THE SCIENCE, TECHNOLOGY AND EXPLOITATION OF WIND ENERGY

I Historical

Man first harnessed wind energy through the sails of boats at some remote period of prehistory. By pre-Dynastic times in Egypt, about 5,500 years ago, relatively advanced cloth sails were depicted. The windmill came a lot later, initially copying the design of its much older cousin, the watermill. The Persian inventors must have been surprised how little power a windmill gave, compared with its progenitor, which is driven by the great weight of falling water, a thousand times denser than air.

Windmill builders quickly adopted the technology of sails - still to be seen in Cretan mills. In western Europe, it was not long before the wood-framed sweep, with canvas sail, became the norm - initially a flat blade inclined at about 20^{o} to the oncoming wind. John Smeaton, the lighthouse builder, improved the efficiency of mill sweeps by incorporating a twist in the blade, which corrected for the different orbital velocities from root to tip of the sweep.

The scene was thus set for the arrival of the airscrew and, indeed, Leonardo da Vinci, who sketched a ‘helicopter’ in the 15th century, had foreseen it. No one knows if a model of the Leonardo’s design was ever built, but children’s flying toys with a bird-feathered rotor date from about that period.

The electrical generator was perfected in the second half of the 19^{th} century and it was not long before inventive curiosity combined the airscrew and the dynamo into the forebear of our modern wind turbine electricity generator.

II The wind turbine

Design. A commercial wind turbine comprises a tower, usually of tubular steel sections, but also sometimes of concrete, steel lattice or cantilevered construction. Set on the head of the tower is a nacelle - the compartment that houses a gearbox, clutch, brake and generator with a near-vertical airfoil rotor mounted on the main shaft projecting from the face of the nacelle (See Appendix 2). The rotor is commonly a three-bladed structure but two or four-bladed turbines are also built. The airfoil rotor is identical in appearance to a gigantic aircraft propeller and indeed the technology of this part of the system is directly a product of aeronautical engineering. The blades are commonly of glass-fibre-reinforced plastic (GRP) or other strong lightweight material such as wood-laminate. The nacelle may be rotated (yawed) on the top of the tower to direct the rotor into the wind as required.

Smaller wind turbines have simple, fixed-pitch rotor blades of which the aerodynamic design is such that they can be kept at constant speed by varying the mechanical load imposed by the generator. Larger and more recent turbines have variable pitch blades (pitch is altered by rotating the blade or part of it around its radial axis) that can be adjusted for maximum power, stalled to reduce torque in high winds or feathered to take no power from the wind.

The tower height is usually 1.0 to 1.5 times the diameter of the rotor. As a 2.0 MW turbine may have a rotor c. 80 m (262 ft) in diameter it is not uncommon for the whole machine to exceed 120 m (almost 400 ft). Visual obtrusiveness is consequently a serious cause of concern.

The hole excavated for a turbine's foundation has a volume of 6,750 to 27,000 cubic feet (191-765m^3) depending on site conditions. It has to provide stability against the loading caused by maximum predicted wind speeds (in which the turbine will be shut down) and also by wind loading and vibration when the turbine is operating. Further substantial site-works such as access roads add to concerns about the 'concreting' of landscape, impact on future development by incidental provision of access, consequences of excavation and extensive overhead cabling. Once installed concrete foundation blocks and much site infrastructure are unlikely ever to be removed on grounds of cost. If acid groundwaters are of very low ionic concentration, leaching of calcium from concrete may be ecologically harmful where affected watercourses drain into sensitive areas.

Operating characteristics. The generator of most wind turbines produces alternating current (AC) at a relatively low voltage which is matched to the local grid network through a transformer station, and is synchronised to the grid-frequency of 50 Hz (cycles per second) by combinations of turbine speed regulation and electronic power converters. Some modern wind turbines are variable speed, rather than fixed speed machines, and the output from the generator then has to be frequency-matched by electronic means.

