North of England Institute of Mining and Mechanical Engineers

and

The Institute of Materials, Minerals and Mining (North East)

held on Thursday 26th October 2006

A suggestion for meeting the UK Government's renewable energy target because the adopted use of windfarms cannot meet it

by

Richard S Courtney

Synopsis

The UK Energy White Paper was published by the UK's Department of Trade and Industry (DTI) in May 2003. It proposed the objective of a contribution to reduction of carbon dioxide (CO_2) emissions by use of 'renewables' mostly in the form of windfarms (i.e. local assemblies of wind turbines) to provide 20% of UK electricity supply. This objective was endorsed by the UK's Energy Review that was published by the DTI on 11 July 2006. However, this paper suggests the use of windfarms cannot make significant contribution to reducing the emissions and suggests the construction of tidal coffer dams instead. Windfarms for power generation provide intermittent power so they merely displace thermal power stations onto standby mode or to operate at reduced efficiency while the thermal power stations wait for the wind to change. They make no significant reduction to pollution because thermal power stations continue to use their fuel and to produce their emissions while operating in standby mode or with reduced efficiency that can increase their emissions at low output. And this need for continuously operating backup means that windfarms can only provide negligible useful electricity to electricity grid supply systems. But the large scale use of windfarms requires upgrading of an electricity grid, more complex grid management, and operation of additional thermal power stations to protect against power cuts in time of supply failure. These effects increase the cost of electricity supplied by the grid in addition to the capital, maintenance and operating costs of the windfarms themselves. And the windfarms cause significant environmental damage. Tidal coffer dams would not have these problems and could provide continuous and controllable power supply at similar cost to off-shore windfarms.

A suggestion for meeting the UK Government's renewable energy target because the adopted use of windfarms cannot meet it

1. The UK's Energy White Paper (1) and Energy Review (2)

The Energy White Paper(1) published by UK Government in May 2003 set out four objectives;

- Cutting carbon dioxide (CO_2) emissions
- Securing the reliability of energy supplies
- Promoting competitive markets to help raise the rate of economic growth and improve productivity
- Ensuring every home is adequately and affordably heated

The White Paper established that a major contribution to the reduction of CO_2 emissions was to be expansion of so-called 'renewable' sources of power [a] to provide 20% of UK electricity supply. At present, 'renewables' provide 4% and windfarms (i.e. local assemblies of wind turbines) provide 0.5% of the total UK electricity supply.

Hydroelectricity schemes provide most existing 'renewable' power sources in the UK (mostly in Scotland), and there are limited opportunities for more hydroelectricity schemes in the UK. The expansion would be nearly 30 GWe of power from use of 'renewables' and would mostly be provided by construction and use of windfarms.

The objectives set out in the White Paper(1) were endorsed by the Energy Review(2) published by UK Government in July 2006[b]. The White Paper and Review did not say that their proposal for increased use of windfarms would require 15000 x 2 MW wind turbine units to be constructed at the rate of 3 per day for the next 15 years. This ambitious project is being supported by large subsidies.

The renewables objective is being addressed by promotion of windfarms because both the White Paper and Review – wrongly – assert that windfarms reduce emissions from power generation and that windfarms and hydroelectricity are the only technically feasible 'renewables' at present. However, the Review advocated investment in research on alternative 'renewables' notably wave power and geothermal power.

This paper explains that the predominant reliance on windfarms for the renewables sector prevents meeting "the Government's targets for CO_2 reduction" from power generation that were established in the White Paper. And this paper also explains that tidal coffer dams are a renewables option which would help to meet the targets. All the technology for tidal coffer dams exists and is proved. They could be installed in places of high tidal rise-and-fall, for example in the Severn estuary.

---

[a] The description "renewable sources of energy" or "renewables" is usually applied to sources of energy where the energy (or fuel) is removed from a place at no greater a rate than it arrives at that place. However, it should be noted that the description is a misnomer because in absolute terms "renewable sources of energy" are not possible: all energy was created at the 'Big Bang'.

[b] The Energy Review also advocated 'distributed power systems', combined heat and power (CHP) schemes, increased energy efficiency especially in dwellings, investment in research on alternative 'renewables' (e.g. wave power and geothermal power), and continued use of nuclear power for electricity generation.

2. The history of wind power

Wind power has been used for centuries. Wind energy powered most of the world's shipping for thousands of years. Primitive wind turbines powered pumps (notably in the Netherlands and England) and mills throughout Europe for centuries.

There are a number of types of wind turbines. They are divided into Vertical-Axis and Horizontal-Axis types.

Vertical-axis windmills to mill corn were first developed by the Persians around 1500 BC, and they were still in use in the 1970's in the Zahedan region. Sails were mounted on a boom attached to a shaft that turned vertically. The technology had spread to Northern Africa and Spain by 500 BC (3). Low-speed, vertical-axis windmills are still popular in Finland because they operate without adjustment when the direction of the wind changes. These inefficient Finnish wind turbines are usually made from a 200 litre oil drum split in half and are used to pump water and to aerate land (3). Low speed vertical-axis windmills for water pumping and air compressing are commercially available (a selection of commercial suppliers is at http://energy.sourceguides.com/businesses/byP/water/wPumpMills/wPumpMills.shtml).

The horizontal-axis wind turbine was invented in Egypt and Greece around 300 BC. "It had 8 to 10 wooden beams rigged with sails, and a rotor which turned perpendicular to the wind direction" (4). This type of wind turbine later became popular in Portugal and Greece. Around 1200 AD, the crusaders built and developed the post-mill for milling grain (3) (4). The turbine was mounted on a vertical post and could be rotated on top the post to keep the turbine facing the wind. This post-mill technology was first adopted for electricity generation in Denmark in the late 1800's (3). The technology soon spread to the U.S. where it was used to pump water and to irrigate crops across the Great Plains (3) (4). During World War I, some American farmers rigged wind turbines to each generate 1 kW of DC current. Such wind turbines were mounted on buildings and towers (3). On western farms and railroad stations, wind turbines for pumping water were between 6 and 16m high and had 2 to 3m diameter. With 15kmh wind speed, a 2m-diameter turbine operating a 60cm diameter pump cylinder could lift 200 litres of water per hour to a height of 12m. A 4m diameter turbine could lift 250 litres per hour to a height of 38m (4).

The above brief history demonstrates that wind turbines can have useful niches to the present day. For example, small wind turbines can be used to economically pump water or generate electricity in remote locations distant to – or disconnected from (e.g. on boats) – an electricity grid supply. But wind power lost favour when the greater energy concentration in fossil fuels became widely available by use of steam engines. Wind power has recently found favour for large scale electricity generation in some places, and this paper explains why such use is uneconomic and impractical.

Today, if wind power were economically competitive with fossil fuels, then oil tankers would be sailing ships. Japan has conducted several studies to ascertain if use of automated sails could assist modern shipping. These studies have demonstrated that available wind power is so small a contribution to the powering of a ship that the systems to obtain it cannot recover their capital costs (5) (which agrees with the considerations provided in this paper).

However, since the 1970s, the use of large, modern wind turbines has become popular for electricity generation in some places. This is especially true in Denmark, Germany, the UK and also in parts of the USA where it has resulted in California's 'Energy Crisis' (as explained in this paper). Reasons for this use are entirely political. As this paper explains, the low energy concentration in wind requires use of very many turbines with associated very high capital and maintenance costs. Also, the output of the turbines depends on the weather and, therefore, cannot be predicted with accuracy for more than – at most – a few days in advance.

Windfarms are local assemblies of wind turbines for power generation. Their turbines generate electricity when the wind is strong enough but not too strong (6). This makes their output intermittent, and electricity is not a commodity so it cannot be stored in significant amounts and must be used at its existing distribution system when generated. This intermittent supply of electricity disrupts the electricity grid (as also explained in this paper).

