UK Large-Scale Wind Power Programme From 1970 to 1990: The Carmarthen Bay Experiments and the Musgrove Vertical-Axis Turbines

by

Trevor J. Price

Reprinted from
WIND ENGINEERING
Volume 30, No. 3, 2006

Multi-Science Publishing Company
5 Wates way · Brentwood · Essex CM15 9TB · UK
Tel: +44(0)1277 224632 · Fax: +44(0)1277 223453
E-mail: mscience@globalnet.co.uk · Web Site: www.multi-science.co.uk

UK Large-Scale Wind Power Programme From 1970 to 1990: The Carmarthen Bay Experiments and the Musgrove Vertical-Axis Turbines

Trevor J. Price
School of Technology, University of Glamorgan, Pontypridd, Wales CF37 1DL
E-mail: tprice@glam.ac.uk

ABSTRACT

This article describes the development of the Musgrove Vertical Axis Wind Turbine (VAWT) concept, the UK 'Carmarthen Bay' wind turbine test programme, and UK government's wind power programme to 1990. One of the most significant developments in the story of British wind power occurred during the 1970s, 1980s, and 1990s, with the development of the Musgrove vertical axis wind turbine and its inclusion within the UK Government's wind turbine test programme. Evolving from a supervisor's idea for an undergraduate project at Reading University, the Musgrove VAWT was once seen as an able competitor to the horizontal axis wind systems that were also being encouraged at the time by both the UK government and the Central Electricity Generating Board, the then nationalised electricity utility for England and Wales. During the 1980s and 1990s the most developed Musgrove VAWT system, along with three other commercial turbine designs was tested at Carmarthen Bay, South Wales as part of a national wind power test programme. From these developmental tests, operational data was collected and lessons learnt, which were incorporated into subsequent wind power operations.

1. INTRODUCTION

It was said in the 1980's that the UK had more wind power experts per unit of wind energy generated than any other country in the world! Despite the sarcasm of this remark, it is correct that the UK has produced continuing interest in wind power, from the earliest patent by Blyth [1], through post second world-war developments by experts such as Golding [2] to the post 1973 lobbying of the British Wind Energy Association, which was a key founding influence for the initiation of the European Wind Energy Association. This article aims to tell the story of one aspect of UK wind energy progress, namely the Carmarthen Bay test site in South Wales. This site was established by the largest nationalised utility of the time, the Central Electricity Generating Board, for the development of commercial-scale wind turbines for grid-electricity supply. Background for this requires an understanding of the historical context and a summary of the UK government's wind-energy policy and funding at the time. A further aim is to outline the background for the most noteworthy type of turbine tested at Carmarthen Bay, namely the Musgrove vertical axis turbine.

Other sites in the UK hosted the commercial development of wind turbines, the most noteworthy probably being the Burgar Hill site on the main island of Orkney, to the north of mainland Scotland. However, the Carmarthen Bay site was nearest to London.

The intention of the author is to 'tell the story' and point to the manner of developments. It is not the intention to analyse the engineering features of the machines, nor their performance. Such information is mostly buried in reports to the funding agencies and in technical articles. Surprisingly few of the latter are in archive journal publications, however, more may be found in conference proceedings.

2. INITIAL STAGES BEFORE LARGE-SCALE DEVELOPMENT

Even though contemporary policy seems to be to buy Danish and German machines, the first industrial-scale electricity-generating wind turbines to be built in the UK were constructed under the direction of the British Electrical and Allied Industries Research Association (more commonly known as the Electrical Research Association, or simply the ERA) during the 1950s and 1960s. Three machines were constructed, all of which were prototype 100kW horizontal axis machines, viz. [3, 4]:

1. A variable pitch, 3-bladed, 15 m diameter machine installed by the Glasgow shipbuilders, John Brown Ltd., during 1950 on Orkney, Scotland.
2. A De Havilland Propellers Ltd., 24 m diameter 2-bladed Enfield-Andreau type turbine erected during 1953 in St. Albans.
3. Another 3-bladed, 15 m diameter machine, with fixed pitch aluminium blades, installed on the Isle of Man during 1960.