The cross-country transmission lines of the National Grid operate at 400 kV or 275 kV. Wind turbines, however are connected to a lower-voltage part of the distribution network as 'embedded' generation. Even a station as large as the Cefn Croes wind 'farm' is planned to have a 132 kV line to a substation near Llywernog. For comparison, domestic electricity is supplied at 240 volts, 50 Hz. In open countryside such links pose their own set of environmental problems with transmission towers and overhead cabling, sometimes necessitating clearance of woodland.

Wind generators do not yield their full electricity output all of the time. Sometimes, there is no significant wind and occasionally the wind speed is too high to allow operation (over c. 50 mph or 22 metres per second [m/s]). Much more frequently the wind speed is between the generating cut-in speed of c. 10 mph (4.4 m/s) but less than the optimal generating speed of c. 30 mph (13 m/s).

The average electrical output is calculated by multiplying its ***Installed Capacity*** by a ***Load Factor*** (***Capacity Factor***) of c. 30% for onshore turbines and c. 40% for offshore machines.

As noted previously, the target for installed capacity of electricity generation from renewables is 10% by 2010, growing to 20% in 2020 This second target was abandoned in the Government's Energy White Paper (February 2003), and simply expressed as an 'aspiration'.

The Institution of Electrical Engineers (IEE) response to the *Energy Review* (PIU, 2002) makes the assumption that some 10,000 wind turbines, rated at 2.0 MW would be necessary to meet the 2020 'target'. These would have an installed capacity of 20,000 MW but a realised generation of only 6,000 to 7,000 MW.

By early 2003 the UK had 1000 wind turbines, but most of these are very small by modern standards, with an average installed capacity of c. 0.5 MW per machine and total maximum generation near 500-600 MW.

III Where our electricity comes from

In 2001, 70% of UK electricity was generated from coal and natural gas (DTI, 2002), with just 1% from oil. These are the 'fossil-fuels': carbon or hydrocarbon compounds which emit carbon dioxide to the atmosphere when they burn ($C + O_2 = CO_2$). The remainder of our power is nuclear-generated (22%) and does not produce CO_2 emissions.

The ***renewable*** sources make a tiny contribution, with hydroelectricity at 1% and wind power 0.25% of actual generation (DTI 2002). Despite hopes for the future, tidal and wave energy and solar photovoltaic electricity produce too little to be counted. These are the technologies, which are being so actively promoted and enormously subsidised at the moment because they do not produce any CO_2 emissions.

The small remaining percentage comes about equally from imports (3% from France - substantially nuclear-generated) and from waste-combustion and landfill-gas, plus biomass-combustion (2.5%). The last two are 'carbon-neutral' technologies, not true renewables, because they re-release CO_2 to the atmosphere with a cycle-time of one year, (for crop biomass), to several years (e.g. willow coppice). Much waste-combustion involves materials derived from fossil hydrocarbons and is not truly renewable energy, despite DTI classification as such.

IV. Why windpower?

The question is really: - 'Why renewables?' Two main reasons are given:

1. We shall run out of fossil fuel.

This is inevitably true, but the time scale is very long, in political terms. Centuries at least, given the unexplored oil fields and untouched oil shales of the world. The period may extend to millennia if we tap the vast reserves of ocean-bottom methane hydrates. There is certainly time for the world to switch to solar photovoltaic electricity, facilitating a non-emitting hydrogen economy (see Hoffman, P., 2001) The development of 'total solar' is the inevitable and only option to nuclear energy, and much of our current fiddling with minor renewables is wasting resources and time.

2. CO_2 emissions cause 'global warming'.

Carbon dioxide is a 'greenhouse gas' - it permits the energy of short wave solar radiation to pass down through the atmosphere but longer wave (thermal) infra-red radiation that carries energy back out of the atmosphere is strongly absorbed by CO_2, effectively 'blanketing in' extra heat if atmospheric CO_2 concentration rises - the 'greenhouse effect'.