3. Theoretically available wind power (7)

Wind is the movement of air. Perpendicular to the wind direction, the wind's kinetic energy per unit time (e_k) is provided by the mass (m) and the square of the velocity (v) of the air with density (ρ) moving through a unit area (A).

$$e_k = ½\, m\, v^2 = ½\, (A\, v\, \rho)\, v^2 = ½\, A\ \rho\, v^3$$

Air has low density (ρ) that varies with its altitude (h). Its density at ground level (ρ_o) is ~1.225 kg / m^3. For heights below ~6 km, ρ can be estimated to a reasonable approximation using the expression.

$$\rho = \rho_o \exp(-0.297\, h / 3048)$$

where h is in meters

ρ also varies with the air's temperature (T) and pressure (P). For heights below ~6 km, the relationship of ρ, T and P can be estimated to a reasonable approximation using the expression.

$$\rho = 3.4843\, P / (T + 273)$$

where P is in kPa and T in °C

For the standard atmosphere, T is defined to decrease linearly with height

$$T = 15 - 1.983\, (h/304.8)\ ^{o}C$$

So, the air affecting a wind turbine blade has little mass per unit of time unless the wind speed is high. This means there is little wind energy available for collection by a wind turbine unless the wind speed is high. Taller turbines can collect more wind energy, but all wind turbines collect little energy from the wind for conversion to electricity unless the wind speed is high. And wind turbines can only operate when the wind speed is low.

4. Technical limitations of wind turbines for power generation

Horizontal-axis wind turbines (developed from post mill technology) are inherently more efficient than vertical wind turbines (6). Hence, horizontal-axis wind turbines are favoured for electricity generation (6) (7). They are fitted with one, two, three or (very rarely) more turbine blades. A schematic of a typical wind turbine for power generation is shown in Figure 1.

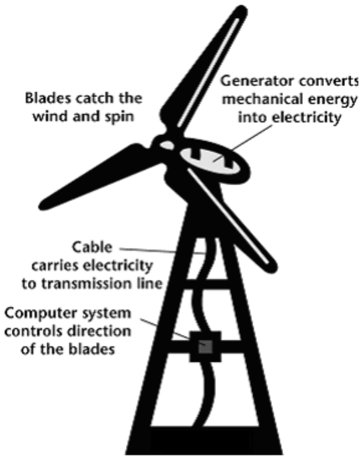


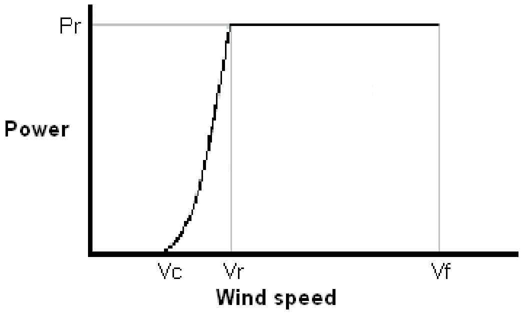
Figure 1. Schematic of a typical 3-blade wind turbine for electricity generation.

Modern wind turbines are large to maximise interaction with the air and, thus, gain efficiency. A typical wind turbine can produce 1.5 to 4.0 million kWh of electricity a year (8). The largest wind turbine in operation is the Vestas V44-600. Its blade is 144 feet in diameter and is mounted on a 160-foot tower west of Traverse City, Michigan (8). It provides slightly less than one percent of the Traverse City Light and Power Company's total output (8).

Wind turbines require much land. Turbines would take the wind from each other if sited too close together (9). Each wind turbine needs about two acres of land (9), and several turbines are needed to generate much electricity. A typical windfarm covers hundreds of acres (9). However, agriculture can be conducted between the foundations of the turbines of an installed windfarm.

As explained in Section 2, little energy is obtainable by a wind turbine unless the air has high velocity (i.e. the wind is strong). But wind turbines only operate when the wind is sufficiently strong and not too strong. Hurricanes, cyclones and tropical storms carry large amounts of energy because they have high wind speeds, but they are rare. A wind turbine designed to collect energy from tropical storms would rarely operate, and a wind turbine designed to collect energy efficiently from ordinary winds would be damaged if it tried to operate in a tropical storm.

The highest wind speed at which a wind turbine generates electricity is called its furling speed. The theoretical maximum output of a typical turbine as a function of wind speed is shown graphically in Figure 2 (7) (10).



Pr is the rated power of the turbine
Vc is the lowest wind speed at which the turbine generates electricity
Vr is the lowest wind speed at which the turbine generates its rated output
Vf is the furling speed

Figure 2. Schematic of an ideal wind turbine's output as a function of wind speed.

The precise values of the lowest and highest wind speeds for power generation from a wind turbine depend on its design. But the proportion of time a wind turbine operates is called its load factor. And the load factors achieved by commercial windfarms are low. This is shown in Table 1 that provides the achieved load factors of windfarms in three countries with significant generating capacity from windfarms.

Table 1 demonstrates that windfarms provide very intermittent electricity supply. Assuming the performance of windfarms could be extended so they provide power for more of the time, then it could be optimistically assumed that their load factors may be increased to 30%. But that should be compared to the typical load factor from a thermal power station of 85 to 90% that does not depend on the wind speed so it stops only for maintenance.

Country	Time Period	Achieved Load Factor	Source	Notes
West Denmark	1999	19.7%	Eltra (Danish grid operator)	Denmark has most installed wind power capacity of any country. West Denmark is its windiest region
	2000	21.0%		
	2001	19.9%		
	2002	18.9%		
	2003	21.0%		
	1999-2003	20.0%		
Germany	2003	14.8%	Reuters	
United Kingdom	1999	28.2%	UK Department of Trade and Industry (DTI)	The UK is Europe's windiest country
	2000	28.2%		
	2001	26.4%		
	2002	29.9%		
	2003	24.1%		
	1999-2003	27.3%		

Table 1. Achieved load factors of wind powered electricity generation.

The problem is compounded by the actual output of a wind turbine being less than its theoretical maximum (shown schematically in Figure 2). As shown in Figure 3, wind turbines have between 30% and 40% efficiency (7) (10) (i.e. they output as electricity about a third of the wind power they collect) which is comparable efficiency to that of thermal power stations.

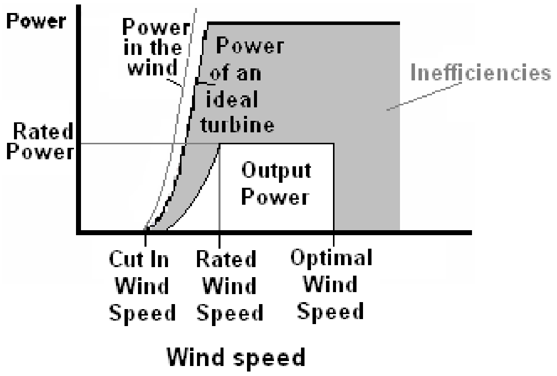


Figure 3. Schematic of actual wind turbine output as a function of wind speed.

5. Relative costs of wind power and conventional electricity generation

The low load factors and low efficiency of wind turbines combine with the little energy available from normal winds to make it very difficult to recover the capital costs of a wind turbine used to generate electricity from sale (at commercial rates and without subsidy) of the small amount of electricity it can produce. For example, an average wind speed of 14 mph is needed to convert wind energy into electricity competitively with coal-fired or nuclear electricity in the U.S., but the U.S. average wind speed is 10 mph (11). This also means that selection of 'windy' sites for windfarms is important for maximising the obtained energy.

A report from the UK's Royal Academy of Engineering on 'The Costs of Generating Electricity' (12) claims that electricity from offshore wind farms will cost at least twice as much as that from conventional sources in the UK. Their report concludes that for the foreseeable future the UK's cheapest electricity will come from gas turbines and nuclear stations, costing just 2.3 p/kWh, compared with 3.7 p/kWh for onshore wind and 5.5 p/kWh for offshore wind. The nuclear cost included decommissioning costs of nuclear power stations.

A significant contributor to the high cost that the Academy estimates for wind power is the need to provide back up generating capacity for when the wind is not at a speed to operate wind turbines. Their report says it is 'rather generous' with its wind generation figures: it assumes only 65% back-up power is needed whereas previous estimates were for 75 to 80% (65% is very generous because it assumes a load factor of 35%, but see Table 1). Even so, their report estimates the need for backup capacity adds 1.7 p/kWh to the costs of wind power.