Coincidental with this wind-power research was a political shift toward technological change that was influencing UK energy policy. The forthcoming Prime Minister, Harold Wilson, had been fervently promoting technological advancement, part of which encouraged new energy supply technologies such as nuclear and wave power [5]. In a speech to the Labour party conference in 1963, Wilson painted '*an image of progress through technology and* [so] *provided a blueprint for modernisation, which crystallised around the Ministry of Technology*' [6]. At the time, wave power was seen by its supporters as the most favourable non-fossil fuel alternative source, although some held reservations as to how much energy supply systems such as nuclear and wave power could contribute to the nation's energy supply mix. Nonetheless the '*official view in the mid-1970s was that wave power was the only renewable energy option that merited support*' as some waves in seas around the coast of Britain had a power density of about 77 kW/m of wave front and so had the potential to supply a large proportion of the UK's electricity needs [4, 5]. So with the expectation in the 1960s of '*abundant nuclear power which would be too cheap to meter*', funding for wind power research in the UK was terminated [4]. However, the oil price crisis of 1973 which increased the price of oil from USD 2 to USD 12 per barrel unexpectedly made renewable sources of energy again of interest. As a result the ERA established an industrial consortium for UK wind power development, particularly that of horizontal axis turbine technology. This consortium became the Wind Energy Group, (WEG) in the early 1980's, with tripartite participation by Taylor Woodrow Construction, by Hawker Siddeley Dynamics and by the Cleveland Bridge and Engineering Company. Taylor Woodrow Construction, the largest company in the whole Taylor Woodrow Group, was then in 5 Divisions [7]. One was the Design and Research Division, within which sat the Alternative Energy Systems Department, employing 15 engineers responsible for the development of renewable energy supply businesses such as wave, tidal, biomass, and wind power. The major interest however was in wind power, which led to Taylor Woodrow becoming the managing agent for the WEG consortium. WEG designed, manufactured and installed, the largest, wind turbine ever built in the UK; the 60 m diameter, 3 MW HAWT LS-1 located at Burgar Hill, Orkney in Scotland. Prior to this, WEG had installed a

smaller 250 kW, 20 m diameter HAWT at the same site, monitoring this prototype in preparation for operating the larger machine. In a separate project, WEG analysed the feasibility of large, off-shore arrays of wind power machines. Combining the results of this feasibility study with the experience of operating the 60 m diameter Burgar Hill LS-1 wind turbine, the next planned phase of WEG's wind power programme was to design and test a 100 m diameter HAWT. However, UK government policy shifted towards a more cautious approach, and WEG later chose rather to test a smaller, 2-bladed machine. Nevertheless, the LS-1 machine continued to operate for several years [8].

3. UK LARGE-SCALE WIND POWER DEVELOPMENT POLICY

The UK's government-led wind energy programme, which began in earnest in 1979, was initially focussed upon '*determining the technical and economic feasibility of the* [wind power] *technology*' [9]. However the programme subsequently evolved, progressing from technical feasibility assessment activities (which ran during the mid-1970s to mid-1980s), to technology development and demonstration projects (which continued into the mid-1990s).

During the 1970s and 1980s responsibility for the UK's wind energy research and development was part of the remit of the UK government's Department of Energy, (DoE). After the DoE had published its assessment of '*the prospects for the generation of electricity from wind energy in the United Kingdom*' it was able, during 1977, to further its wind energy programme by allocating £200,000 (which was to be spent between 1977 and 1979) to wind energy research [4, 10]. The remit of this part of the research programme was to evaluate industrial-scale, electricity generating turbine designs. This included the aerodynamic efficiency of the machines, how much energy they were able to extract, as well as an analysis of structural engineering issues, such as operational vibrations, stresses, strains and costs [7]. Throughout this early phase of development of the UK large wind turbine industry, it was thought that an expansion of wind power was likely and would result in a need for associated concrete structures such as foundations and wind turbine towers. This attracted civil engineering companies such as Taylor Woodrow, Sir Robert McAlpine and Sons Ltd, and Balfour Beatty Construction Ltd. All these companies became involved in wind turbine development, as they predicted that the construction of wind power plant would provide a substantial market for their civil engineering expertise. So, during the 1970s and 1980s, the UK's large-scale wind energy programme was being spearheaded by consortia comprising large engineering companies such as James Howden and Co., the Wind Energy Group Ltd. (which involved Taylor Woodrow Construction), and Vertical Axis Wind Turbine Ltd., (which was a subsidiary of Sir Robert McAlpine and Sons, which later transmuted into RES Ltd.). Figures 1–3 show details of the projects [11]. These consortia undoubtedly affected the form, pace, and direction of the UK wind industry as these companies co-operated in lobbying, but also pursued their own agendas.