The first justification need not be pursued at present because of the very long time scale. The second raises the question: can we avoid future problems if the world and the UK reduce CO_2 emission by a renewable energy programme and other measures? There is considerable scientific dissent concerning this issue, but most governments have accepted that there is a long-term problem. As a result, the Kyoto Treaty of 1997 committed many countries to reducing 'greenhouse' emissions. Britain agreed to a 12.5% cut in its CO_2 emissions by 2010 and has voluntarily agreed a further target reduction of 20%.

It is likely that most of the renewable energy will be wind power, because most UK hydroelectric sources are already exploited, biomass is unlikely to provide sufficient energy and tidal/wave technology will not come on line in time to be useful.

V. Will saving CO2 emission make any difference and is it feasible?

It is interesting to read the Introduction to the Welsh Assembly's consultation draft of *Review of Energy Policy* I. *Renewable Energy* (WAG 2002). The Co-Chairman of IPCC's Scientific Working Group, Sir John Houghton, wrote in Section 1.4 that even an immediate total cessation of CO_2 emission would make no difference to temperature and sea level rise for 50 to 100 years.

Total and immediate cessation is impossible. Houghton's statement embraces all CO_2 from electricity generation, industry, heating, cooking and the rather large temporary contribution from forest-clearance in some parts of the world. Reality says that none of these things can be done - even on the longest of time scales.

So, even if Houghton's faith in the IPCC models is well placed (and there is considerable scientific dissent), a small reduction in CO_2 emission is patently not likely to have any measurable effect, perhaps for several lifetimes.

This information is discomfiting to Government and, to its shame, the Assembly EDC removed all mention of this section from the Final Report *Renewable Energy* (WAG 2003).

As noted previously, the target for installed electricity generation from renewables is 10% by 2010. Ten percent of installed capacity would be some 10,000 MW and give a realised generation of 3,000 to 3,500 MW. It is this average electrical output which will govern any saving of CO_2 emission by the UK windpower installation.

The 2010 target will provide a maximum saving of at most 3,500 MW-worth of CO_2 emission and this is about 8% of the UK's average generation. Electricity generation in 2001 was responsible for only 29% of UK total CO_2-emission so, at face value the 2020 'aspiration' for windpower would give an overall reduction of only c. 2% of all UK CO_2 emission.

Other emission sources are industrial combustion 24%, transport 22% and domestic, commercial and public service sources 32% (DTI 2002). Air transport represents about a fifth of the transport emission at the moment, but RCEP (2003) warned the Minister of Transport that it would increase fourfold by 2050.

Proponents of windpower claim it saves more than the average CO_2 emission rate because coal fired generation is ramped-down first, when windpower is available, and coal is much 'dirtier' than gas-fired CCGT (Combined Cycle Gas Turbine) in CO_2 emission. However there is strong evidence that choice of fuel for ramping-down is entirely governed by NETA (Appendix I below) which has actually increased CO_2 emission, by favouring cheap coal, since its introduction.

VI. Security of supply and backup and cost of electricity

Most genuinely renewable electricity generation, apart from hydro-electricity, poses a serious problem of **intermittency.** Tides turn, winds rise and fall and with them, exploitable wave-power.

Our 21st century life-style demands 24-hour uninterrupted electricity supply. As the amount of wind power embedded in local networks increases so will the problem of maintaining voltage and frequency within legally required limits. The first equipment to suffer will be modern computers. Without a constant electricity supply, hospital patients die, central heating systems cease to pump, fridges and freezers thaw, banking systems go down, and even such minor things as lost TV, all cause a public outcry.

There is no option. Wind must be provided with an infallible backup, and it must be available, often within minutes. Only fossil fuel systems provide this degree of flexibility and even they cannot start from cold without many hours' delay.

The consequence is that backup must be provided by a **spinning reserve** (spare capacity). This is analogous to a car being driven below its top speed but having some acceleration left for emergency manoeuvres. Some generators are run below peak output to provide instant 'acceleration' when an existing generator fails. Unfortunately fossil-fuelled turbo-generators are less efficient below maximum generation and so emit more CO_2 per unit of generation in this mode.