6. Environmental effects of windfarms

Windfarms have significant environmental costs. Some people dislike their appearance, but this is a matter of aesthetic opinion. More importantly, windfarms cover the landscape in concrete foundations for their turbines and roads to access the turbines. They are very effective at this in the UK because

1. the UK Planning System has been deliberately altered to encourage construction of windfarms and the Energy Review(2) suggests additional such amendment,
2. large subsidies are provided to owners of windfarms, and
3. so-called environmentalists who oppose roads for normal transportation campaign for construction of windfarms.

Some other European countries and American States are providing similar biases towards construction of windfarms. The situation in the U.S. provides a clear demonstration of the effectiveness of the lobby promoting windfarms. The U.S. does not have any target for CO_2 emission reduction but some U.S. States provides tax breaks to offset maintenance costs of power plants that use 'renewable' energy sources and the Public Utility Regulatory Policies Act (PURPA) requires utility companies to purchase electricity from independent power producers throughout the U.S..

The long-term effects are potentially serious. Land that has been converted to an industrial use (i.e. power generation) is not likely to return to agriculture.

Windfarms also swat birds and bats. One windfarm at Altamont Pass, California, kills thousands of birds – including an estimated 880 to 1300 birds of prey – each year (13). Hence, the widespread use of windfarms may alter local ecology and reduce biodiversity.

Additionally, windfarms provide serious noise pollution down-wind. An efficient wind turbine blade removes much energy from the air. For this reason, a rotating blade generates pulses of reduced pressure in the air flowing behind the turbine which provide loud, throbbing, often subsonic noise. This has potential to disturb breeding habits of wildlife and is certainly unpleasant for people exposed to it (14).

Winds are stronger and more constant at sea than on land, and the noise pollution from wind turbines would not be a problem at sea. But large ocean waves would be likely to displace the turbines from their moorings unless the turbines' mountings were very expensive (12), and these mountings would destroy the sea bottom where they were sited. Also, the wind turbines would provide hazard to shipping if not carefully sited, charted and lit.

It is sometimes claimed that some of these environmental effects of windfarms may be overcome by dwellings each having their own wind turbine(s) for their personal use as electricity generators. Indeed, the Energy Review advocates this(2). It should be noted that large adoption of this policy by an urban area would significantly increase the noise pollution in the area (14). Also, such an urban windfarm would have all the other problems of every windfarm.

7. The purpose of Windfarms

Windfarms have negative environmental effects and generate expensive electricity, but some governments are promoting them. The justification for this promotion is often said to be that

- windfarms provide useful electricity to an electricity supply grid, and
- the use of windfarms reduces emissions from conventional power stations supplying to the grid.

Indeed, the Energy Review(2) makes these claims.

Both these claims are false: the following Sections of this paper explains that the grid supply and demand profiles ensure that

- windfarms add a large, unnecessary cost to the provision of electricity by a grid supply,
- windfarms cannot provide significant amounts of useful electricity to an electricity grid at any time, and
- the large use of windfarms increases emissions from conventional power systems supplying to the grid.

8. Thermal power stations

Conventional (i.e. thermal) power stations fission a material or burn a fuel to obtain heat that is used to boil water and superheat the resulting steam which is fed to the steam turbines (some power stations – e.g. combined cycle gas turbine: CCGT – also use gas turbines in combination with steam turbines). The turbines drive turbogenerators that make electricity.

A thermal power station takes days to start producing electricity from a cold start (15). Time is needed to boil the water, to superheat the steam, to warm all the components of the power station, and to spin the turbogenerators up to operating speed.

Each thermal power station is designed to provide an output of electricity. It can only provide very little more or very little less than this output (i.e. a power station has a "low turndown ratio") (16).

9. Electricity demand matching (17)

Electricity is wanted from a grid supply all the time but the demand for electricity varies from hour to hour, day to day, and month to month. The electricity grid has to match the supply of electricity to the demand for it at all times. This is difficult because thermal power stations cannot be switched on and off as demand varies, and only small variation to the output of each power station is possible.

The problem of matching electricity supply to varying demand is overcome by operating thermal power stations in three modes called

- ‘base load’,
- ‘generation’ and
- ‘spinning standby’ as backup capacity.

Some power stations operate all the time providing electricity to the grid, and they are said to provide the ‘base load’.

Other power stations also operate all the time but do not provide electricity all the time. They burn (or fission) their fuel to boil water and superheat the resulting steam which is fed to the steam turbines that are thus kept hot and spinning all the time. Of course, they emit all the emissions from use of their fuel all the time. But some of this time they dump heat from their cooling towers instead of generating electricity, and they are then said to be operating ‘spinning standby’.

One or more power stations can be switched from spinning standby to provide electricity to match an increase to demand for electricity. It is said to be operating ‘generation’ when it is providing electricity.

Power stations are switched between spinning standby and generation as demand for electricity changes. Thus the grid operator manages the system to match supply with demand for electricity by switching power stations between ‘generation’ and ‘spinning standby’. And the small available variation in output from each power station is used to avoid large step changes in the supply when this switching is conducted. But operating a power station at less than its optimum output severely reduces its efficiency so it has little reduction to its fuel consumption and emissions although it supplies less electricity. (17)

Additionally, the need for power stations to operate is reduced by use of ‘pumped storage’. Electricity is used to pump water uphill to a reservoir when there is little demand from the grid. Then, when there is peak demand for electricity the water is allowed to flow back down and generate power. This consumes electricity because of mechanical losses, but it is economic because it removes the need for a few power stations to operate almost continuously on standby mode so they can supply electricity at the (very short) times of peak demand. The pumped storage provides the extra electricity needed to meet the peak demand.

10. Windfarm input to electricity grid supply

Windfarms provide intermittent electricity because the wind changes. The grid operator must match this changed supply of electricity to the existing demand for electricity. Of course, the grid operator achieves the match by switching a conventional (i.e. thermal) power station to spinning standby mode or by operating it at low output with much reduced efficiency. That power station continues to operate in this manner so it can provide electricity when the windfarm stops supplying electricity because the wind has changed again. Therefore, large use of windfarms provides no reduction to the need to operate conventional thermal power stations and makes little or no reduction to emissions from them.

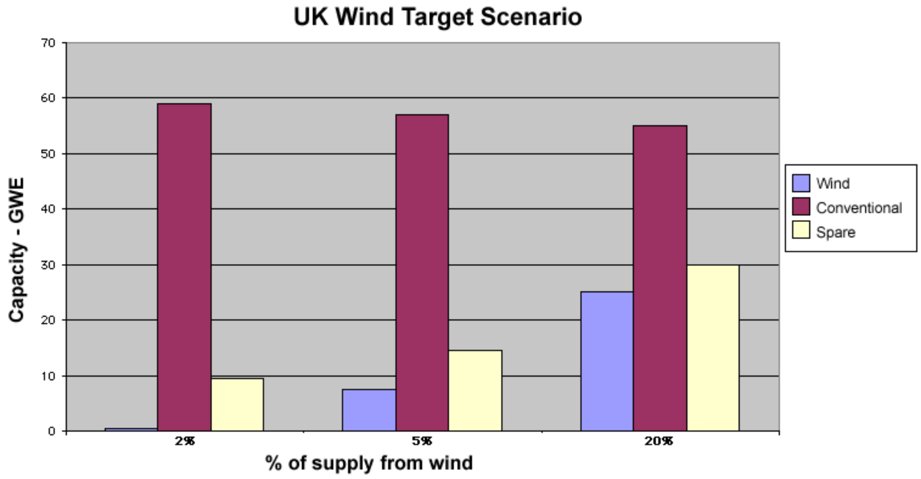
David Tolley (Head of Networks and Ancillary Services, Innogy (a subsidiary of the German energy consortium RWE) has said of windfarms in the UK, "When [thermal] plant is de-loaded to balance the system, it results in a significant proportion of deloaded plant which operates relatively inefficiently. **...** Coal plant will be part-loaded such that the loss of a generating unit can swiftly be replaced by bringing other units on to full load. In addition to increased costs of holding reserve in this manner, it has been estimated that the entire benefit of reduced emissions from the renewables programme has been negated by the increased emissions from part-loaded plant under NETA." **(18)** (NETA is the New Electricity Trading Arrangements, the UK's deregulated power market.)