The fossil and nuclear-fuelled Grid incorporates about 23% spinning reserve, which insures against major loss of generating capacity or failure of transmission lines (accidents or terrorist sabotage). At present, wind generation is allowed to 'steal' from this spare capacity. Because wind provides only 0.25% of UK electricity, even total failure would leave over 22% cover for emergencies! However the utilisation of the existing spare capacity even now incurs an energy and carbon-emission cost, which is ignored by the wind industry.

However, as the renewable contribution increases, it becomes progressively more dangerous to 'steal' from the reserve. All major engineering bodies that responded to the *Energy Review* (PIU 2002) have highlighted the need for **dedicated spinning-reserve** and suggest that it needs to equal (or nearly equal) the full installed generating capacity of the windpower and other renewables which it covers (IEE; RAE & IChemE, 2002).

Comparative cost of windpower. At the moment, without provision of dedicated spare, **windpower costs £28.80/MWh** (Renewable 2002) which is almost twice the wholesale price of fossil-fuel electricity **(£16/MWh**). WAG (2003) makes the assumption that the baseline price paid for wind will be negotiated down to **£20/MWh**. It seems unlikely that 90-100% backup could be provided in future without at least doubling this figure for wind, making it remarkably expensive.

'Subsidy'. The cost to the consumer is also loaded by the 'subsidies' of the **Renewables Obligation** and **Climate Change Levy Exemption** (See Appendix I below), which add **£34.30/MWh**. The windpower generator is thus guaranteed a price of up to **£54.3/MWh -**

three times the normal wholesale price! It is a matter of concern that WAG (2002), the consultation draft of *Renewable Energy*, described these payments as a 'subsidy' but the final report was amended to read 'there are no direct subsidies'!

These wholesale prices equate to 1.6 pence/Unit for the cheapest fossil fuel electricity. Domestic consumers currently pay 7.54p/Unit daytime rate and 2.84p/Unit for Economy 7. Thus, the cheapest domestic electricity is about half the price paid for wind which is 5.4p per unit!

CO_2 saving much less than promised. The obvious inference is that the need for inefficient spinning backup will negate much or all of the CO_2 saving. The IChemE, (2002) response to the DTI spells this out by saying that 'fossil fuel has to be wasted and CO_2 discharged to atmosphere in order to accommodate wind generation into the system. Thus, the notional CO_2 reduction benefit of wind is dissipated to around 50% of the theoretical saving according to a review of the Danish experience.'

A recent study from the Oxford University Environmental Change Institute shows that with the present policy, 0.93 units will have to be on spinning reserve (OUECI, 2003). It is hard to believe that even 50% of the CO_2 saving could be achieved if this is so.

VII Landscape and visual perception

Landscape impact is the crux of the wind turbine problem and though it is largely outside the scope of technical assessment has been the major factor in the rejection of many planning applications. The reasons for such rejections have usually been the inappropriateness of tall, moving industrial structures in rural environments. However, such judgement is a matter of aesthetics, and from the proponents of windpower we have contrary assertions that wind turbines improve boring landscape and even that they re-create the landscape of windmills, which once characterised Britain! The latter comparison is instantly refutable in terms of size, siting and sheer numbers. The former is irrelevant within the planning process. No other structure, however beautiful would be allowed in sites where wind turbines have been built.

The problems of reflective flicker and shadow flicker are more open to analysis. In some conditions, reflective flicker or interruption flicker makes wind turbines remarkably obtrusive. Our primeval inheritance of the 'need to know' that something is moving in the landscape irritatingly draws the eye. It is difficult to coat turbine blades to eliminate the reflections without aerodynamic-roughness reducing power. In low sunlight, the cast shadows may pose an even more serious problem of visual perception if they are cast on residences or roads (if flicker deserves warning on TV, what of landscape and traffic?).