Table 2 shows the results of model studies conducted by the UK's National Grid Corporation that indicate the effect of wind power's intermittent supply on the generating plant required to achieve that 20% UK renewables target **(12)**:

Contribution from wind % of 400 TWh	**Wind capacity GWe**	**Conventional capacity GWe**	**spare capacity GWe**
2%	0.5	59	9.5
5%	7.5	57	14.5
20%	25	55	30

Table 2. Generating capacity to achieve increased use of wind power in the UK (12).

Table 2 shows that the building of 25 GWe of wind capacity – approximately equal to the present world total and equivalent to almost half of UK peak demand – will only reduce the UK's need for conventional fossil and nuclear plant capacity by 6.7% (and arguably less). Some 30 GWe of spare capacity will also be need to be on immediate call continuously to provide a normal margin of reserve and to back up the wind plants' inability to produce power on demand – about two thirds of it being for the latter. Figure 4 also shows this problem **(12)**.



UK National Grid Corporation (per Prof M. Laughton)

Figure 4. Histogram of generating capacity to achieve increased use of wind power in the UK (12).

Windfarms have capital, maintenance and operating costs that add to the cost of electricity. These costs are their only real contribution to the electricity supply system. And a windfarm is the true source of emissions from a thermal power station operating spinning standby as spare capacity in support of the windfarm. But windfarms disrupt operation of the electricity grid system.

11. Power surges

A sudden, large addition to electricity in part of the grid is called a ‘power surge’. It can overload a component of the grid with resulting widespread damage to the grid. For example, during recent years power surges have damaged grid components with resulting loss of power to the London Underground system, the city of Turin, and most of North America.

Wind turbines provide power when the wind is strong enough and not too strong. It is very difficult to predict the precise moment when a windfarm will start to provide electricity to the grid. And the wind can change over a large area. Hence, the presence of many windfarms (or a large windfarm) in a locality causes power surges (19).

Denmark has many windfarms and so is subjected to power surges from them. The Danish grid manages this problem by dumping the electricity across its borders as a free gift to Denmark’s neighbours (20). Indeed, on some occasions it has paid its neighbours to take the surged electricity (20). But some countries cannot do that. For this reason in December 2003 the Irish grid operator announced that he would accept no more electricity from windfarms onto the Irish grid. Additional wind power would be so unmanageable that grid failures would be inevitable. Since then Ireland has upgraded its grid to cope with the problem. Of course, the Irish electricity consumers have had to meet the cost of this upgrade that has the sole purpose of enabling the operation of pointless and expensive windfarms.

The UK has a similar problem. The Interconnector with France could not handle the dumping of a power surge. Hence, large use of windpower in the UK would cause damage to components of the UK grid and frequent power cuts throughout the UK. Indeed, the UK grid is being upgraded to withstand the problems caused by the intermittent operation of the existing windfarms.

12. Managing supply risk

As earlier explained, power stations operate spinning standby to match electricity demand to supply. In addition to this, other power stations operate spinning standby to manage risk of supply failures. There is a risk of failure of a base load power station or the transmission system from it. Such failures would cause power cuts in the absence of the additional spinning standby. (17)

Windfarms provide intermittent power. Hence, windfarms increase the risk of supply failures. Indeed, they give the certainty of supply failures when the wind is too strong or not strong enough.

The increased risk of supply failures from windfarms is insignificant when there is small contribution of electricity to the grid from windfarms. All the output from the windfarms forces thermal power stations to operate spinning standby or at reduced output that can cope with the risk.

But the problem of managing the risk increases disproportionately as the risk increases.

Electricity is not wanted in the same amounts everywhere, and electricity is lost when it is transmitted over long distances. The additional risk management difficulties require additional spinning standby when the risk of supply failures is very large. Otherwise it would be impossible to match supply with demand throughout the grid when a large supply failure occurred (17). This is demonstrated by the needed amounts of spare capacity shown in Table 2 and Figure 4.

Additional power stations must be built and operated on spinning standby (using their additional fuel and providing their additional emissions) to manage the increased risk of power cuts from supply failures when windpower contributes more than 20% of the potential electricity supply (17). Indeed, this limit is the reason why the UK target for 'renewable' electricity generation is 20%: the UK generates hydropower (mostly in Scotland) so wind power will not reach the 20% limit if the target is met.

But the problem has been realised in California although California uses much less wind power than 20% of its grid supply. Some 13,000 wind turbines produce more than one percent of California's electricity. (This is about half as much electricity as is produced by one nuclear power plant.) The windfarms were constructed instead of thermal power stations (or instead of re-opening mothballed Californian nuclear power stations), and excess capacity in adjacent States was used to overcome the need for the windfarms to have backup. But California obtained a power crisis when that excess capacity was consumed by the adjacent States. Hence, California has inadequate spare capacity for the needed additional risk management associated with its small use of wind power. This has resulted in California needing to continuously apply scheduled voltage reductions (known as 'brown outs') around the State as an alternative method to manage the risk of power cuts from supply failures.

13. Summary of the problems of using windfarms to reduce CO_2 emissions

Windfarms are expensive, polluting, environmentally damaging bird swatters that produce no useful electricity and make no significant reduction to emissions but threaten electricity cuts.

14. Possible alternatives to use of windfarms for reduction of CO_2 emissions

The above considerations indicate that a serious error is being made by the present use of windfarms as an attempt to meet the objective of CO_2 reduction set by the Energy White Paper. Hence, consideration of alternative 'renewable' energy sources is required if the objective is to be met. This Section provides an overview of such consideration.

14.1. Possible sources of 'renewable' energy

All usable energy derives from the "big bang" which initiated the universe. All energy flows capable of conducting work are stages in the process from that event to the heat death of the universe.

Fuels are stores of energy. They are commodities which can be stored, transported when and where desired, and used as required. Thus, they can be used to provide energy which can be distributed as electricity when and where it is wanted.

Electricity is a form of energy. It is not a commodity. It cannot be stored in significant amounts and must be used at its existing distribution system when generated.

Only three processes provide energy flows which can be sampled by humanity. They are

- the residual energy which was concentrated in ancient - now dead - stars,
- the residual energy from the formation of the solar system, and
- the energy flowing from the sun.

Processes which initiated during the lives of ancient stars have generated radioactive substances notably uranium. Amounts of these substances were part of the material which accreted to form the Earth, and they may be utilised as fuel in nuclear power plants.

Residual energy from the formation of the solar system is observed in the power of the tides and geothermal forces. Indeed, it can be argued that the Earth and Moon system is still forming because these processes still continue.

Energy flowing from the sun consists of radiations and particles. To date, only sunlight and solar heat have been utilised as energy sources by humans.

All the three sources of energy have been suggested for provision of so-called ‘renewable’ energy.

14.2. Wind Power

Wind is the movement of air. The energy in wind is solar energy collected by the heating of air over very large areas of the surface of the planet. But air has low density, so the concentration of the energy is small and very high wind velocities are required to provide high energy flow. As previously explained, this combines with the intermittent supply of electricity to prevent windfarms providing useful electricity to a grid supply: electricity is not a fuel.

14.3. Hydro power

Water power (i.e. hydro-power) has been used for centuries. Its use continued when the high energy intensity in fossil fuels became widely available by use of the steam engine because it is cheap, efficient and controllable (NB this differs from wind power that is expensive, inefficient and controlled by the wind). Much of Scotland’s electricity is hydro-electricity.

Hydro-electricity relies on the collection of rain and so is a form of solar energy collected by evaporation of water over very large areas. It is economic because the high density of water provides large energy flows in moving water.

Sites for additional hydro power are very limited in the UK. A new site for a hydro-electric plant may require flooding of a valley and the environmental cost may not warrant the energy benefit.