VIII Further objections

The landscape-impact of wind turbines is enormous, compared with the benefit of their insignificant electricity generation. This and the fact that promised savings of CO_2 emission cannot be achieved, is irrefutable, and very serious. Other harmful effects seem lesser by comparison though each has aroused passionate feelings amongst opposition groups.

Birds. The RSPB has steadfastly maintained there is no significant impact on bird populations in the UK, but experience in California and Spain and the Low countries casts some doubt on this, particularly re-analyses of surveys in Spain. It is repeatedly claimed that modern, large turbines turn slowly and hence pose a lessened hazard. However, a Vestas V-80 rotor tip has a velocity of c. 300 kph. Not much time to duck when the swept area is the size of half a football field! It is not yet possible to comment on the impact on bird populations, and further independent research in the UK is urgently needed. (See RSPB chapter). Onshore, data-collection is difficult because scavengers remove dead birds, and offshore, of course, they fall in water.

Sound. Wind turbines produce aerodynamic noise (the 'swoosh' of the blades), regular low frequency sound, in particular the almost inaudible 'thump' of blades entering the wind-shadow of the tower, and gearbox/generator sound. Modern design has substantially reduced mechanical sound but aerodynamic noise is intractable. For those who live near wind 'farms', noise has been a matter of serious concern and ill-health, and in extreme cases has caused individuals to sell property so affected.

TV interference. Television signals may be interfered with by 'shadowing' or by reflective interference. Windpower companies have often responded that tuning to a different aerial will solve the problem, but those who live in hill country rarely have more than a single satisfactory option. Building of relay transmitters can solve the problem but is a further intrusion into open country.

Dangers - shedding of blades and ice, turbine collapse, aircraft and shipping. Early wind turbines often suffered mechanical failure. This is less common now, but it does happen and blades and other components have been thrown hundreds of metres. In certain conditions, blades can ice-up, not only interfering with generation but also causing the throwing of large ice blocks. A few examples of turbine collapse are on record following failure of foundations or tower under wind-loading. Because of the siting of turbines it is rare for these problems to pose a serious public hazard – the hill-walker probably has a greater chance of an accidentally broken ankle! However, the perception of danger is probably already preventing recreational use of some land adjacent to wind turbines as will demands for fencing and other precautionary measures.

There are undoubted hazards to aircraft and many proposals have been opposed by the MOD on such grounds. Surprisingly, because of its situation and frequent low flying in the area, the MOD did not object to the Cefn Croes application (see MOD chapter). Offshore turbines also pose shipping hazards and will need warning lighting and paint, which will increase their landscape obtrusiveness (e.g. current Scarweather proposal off Porthcawl, Vale of Glamorgan). [Editor's note – this has now been 'called in' for a public inquiry].

IX The meeting of politics and technology

Central government made a commitment to Kyoto for a 12.5% reduction in CO_2 emissions and voluntarily stepped this to 20% by 2010 (see Section IV above). This has happened despite the refusal of the USA and other high-emission countries to sign the treaty.

Within this framework the DTI's Policy and Innovation Unit has produced a consultation document *The Energy Review* (PIU 2002) and Energy White Paper (DTI 2003), and WAG has published A *Review of Energy Policy in Wales - Renewable Energy* (WAG 2003), after a public consultation.

Amongst the corporate responses to PIU (2002) were those of the Institution of Chemical Engineers (IChemE 2002), Institution of Electrical Engineers (IEE 2002) and Royal Academy of Engineering (RAE 2002).

These three institutional responses warned in unequivocal terms that dedicated spinning spare reserve would have to be provided, once wind power reach significant levels in the market. All pointed out that it would be expensive and maybe unaffordable. The IChemE (2002) response went further, and questioned the saving of $CO_{2,}$ which might be achieved. Much of the saving, perhaps more than 50%, would be negated by the emissions of the reserve.

X Wales and Ceredigion

Annual average power generation in Wales is some 3,800 MW, based on an installed generating capacity of c. 4,500 MW coal/gas fired and c. 1,000 MW nuclear.