14.4. Wave Power

Ocean waves are also solar energy collected over very large areas. The density of water is much more than that of air so waves carry a lot of energy. This is why off-shore wind turbines could be dislodged by strong waves. It also means that wave energy collectors are potentially more efficient than wind energy collectors.

Several methods are being developed for collecting energy from waves. They have potential for generating economic power along the west coasts of Europe, the US and Africa. However, they would provide intermittent power because the sea is sometimes calm. This reliance on weather provides difficulty in accurate prediction of future power generation. However, waves arrive at UK coasts throughout winter months, so the UK has potential for economic and useful electricity generation from waves during winter months when UK power demand is highest. This indicates that completing the developments of wave power could be beneficial for the UK.

UK Government is spending relatively little on development of wave power but is providing large financial subsidies to windfarms that cannot be economic. This would seem to be an error of priorities. Wave power cannot provide a useful source of ‘renewable’ energy for the UK at present and until its development is completed.

Sites of wave energy collectors would need to be carefully planned. Removal of energy from waves means that less wave energy would be received at the coasts: this could affect the coastal ecologies and the distribution of sediments along the shores.

14.5. Fossil fuels

Fossil fuels are the most effective use of solar power. They represent the remains of energy collected by living things over long times (geological ages) and large areas then compressed into small volumes of dried material. This high collection efficiency makes fossil fuels the most economic form of solar power.

Peat is the only fossil fuel which could be used as a ‘renewable’. Coal, oil, natural gas and peat continue to be formed by natural biological and geological processes, but these processes are very slow and most take geological ages. Fossil fuels would be ‘renewable’ energy if their uses were reduced to rates which equalled their formation. This is only possible for peat.

The use of peat to displace the use of coal would make no significant reduction to CO_2 emissions and, therefore, would not contribute to the CO_2 reduction target set in the White Paper.

14.6. Bio-mass

Like wind power, bio-mass is an ancient idea which has recently again found favour. Simply, bio-mass consists of harvesting crops for use as - or conversion to - fuel. Coppicing and charcoal manufacture were standard forms of bio-mass use throughout much of Europe for centuries. It also lost favour when the high energy intensity in fossil fuels became available by use of the steam engine.

Bio-mass is solar energy collected by photosynthesis over a small area and a few growing seasons in plants that are not compressed and not dried. Fossil fuels are solar energy collected by photosynthesis in plants over large area and many years that is in a compressed and dried form. However, the use of bio-mass circulates carbon through the carbon cycle while the use of fossil fuels returns carbon to the cycle. Hence, the use of bio-mass to displace use of fossil fuels could reduce CO_2 emissions. Any such displacement would be small because energy is consumed by harvesting and transporting the bio-mass to its point of use. There is a net loss if the farming, harvest and transport consume as much energy as the use of the bio-mass provides. This sets a limit on the area of bio-mass which can be grown for profitable use in any one place.

Other forms of bio-mass include synthetic chloroplasts with accelerated growth to improve yields and production of ethanol from plants for transport fuels. The ethanol is usually blended with petroleum and its production from sugar cane is a major industry in Brazil.

Simple calculations of the solar energy collection at the Earth's surface demonstrate that no developments of bio-mass can be economic because the net amount of energy harvested can only be small (because of the energy required to farm and harvest it is large relative to the solar energy collected). Indeed, governments would not need to subsidise bio-mass if it were an economically competitive fuel.

Bio-mass is not likely to be an economic method to avoid reintroducing carbon to the carbon cycle for centuries to come. Synthetic oil made from coal for use as fuel with (very expensive) carbon dioxide sequestration would be cheaper than bio-mass. Carbon dioxide sequestration captures carbon dioxide from combustion gases and stores it e.g. in aquifers or at ocean bottoms. And coal will continue to be available for at least the next 300 years.

14.7. Solar power

Solar energy which reaches the surface of the Earth is very diffuse. It must be collected over very large areas or large times to be useful. And it heats and lights the ground. Removal of significant amounts of solar energy from one place to use it in another would have unpleasant climatic effects (i.e. cooling) in the collection area.

Only small amounts of direct solar energy can be collected without need for another energy source to replace the collected heat and light. This limits the ability of direct solar collectors to provide usable electricity generation. For example, using direct solar energy collectors to replace a single 2 GW coal-fired power station in the UK would cover 23% of the UK with the collectors.

The Energy Review(2) advocates individual buildings having their own solar collectors mounted on their walls and roofs. This would overcome the problems of using the power at localities distant from its collection site. However, solar power is intermittent – it is not available at night – and, therefore, could not provide useful electricity to a grid supply for the same reasons that the intermittency of wind power prevents wind power form providing useful electricity.

Three basic technologies exist for direct solar collection. They are photovoltaic cells, solar boilers, and heat ponds.

Photovoltaic cells generate electricity when the sun shines and not at night. And electricity is not a commodity.

Solar boilers consist of arrays of mirrors which concentrate the heat of the sun’s rays onto a container of a fluid, usually water. The boiled fluid can then be used to power a turbine. Many experimental arrangements of these systems exist. They have high capital cost and require much maintenance. It is just possible that such a system may be profitable in very hot regions of the world which do not have indigenous fuels, but not in the UK.

Heat ponds consist of pools of water in tanks with dark coloured (usually black) bottoms inside transparent covers which prevent evaporation. The water absorbs much solar heat. In very hot regions of the world this can generate usable heat to assist power generation. In much of the US and Europe, heat ponds which cover roofs can be a useful method to increase the amount of solar heat absorbed by buildings and thus reduce other heating requirements. But the energy gain would be negligible in the UK.

The problem of low solar flux at the Earth's surface has been addressed by several proposals. They all utilise mirrors in space. The simplest systems would focus additional solar energy at solar boilers on the ground. The others focus the energy on satellites which convert it to high-energy radio waves which can be directed at receivers on the ground. All these suggested systems would have tremendous risk. Failure to sustain focus on the ground targets could provide a disaster on an unprecedented scale.

Passive solar power is the solar energy falling on us and is used all the time for heat and light. The efficient use of passive solar could be improved, especially in buildings. For example, thick walls can absorb solar heat during hot days and release it during cold nights. This is an example of efficient energy use.

Not wasting energy could make significant reductions in the demand for electricity and thus reduce CO_2 emissions from power generation. The environmental group Greenpeace estimates that nearly a quarter of Europe's electricity demand could be removed if energy were not wasted. Unfortunately, several studies indicate that improved energy efficiency reduces energy costs with the net effect that energy usage increases with resulting increase to CO_2 emissions.

14.8. Geothermal power

Winds, waves, hydro-power and fossil fuels result from energy provided to the surface of the Earth from the Sun. Geothermal energy is provided to the Earth's surface from beneath the ground.
Regions of geothermal activity provide sources of heat which can be utilised, and this is done. For example, Iceland obtains most of its energy from geothermal sources. Where it is possible, geothermal energy is very economic.

Few sites exist where additional geothermal power can be obtained and none are in the UK. This has led to some studies attempting to utilise "hot rocks", for example in Cornwall, UK. All such studies have failed (which is not surprising). Water is pumped through cracks in the rocks to extract the heat, but the cracks close under gravity. Energy has to be expended to create more cracks and the result is that more energy is used to crack rock than is available for extraction.

There is no possibility that new technologies will extend the potential for geothermal energy in the foreseeable future. In centuries to come it may be possible to utilise heat directly from the molten layers of the Earth's mantle, but no potential methods for this exist.

14.9. Nuclear power breeder reactors

Most existing fission reactor nuclear plants are not renewable energy systems. However, breeder reactors can moderate substances to generate as much fuel as they use, so they are a potential renewable energy source. The substances to be moderated are put in the reactor and this exposes them to radiations which convert them to radioactive nuclear power station fuel.

It was thought that uranium was scarce when fast breeder reactors were conceived, but uranium is now known to be more common than copper. It is probable that fission reactors will be replaced by nuclear fusion plant long before there is a shortage of uranium. Fusion plant would not use uranium; they would use hydrogen which could be extracted from water. Also, the fuel produced by breeder reactors is plutonium which is capable of misuse for nuclear weapons production. Japan continues to try to perfect a nuclear breeder reactor, but research into breeder reactors has been abandoned by other countries with nuclear power industries.