Main power stations are Aberthaw, Vale of Glamorgan (coal 1400 MW); Connah's Quay, Flint. (CCGT 1,400 MW); and Wylfa Head, Anglesey (Magnox nuclear 950 MW) together with the pump-storage backup stations at Dinorwig and Ffestiniog both in Gwynedd.

Annual electricity consumption in Wales is slightly more than half of generation, so our country is **<u>already a net exporter of electricity</u>**.

Ceredigion has no conventional fossil-fuel generators but the largest **hydroelectric** plant in Wales is at Cwm Rheidol (56 MW installed capacity). In 2000 the station averaged a generation of 14.8 MW (equivalent to 6.3 hours a day), essentially limited by water availability but in some years greater generation would be possible. Powergen claims that this would supply the needs of 40,000 homes (there are 34,000 in Ceredigion)*
*It should be noted that there are about 1,250,000 homes in Wales. Ceredigion is very sparsely populated.

There are also three **wind power stations** in Ceredigion: Banc Bwa Drain, Rheidol (8 turbines 2.4 MW Installed Capacity IC)); Mynydd Gorddu (19 turbines 10.2 MW IC) and Llangwyryfon (20 turbines 6 MW IC).

Banc Bwa Drain produced at a 28% capacity factor in 2000, yielding an average of 0.67 MW (Powergen website). Similarly, the other two stations would have yielded a total average generation of 4.9 MW so the total average wind energy yield in Ceredigion would be about 5.6 MW, supplying about 15,000 homes.

Shortly to be constructed is Cefn Croes, which will have 39 turbines of 1.5 MW each, a total installed capacity of 58.5 MW and, at 30% capacity factor, a maximum average generation of 17.6 MW and supplying another 47,000 homes.

Thus it is apparent that Wales is over-supplied with conventional generation by a factor of almost two and **Ceredigion has renewable generation for over 50,000 homes - 1.5 times its entire need.** However, because of the intermittency of generation, there will be substantial export in windy weather and import when it is calm. The county thus depends on the backup of the grid to sustain this intermittency and so, despite the over-production, it is not self-sufficient.

Targets have been discussed above, in sections **II**, **IV** and **V.** The overall UK commitment is for a 10% of electricity generation from renewables by 2010 rising to an 'aspiration' of 20% by 2020 (DTI, 2003). Electricity generation produces just under a third of UK CO_2 emissions but takes the highest profile role in the strategy for reducing emissions.

In Wales, a target of 4 TWh per year of renewable electricity generation for 2010 has been set by WAG (2003). Realistically, the majority of this will be provided by onshore and offshore windpower.

This figure of 4 TWh is based on just over 10% of predicted Welsh electricity **production** in 2010 and will represent about 21% of Welsh **consumption** (WAG 2003). In other words the overproduction of electricity by Wales, noted above, will be continued in the deployment of wind generators.

Both the Government Energy White Paper (DTI, 2003) and the Assembly's *Renewable Energy* report WAG (2003), acknowledge that there will be a problem in obtaining the necessary planning consents and stress the need for 'streamlining' the planning process. WAG (2003) also recommends an 'extension of powers' regarding electrical generation. This is worrying in the light of the concern that Cefn Croes was permitted in the face of substantial opposition.

Government's targets will be enforced by the Renewables Obligation (RO), which compels the electricity supplier to purchase a proportion of renewable generation - 3% at the moment rising to 8% in 2010. (Ref. WAG 2003), although 10% is widely stated. To the effect of this is added the Climate Change Levy (CCL), exemption from which gives a further inducement to use renewable electricity. The charges made under the RO and CCL are used to 'subsidise' the price paid for wind electricity to about three times normal wholesale price of conventional generation.

Appendix I : Abbreviations and units

Capacity expresses the maximum amount of power, which can be produced by an electrical generator. Large turbo-generators in fossil-fuel power stations typically have a capacity of c. 500 MW. Big wind turbine generators are rated at 2.0 MW (now being installed onshore) and up to 4.0 MW (offshore). These ratings are referred to as the **Installed Capacity**, which has to be multiplied by a **Capacity Factor** to give approximate average generation. Onshore capacity factor is near 30% and offshore perhaps 40%. The capacity factor allows for the fact that a wind generator rarely runs at full power - wind speed being too low or too high.