Furthermore, nuclear fission reactors provide no CO_2 emissions and the UK uses them.

14.10. Tidal power

Tidal power has not been utilised in any substantial amount. Tides move immense amounts of energy around the Earth. But the Earth is a big place, so the tidal energy flow is small at any point on the Earth. However, there is potential for large energy collection at sites of high tidal range such as the Severn Estuary.

Sensible utilisation of tidal energy requires that the energy of very large amounts of moving water must be collected. The collection consists of sampling changes in gravitational potential energy provided by the tidal rise in the level of sea surface or sampling the stream flow of water (like a wind turbine samples the stream flow of air) using a turbine. To sample the gravitational potential energy, either the raised water must be constrained so its downward flow can do mechanical work, or a heavy weight must be lifted by the raised water so its movement can do mechanical work. This requires use of very large barrages to contain the moved water or enormous floats to raise and lower the heavy weight. Both these methods have very high capital and maintenance costs but, of course, no fuel costs.

The world's largest tidal power station is at La Rance on the Brittany coast of France. It is an experimental installation and so the very, very high costs of its electricity cannot be directly compared to the costs of commercial power stations. But studies using this tidal barrage indicate the potential economics of tidal power.

It is sometimes suggested that a tidal barrage could be built across the Severn estuary. But using tidal barrages or tidal floats would be environmentally disastrous. The barrages would destroy the coastal ecologies in and near the areas of the constrained water. A float would have ecological effects on nearby shores, and the potential effects of an escape of a float from its moorings are too awful to contemplate. Importantly, such devices and tidal stream flow samplers would provide intermittent power (i.e. they would provide no power when the tide was changing) and, therefore, they would provide negligible useful electricity and would make negligible reductions to CO_2 emissions (for the same reasons that windfarms provide negligible useful electricity and make negligible reductions to CO_2 emissions).

The use of tidal coffer dams offers a solution to the problems of tidal barrages. Two concentric dams are constructed and water is allowed to flow through holes in them. The flows through these holes can be constrained to vary the energy of the flows, and turbines can extract energy from these flows. Importantly, the ability to control water flowing in and out of the inner dam allows the system to provide continuous and controllable amounts of energy at all times including when the tide is changing. Such a system would not damage coastal ecologies because it would be distant from the shore. And it could produce a large and useful amount of power if constructed at sites of high tidal flows (e.g. in the Severn estuary). However, the large coffer dams would have high construction costs and the system would have high maintenance costs because the dams would need continuous dredging (the inside of each dam would act as a settling tank). Hence, the electricity from such a system would be more expensive than is obtainable from coal-fired or nuclear power stations. This cost may be worthwhile because the controllable electricity supply from such a system would give the same benefits as pumped storage and the electricity would be cheaper than that from offshore windfarms.

14.11. Thermal gradients

In 1975 Philip Carson in the US suggested giant towers to make cheap electricity from falling air. He suggested that a hollow tube at least 1 kilometre long should be stood on its end to form a tower. Then, tonnes of sea water should be pumped up it and sprayed into its top. The water would evaporate and thus cool the air. Cold air falls, and the cooled air would fall down the tube at 60 kilometres per hour. Wind turbines mounted at the bottom of the tube could then produce a large, controllable amount of constant electricity. Some of the obtained energy would be used to pump water up to be evaporated at the top of the tower. This is not 'perpetual motion': the obtained energy is solar power provided by the different air temperatures at the top and bottom of the tube.

In theory, Carson Towers (sometimes called "energy towers") could supply all the world's electricity needs several times over. And the electricity would be very cheap, costing about a third of the cost of coal-fired electricity, for example. Laboratory studies show that they should work.

The Technion Institute in Haifa has produced detailed designs for construction of a 50 MW prototype Carson Tower which would only be 200 meters tall. But this would only demonstrate the principles. Proving the economics of the process would require construction of a Carson Tower which is at least 900 meters tall, and that would cost at least US$650 million. Nobody is yet willing to make that gamble.

Like wave power, Carson Towers cannot provide a useful source of 'renewable' energy for the UK at present and until their development is completed.

Air is not the only fluid which can have temperature gradients. It has often been observed that the oceans are much colder below the thermocline than at their surfaces. This provides potential for a significant energy flow with large capability for electricity generation. And the ocean thermal energy conversion (OTEC) device is a step towards this objective.

The Pacific Institute in Hawaii has developed technology for economic power from OTEC but most of the power is cold water for air conditioning (air conditioning is a major user of electricity in warm climates) with some electricity as a by-product. The system is only useable in locations with direct access to deep ocean (e.g. Hawaii and parts of the coast of India). The UK cannot utilise OTEC because the continental shelf is too far from the UK's shores, and electricity is mostly used for heating – not cooling – in the UK.

14.12. Conclusion from the consideration of alternatives to windfarms

The above considerations indicate that at present tidal coffer dams offer the only viable option for expanding 'renewable' energy sources for electricity supply in the UK as a method to reduce CO_2 emissions from power generation.

Wave power may also become viable in the foreseeable future but only if sufficient investment is provided for its development.

Carson Towers and fusion power may be developed in the more distant future, and in the far distant future other not-yet-developed cheap energy systems may also become available. These systems include geothermal energy from the Earth's core and the sampling of thermal gradients across the oceanic thermocline.

15. Tidal coffer dams

As explained in Section 14.10 (above), the use of tidal coffer dams offers a solution to the problems of tidal barrages with minimal environmental damage. Each dam consists of two concentric or adjacent coffer dams and water is allowed to flow through holes in them. The flows through these holes can be constrained to vary the energy of the flows such that the system is enabled to provide continuous and controllable amounts of energy at all times including when the tide is changing. Turbines extract the energy from these flows.

Tidal coffer dams would destroy the sea bottom where they were sited, could pose a hazard to shipping if not properly lit and charted, and would require careful planning if they were not to affect nearby coastal currents. Hence, they provide similar environmental damage to that of off-shore windfarms, but they would not cause the destruction of coastal environment that would result from tidal barrages.

It is not possible to accurately assess the cost of electricity supplied from tidal coffer dams because none has been built. However, they operate like a tidal barrage and, therefore, the costs of electricity generated by the tidal barrage at La Rance provides an indication (see Section 15.4 of this paper). It should be noted that a tidal coffer dam operates as a settling tank and, therefore, will have higher dredging costs than a tidal barrage but this may be negated by the economic gains from its ability to match peak demand (like pumped storage). Indeed, tidal coffer dams can be considered to be ‘pumped storage’ but with the tides providing the pumping.

15.1. Constructed tidal barrages

At present there are two large scale tidal barrages in operation in the West: a 240 MW bulb turbine at La Rance, Brittany, France and a 20 MW plant at Annapolis Royal, Nova Scotia, Canada (21).

The 240MW experimental La Rance tidal power project was commissioned in 1966. Operated by Electricité de France, it is equipped with 24 bulb-type turbine generators. The turbines measure 5.35m diameter with generators rated at 10MW. They were designed to generate energy on either the incoming or outgoing tide, to pump at periods of slack tide either into or out of the basin and to serve as orifices, passing water either into or out of the basin. The plant therefore could, and quite often did, operate as a single high-basin plant, generating energy on the outgoing tide. With the given versatility of its turbine generator equipment, the plant also operated equally well as a single low-basin plant, generating energy during the incoming tide. In addition, it operated at times as a single-basin double-effect plant, generating energy on both the incoming and outgoing tides. This experience demonstrates that all the technical requirements for tidal barrages have been proven by commercial operation over a period of decades (21).

The Annapolis Royal pilot tidal power plant (TPP) is in Canada’s Bay of Fundy on the Atlantic coast in the province of Nova Scotia. It has a rim-type turbine generator with a 7.6m diameter Straflo turbine and a generator with a 20MW capacity. This device is a modern version of the axial flow turbine with rim-type generator, patented by Leroy Harza in 1919. This single high-basin plant has been in successful operation since it was inaugurated in 1984 (21).

Other tidal power plants have been built. The Chinese have experimented with a variety of them and by the end of 1984, there were eight TPPs operating in China. Four have since closed. (22)

China’s Jiangxia experimental TPP is located in Zhejiang province, about 200km to the south of Hangzhou. It was built in the dry behind coffer dams within the left bank, and operates in double effect (i.e. it generates power when the tide is coming in and going out). The highest basin level is restricted to 1.2m and approximately 3.8 km^2 of land was reclaimed in the basin above El. The inter-tidal zone of the basin has an area of 1.2km^2. The basin area at lowest low water is 0.8km^2. The first 500kW bulb power unit was commissioned in May 1980, with the second, a 600kW unit, in June 1984. Five units were operating by the end of 1985. The third, fourth and fifth units each had a rated capacity of 700kW, and the installed capacity with five units totals 3.2MW. The plant is still in operation, producing 6GWh of energy per year. Its sluice structure was originally built as part of a land reclamation project and has five openings which are controlled by reinforced concrete gates each 4.2m high by 3.3m wide. These features demonstrate the long-term feasibility of flow control that would be needed for tidal coffer dams. (22)

The Haishan TPP on Maoyan Island in Zhejiang province is noteworthy because it is the only linked-basins plant in the world. It has a high and a low basin with the power plant in between these two basins, generating energy from water flowing from the high into the low-basin. Hence, its electricity generation can be controlled in the manner required to provide a continuous output from a tidal coffer dam. It provides power to an isolated community of 760 families and was designed for two 75kW units of which only one was installed and commissioned in 1975. This unit operated continuously and the electricity was used partly to pump fresh water into the community reservoir for domestic and irrigation use. The plant has since been upgraded to an installed capacity of 0.25MW, producing 0.34GWh per year. (21)

The most recent Chinese TPP began operating in Daishan County, Zhejiang province, on 6 January 2006. This 40 kW tidal power station was developed by Harbin Engineering University assisted by Daishan Technology Bureau (22).

Also, since the 1930s, Russia has constructed several experimental TPPs (23).

A small 400 kW pilot plant was built at Kislogubsk near Murmansk and commissioned in 1968 and its success led to several design studies for much larger tidal plants at sites in the north and east of Russia. These included Lumbov (67 MW) and Mezen Bay (15 000 MW) in the White Sea, and Penzhinsk Bay (87 400 MW) and Tugur Bay (6 800 MW) in the Sea of Okhotsk. Eventually, the Tugur station emerged as the only feasible major scheme and this illustrates the care needed when planning a tidal power project (24).

A pre-feasibility study of the Tugur tidal power station in the Khabarovsk Region assessed its capacity at 6,800 MW with a generation volume of 16,200 million kWh. However, it seems that there is not likely to be demand for these projects in the Russian Far East until at least 2020 because of economic conditions in the Russian Federation. Also, it seems that their development will require cooperation with neighbouring countries interested in importing power from Russia (23).

15.2. 300MW tidal energy project in China

In late 2004 the Chinese Government endorsed a 300 MW project for a tidal lagoon to be built by the U.S. company Tidal Electric (22). A tidal lagoon has one dam so operates as a tidal barrage. Tidal Electric's offshore tidal lagoon is to be in the waters near the mouth of the Yalu River. At 300 MW, this project will be the largest tidal power project in the world, topping the capacity of the 240 MW French tidal power plant in La Rance.

15.3. Projected sites for tidal energy projects in the UK and elsewhere

Tidal Electric, a U.S. company, has proposed two offshore tidal lagoons for Wales. The smaller initial project is for Swansea Bay. The 60 MW plant would have an area of 5km^2 and would be about a mile offshore. A feasibility study conducted by WS Atkins finds that the project is technically feasible, environmentally plausible, and economically viable. The larger project would depend on the success of the project at Swansea, and it would be built at Rhyl.

It would have a generating capacity of 400MW. To provide more nearly continuous output, the reservoir of the Rhyl scheme would be subdivided into segments with each being filled and emptied in turn and thus it would operate as a tidal coffer dam. The reservoirs would be constructed from rocks (30 million tonnes for the Rhyl system), like a causeway, so would be cheaper than a conventional dam or tidal barrage. This tidal lagoon would be nine miles long and two miles wide, and it would be the largest single renewable energy project in the UK - the Rhyl scheme. Hence, **the proposed project at Rhyl is for a 400 MW tidal coffer dam in the UK**.

Several other tidal energy projects have been suggested as being feasible in the UK and elsewhere. Some of these are listed in Table 3.

Prospective Sites for Tidal Energy Projects

Country	**Region**	**Mean tidal range (m)**	**Basin area (km^2)**	**Installed capacity (MW)**	**Approximate annual output (TWh/year)**	**Annual plant load factor (%)**
UK	Severn	7.0	520	8 640	17.0	23
	Mersey	6.5	61	700	1.4	23
	Duddon	5.6	20	100	0.212	22
	Wyre	6.0	5.8	64	0.131	24
	Conwy	5.2	5.5	33	0.060	21
Argentina	San José	5.8	778	5 040	9.4	21
	Golfo Nuevo	3.7	2 376	6 570	16.8	29
	Rio Deseado	3.6	73	180	0.45	28
	Santa Cruz	7.5	222	2 420	6.1	29
	Rio Gallegos	7.5	177	1 900	4.8	29
Australia	Secure Bay	7.0	140	1 480	2.9	22
	Walcott Inlet	7.0	260	2 800	5.4	22
Canada	Cobequid	12.4	240	5 338	14.0	30
	Cumberland	10.9	90	1 400	3.4	28
	Shepody	10.0	115	1 800	4.8	30
India	Gulf of Kutch	5.0	170	900	1.6	22
	Gulf of Khambat	7.0	1 970	7 000	15.0	24
Korea (Rep.)	Garolim	4.7	100	400	0.836	24
	Cheonsu	4.5			1.2	
Mexico	Rio Colorado	6-7			5.4	
USA	Pasamaquoddy	5.5				
	Knik Arm	7.5		2 900	7.4	29
	Turnagain Arm	7.5		6 500	16.6	29
Russian Fed.	Mezen	6.7	2 640	15 000	45	34
	Tugur *	6.8	1 080	7 800	16.2	24
	Penzhinsk	11.4	20 530	87 400	190	25

Table 3. Some potential Tidal Power Projects (24)

All the proposals in Table 3 are for tidal lagoons or barrages and this is reflected in their low load factors.

15.4. The economics of tidal power (25)

OFGEN (the Office of Gas and Electricity Markets) developed and used a financial model to estimate the trajectory of unit costs (progress curve) in the period from 2005 to 2020 for wind power, wave power, tidal lagoons, and tidal streams (25). Their estimates for each technology were in terms of the premium required (in £/MWh) over the cost of new CCGT power to enable each technology to earn required return on capital.

According to these OFGEN estimates the required premiums are:

• wind power	41 £/MWh
• off-shore wind power	62 £/MWh
• wave power	187 £/MWh
• tidal lagoons	60 £/MWh
• tidal streams	187 £/MWh

OFGEN's paper does not make clear how their model calculated the costs of wave power and tidal streams when there are several different wave power systems but none has been perfected and no tidal stream TPP has been built. And the fact that they estimate the premiums required by wave power and tidal streams to both be 187 £/MWh suggests some doubt.

However, OFGEN's estimates suggest that tidal lagoons would have similar, possibly lower, cost than off-shore wind power. Electricity from tidal coffer dams would have similar cost to that from tidal lagoons but would obtain the relatively high return from their controllable output. Indeed, they could gain the same high return as the output from pumped storage, and OFGEN did not include this consideration in their analysis.

This paper has explained that the intermittency of windfarms means they provide no useful electricity and no significant reduction to CO_2 emissions. But tidal coffer dams do not suffer from these problems. And the government is subsidising off-shore windfarms. Clearly, the subsidies would be better spent on tidal coffer dams.