Electrical units. The **watt** (**W**) is the unit of electrical power (familiar in the rating of electric lamps e.g. as 60W). This is very small, and for domestic purposes we often refer to the **kilowatt, kW** (= 1,000W). Generators are rated in kW or in **megawatt, MW** (= 1,000 kW). Very large amounts of generation are rated in **gigawatt, GW** (= 1,000 MW) or **terawatt, TW** (= 1,000 GW).

Electrical energy (work) is measured in units of power multiplied by time. It represents total generation or consumption over a period. The **kilowatt-hour** (**kWh**) is the **Unit** of domestic electricity billing. One kilowatt running continuously for a year is 1 x 365 x 24 = 8,760 kWh or 8.76 MWh

The **volt** (**V**) is the unit of electromotive force. High voltages are usually expressed as **kilo-volt** (**kV** = 1,000 V).
Climate Change Levy. Essentially a hidden subsidy by which commercial consumers are charged extra for fossil-fuel electricity, thus encouraging the use of renewable electricity which benefits by 0.43 p/kWh.

NFFO (**Non Fossil Fuel Obligation)** - the original source of financial support (subsidy) for wind. Now replaced by the Renewables Obligation and Climate Change Levy.

NETA (**New Electricity Trading Arrangements**) – governs the selling of electricity to the Grid at the cheapest source-price. Effectively it forces short-term manipulation of generation and results in inefficiency and extra CO_2 evolution said to exceed the amount renewables have saved!

RO (Renewables Obligation) places an obligation on suppliers to buy a specific proportion of renewable electricity from the generators. Enforced by a 'fine' for non-compliance and results in wind electricity being subsidised by 3.0 p/kWh

Spinning reserve (or spare-capacity). The conventional electricity generation system includes 23% spinning reserve. This comprises generators, which are not running at full output and can be 'throttled-up' to compensate sudden power failures in the system. It has to be spinning, as normal generators take hours to start up from cold. At the moment our tiny wind electricity industry parasitises on this spare-capacity but as it grows it will become necessary to provide dedicated spinning spare for wind, perhaps up to almost the installed capacity.

Windspeed. Electricity generation is proportional to the swept area (or 'disc') of the wind turbine rotor so increasing the diameter of the rotor pays off handsomely (doubling the diameter gives four times the power). In the mid-1990s turbines were typically of c. 0.3 MW with a height of 45.5 m or 150 feet (e.g. Llandinam). Recent onshore machines have grown to 1.3 MW and 76 m or 249 feet (Blaen Bowi) and new proposals are now for 2.0 MW machines onshore (120 m or 400 feet) and 4.0 MW offshore (120-153m or 400-500 feet tall). Generation is related to windspeed by a cubic power law, so doubling the windspeed gives eight times the power. This is why wind developers have always sought windy hilltop and coastal sites (which are usually of high landscape value).

Appendix II: Commonly asked questions

Can intermittency and the need for spinning reserve be overcome by electricity storage?

No - there is effectively no such thing. A pump-storage facility such as Dinorwig is intended to cover very short surges in demand (the 2,000 MW *Coronation Street* kettle-peak!). Though it can generate 1,250 MW it can only do so for a short time - it is not suitable for large-scale electricity storage. Dinorwig and Ffestiniog are thus needed for surge control and there are in any case few, if any, sites where additional pump storage could be built. Such storage is very expensive to provide and the energy cost of pumping, enormous. Suggestions that hydrogen generation, storage and regenerative fuel cell technology could bridge this energy storage gap are also economically out of the question, and contrary to thermodynamic common sense.

How many homes does a wind power station supply?