16. Conclusions

The UK Government is spending much public money to subsidise on-shore and off-shore windfarms in an attempt to contribute to its target of a 20% reduction to CO_2 emissions from power generation. This policy is endorsed by the Energy White Paper 2003(1) and the Energy Review 2006(2). However, the intermittent supply from windfarms means they provide no useful electricity and no significant reduction to CO_2 emissions. But tidal coffer dams can provide continuous, controllable electricity so they do not suffer from these problems. And OFGEN estimates that tidal coffer dams would produce electricity at similar cost to off-shore windfarms when taking no account of the high return that can be expected for the controllable output from tidal coffer dams.

It is concluded that the UK Government should cease the waste of public money that is the subsidising of windfarms and use the saved expenditure to subsidise tidal coffer dams instead.

References

1. UK Government Department of Trade and Industry, Energy White Paper, May 2003

2. UK Government Department of Trade and Industry, Energy Review, 11 July 2006 http://www.dti.gov.uk/energy/review/

3. Hills, Richard L. 'Power From the Wind: A History of Windmill Technology' London: Cambridge University Press, 1994

4. Naar, Jon. 'The New Wind Power' New York: Penguin Books, 1982

5. Hamer M. 'The New Age of Sail' New Scientist, 25 February 2005

6. Hau, E., J. Langenbrinck, and W. Palz. 'Large Wind Turbines' Berlin: Springer-Verlag, 1993

7. Justus, C. G. 'Winds and Wind System Performance' Philadelphia: The Franklin Institute Press, 1978

8. http://www.vestas.com/uk/Home/index.asp

9. Cheremisinoff, Nicholas P. 'Fundamentals of Wind Energy' Ann Arbor: Ann Arbor Science Publishers, Inc. 1978

10. Calvert, N. G. 'Windpower Principles: Their application on the small scale' London: Charles Griffin and Co., Ltd., 1979

11. Gipe, Paul. 'Wind Energy Comes of Age' New York: John Wiley and Sons, Inc. 1995

12. Ruffles P. ed. 'The Costs of Generating Electricity', Royal Academy of Engineering, 2004

13. Thelander C G, Smallwood K S, & Rugge, L. 'Bird Risk Behaviors and Fatalities at the Altamont Pass Wind Resource Area - March 1998-December 2000' National Renewable Energy Laboratory Report SR-500-33829, December 2003

14. Royal Geographical Society Conference Session on 'Urban Sustainability: Rethinking Senses of Place' RGS-IBG Annual Conference 2005, RGS Proceedings, London, September 2005

15. Worley Parsons http://www.worley.com.au/v5/page.aspx?id=166

16. Flynn P & Kumar A, 'Site visit to Alholmens 240 MW power plant, Pietarsaari, Finland' University of Alberta, September 2005

17. Laughton, M.A., Renewables and the UK Electricity Grid Supply Infrastructure, Platts *Power in Europe*. 2002

18. Tolley D, 'NETA -- The Consequence,' keynote address, to the Institution of Mechanical Engineers, January 15, 2003

19. Siegfried Heier, 'Grid Integration of Wind Energy Conversion Systems,' John Wiley & Sons Ltd, ISBN 0-471-97143-X, 1998

20. Taylor, R. H. ‘Alternative Energy Sources for the Centralized Generation of Electricity’ Bristol, England: Adam Hilger, Ltd., 1983

21. Wilmington Media, International Water Power and Dam Construction. 2004, “Barriers against Tidal Power” (Online) http://www.waterpowermagazine.com/story.asp?storyCode=2022354

22. Power Engineering International. 2006, “China Operated Tidal Power Project” (Online) http://pepei.pennnet.com/Articles/Article_Display.cfm?Section=ARTCL&Category=PRODJ&PUBLICATION_ID=6&ARTICLE_ID=244908

23. Minakov. V, 2005, “Transmission Line Project Linking the Russian Far East with the DPRK (Chongjin)” (Online) http://www.nautilus.org/aesnet/Minakov_Niigata_2004_Peport.pdf

24. World Energy Council. 2001, “2001 Survey of Energy Resources – Tidal Energy” (Online) http://www.worldenergy.org/wec-geis/publications/reports/ser/tide/tide.asp

25. Office of Gas and Electricity Markets (OFGEN), ‘Assessment of the Benefits from Large-Scale Deployment of Certain Renewable Technologies’, Cambridge Economic Policy Associates, April 2005

About Richard S Courtney

Richard S Courtney is a Member of the European Science and Environment Forum (ESEF) and acts as a technical advisor to several UK MPs and mostly-UK MEPs. He is Chairman of the Southern Region of a Trade Union (BACM-TEAM) affiliated to the UK’s Trades Union Congress. He was the Vice-President of BACM-TEAM from 1995 until May 2000, and he was also a Member of the Executive of the Federation of European Energy Industry Executives throughout that time. Having been the contributing Technical Editor of CoalTrans International, he is now on the Editorial Board of Energy & Environment. His present work mostly consists of providing commissioned advice to national governments, although he has recently conducted research studies of energy interactions at sea surface.

Richard is a respected authority on energy issues, especially clean coal technology. He has been the Senior Materials Scientist of the UK’s Coal Research Establishment, has served as a Technical Advisor to the European Coal and Steel Community (ECSC), possesses several patents, and has published papers in many journals including Nature, Microscopy and Filtration. He is the author of the chapter on coal in Kempes Engineers Yearbook.

His scientific achievements have obtained much recognition. The British Association for the Advancement of Science appointed him as a Member of the Association of British Science Writers in recognition of his “clear presentation of scientific information to politicians”. The UK’s Royal Society for Arts and Commerce appointed him as a Life Fellow in recognition of his “services to British industry”.

PZZK (the management association of Poland’s mining industry) gave him an award in recognition of his “services to Europe’s industry”. He has broadcast on radio and TV around the world in response to requests from several media companies, notably the BBC, and he lectures around Europe.

His knowledge of energy and environment issues is widely respected. He has been called as an expert witness by the UK Parliament’s House of Commons Select Committee on Energy and also House of Lords Select Committee on the Environment. UNESCO commissioned a paper from him on Coal Liquefaction. An Expert Peer Reviewer for the UN Intergovernmental

Panel on Climate Change (IPCC), in November 1997 he chaired the Plenary Session of the Climate Conference in Bonn at the joint request of the European Academy of Science, the Science and Environment Project (USA), and the Europaische Akedemie fur Umweltfragen e.v. (Germany). In June 2000 he was one of 15 scientists invited from around the world to give a briefing on climate change at the US Congress in Washington DC, and he then chaired one of the three briefing sessions.

Richard is also an Accredited Methodist Preacher. He is a founding Member of the Christ and the Cosmos Initiative that explores the interactions of religious and scientific ideas. The Initiative started in the UK but became active in 28 countries.

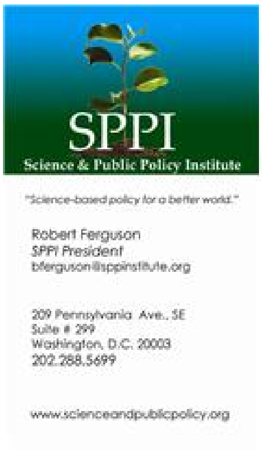
Richard avoids confusion about him in his scientific and religious activities by rarely citing his academic achievements, but his material science qualifications include a DipPhil (Cambridge), a BA (Open) and a Diploma (Bath). He may be contacted at:

Address: 88 Longfield
Falmouth
Cornwall
TR11 4SL
United Kingdom

Tel.Fax.: +44 (0) 1326 211849
Mobile (UK): 07720 759268
Email: RichardSCourtneyATaol.com

Cover credit:

Kilchurn Castle in picturesque Argyll, Western Scotland, a wild and beautiful region now being marred by windfarms - Pastel painting by Jenny Keal, an artist based in mid Wales.



SPPI
Science & Public Policy Institute

"Science-based policy for a better world."

Robert Ferguson
SPPI President
bferguson@sppinstitute.org

209 Pennsylvania Ave., SE
Suite # 299
Washington, D.C. 20003
202.288.5699

www.scienceandpublicpolicy.org

www.scienceandpublicpolicy.org
[202] 288-5699