The 'average' household uses 3,300 kWh per year, an average running consumption of 0.38 kW (this would represent an annual bill of £264 before standing charges etc.). A 1.0 MW turbine at 30% capacity factor will yield 0.3 MW (= 300 kW) and so, nominally, supply 790 homes. Ten such turbines would support nearly 8,000 homes.

The number of houses 'totally' supported per unit of electricity is much less, as domestic consumption is only one-third of the total. Industrial and service use of electricity takes the other two-thirds. The 'number of homes' calculation targets a sub-item in the electricity account making the number of homes seem larger.

Is it true that 1 kWh of wind electricity displaces the CO_2 emission of 1 kWh of fossil-fuel electricity?

No, for several reasons. Nuclear energy gives 22% of our power, so displacing 1 kWh of 'average' generation with wind only replaces 88% - that is 0.78 kWh-worth of CO_2. Wind energy is intermittent and when it is underspeed or overspeed, must be backed-up by fossil fuel. At the moment the backup is 'stolen' from the conventional grid (where it provides insurance against plant and transmission failure). When wind provides a lot more than the present pathetic 0.25% of generation it will no longer be safe to steal, and extra backup will have to be provided. At least half the saved CO_2 will be lost to emissions from backup not to mention huge extra costs.

Is it true that we have a stark choice of nuclear power or windpower?

Perhaps, in the sense that an ostrich with its head in the sand has an option! It is just not feasible to replace nuclear generation with wind. Wylfa Head, Anglesey is a Magnox nuclear station of 950 MW. The largest onshore wind turbines being built at the moment are 2.0 MW installed capacity. With a generous capacity factor of c. 0.33, these will yield an average of 0.66 MW each. Thus to replace Wylfa requires 1,439 wind turbines but (WAG 2003) suggests a maximum of 200 onshore and 150 offshore wind turbines in Wales. In any case 950 MW is 40% of Welsh generation and would demand dedicated backup (which negates much of the electricity generation and CO_2 emission control). More turbines could be built to compensate, but there is 'a hole in my bucket' fallacy!

Is it true that Wales has to import electricity?

False. Welsh running generation exceeds 3,000 MW and is about twice our electricity consumption (Section X). The balance is exported to England. This degree of over-provision has been maintained in future proposals for wind generation (WAG 2002 & 2003).

Is it better to build wind turbines offshore?

If this were just a matter of getting them out of sight it would be. Many people, including at least one MP, assumed that offshore meant more than 12 miles from the land. Recent events at Porthcawl and North Hoyle show that this will not be the case and that the industry has misrepresented its intentions! Coastal and offshore capacity factoring may be more favourable than onshore, but transmission line-losses may negate this. There are many shipping and aircraft hazards, which have yet to be resolved. Problems of spinning spare are just the same as for onshore turbines.

References

DTI (2002) UK Energy in Brief and pers. comm. Rachael Winther, DTI.
DTI (2003) Energy White Paper. Our energy future: creating a low carbon economy, February 2003.
Hoffman, P. (2001) *Tomorrow's energy*. MIT Press.
IChemE (2002) Institution of Chemical Engineers. Response to PIU *Energy Review*.
IEE (2002) Institution of Electrical Engineers. Response to PIU *Energy Review.*
OUECI (2003) Oxford University Environmental Change Institute www.eci.ox.ac.uk
PIU (2002) DTI *Energy Review.*
Powergen (2003) Website.
RAE (2002) Royal Academy of Engineering. Response to PIU *Energy Review.*

RCEP (2003) Royal Commission on Environmental Pollution report on aviation's contribution to global warming.

Renewable (2002) *A Strategic Study of Renewable Energy Resources in Wales* - a background document, commissioned by WAG in preparing WAG (2002 & 2003).

WAG (2002) Wales Assembly Government. Economic Development Committee consultation draft Report, *Renewable Energy.*

WAG (2003) *Renewable Energy.*

This chapter has been written by:

John R. Etherington PhD, DIC, BSc, ARCS (former Reader in Ecology, University of Wales)
eth.pbont@virgin.net