During the financial year 1985/6 over 50% of the DoE's total renewable energy research and development budget was planned to be spent on wind power, something that '*underlined the Department's commitment to the development of wind energy technology*' and the DoE's hope that the cost of electricity generated by wind power would fall to 2.5 – 3.2 p/kWh (1984 prices) [12]. Cumulatively until March, 1985 the DoE had spent a total of £17 million on wind energy, split as shown in Fig. 4, with a further £6 million planned for expenditure during 1985/6 [13]. During 1986/7 the DoE spent £3 million on its large-wind machine programme, and approximately £1 million '*in support of underlying research and development*' [11].

Until 1986, the DoE had supported UK wind power development in two ways, i.e., gaining operational experience of the 3 MW LS-1 Orkney HAWT and, separately, development of a 135 kW, 25 m diameter VAWT at Carmarthen Bay constructed by Vertical Axis Wind Turbines

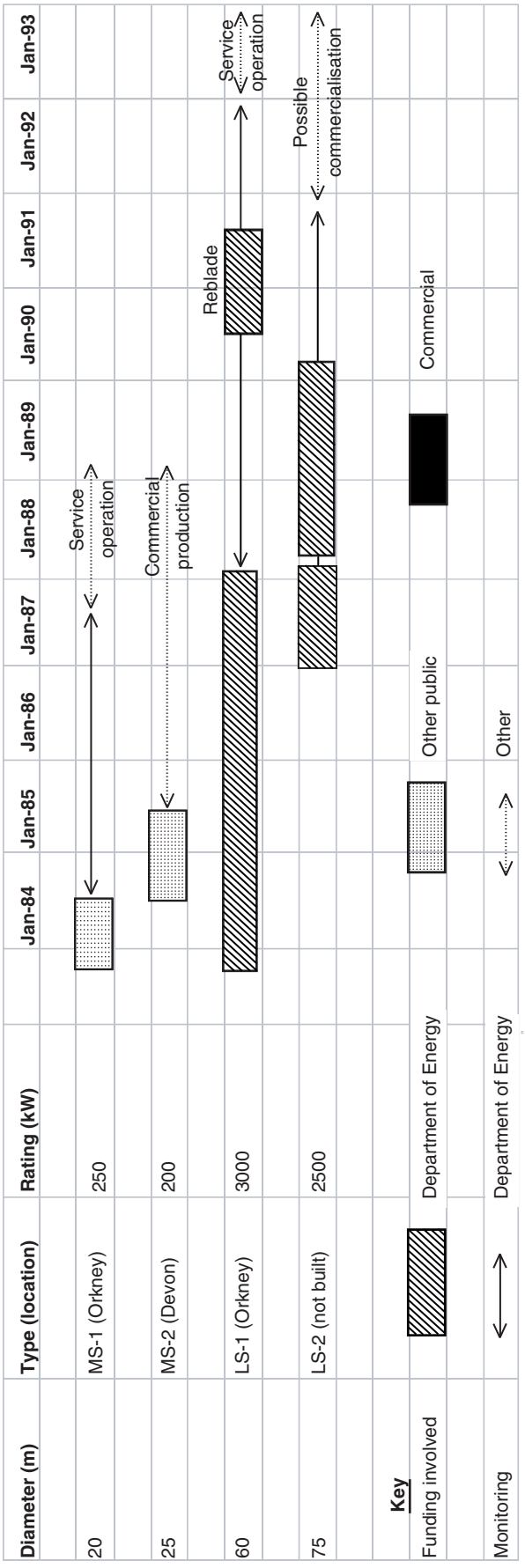


Figure 1: Large wind machine developments by the Wind Energy Group (Page, Bedford, McAnulty and Maskell, 1987).

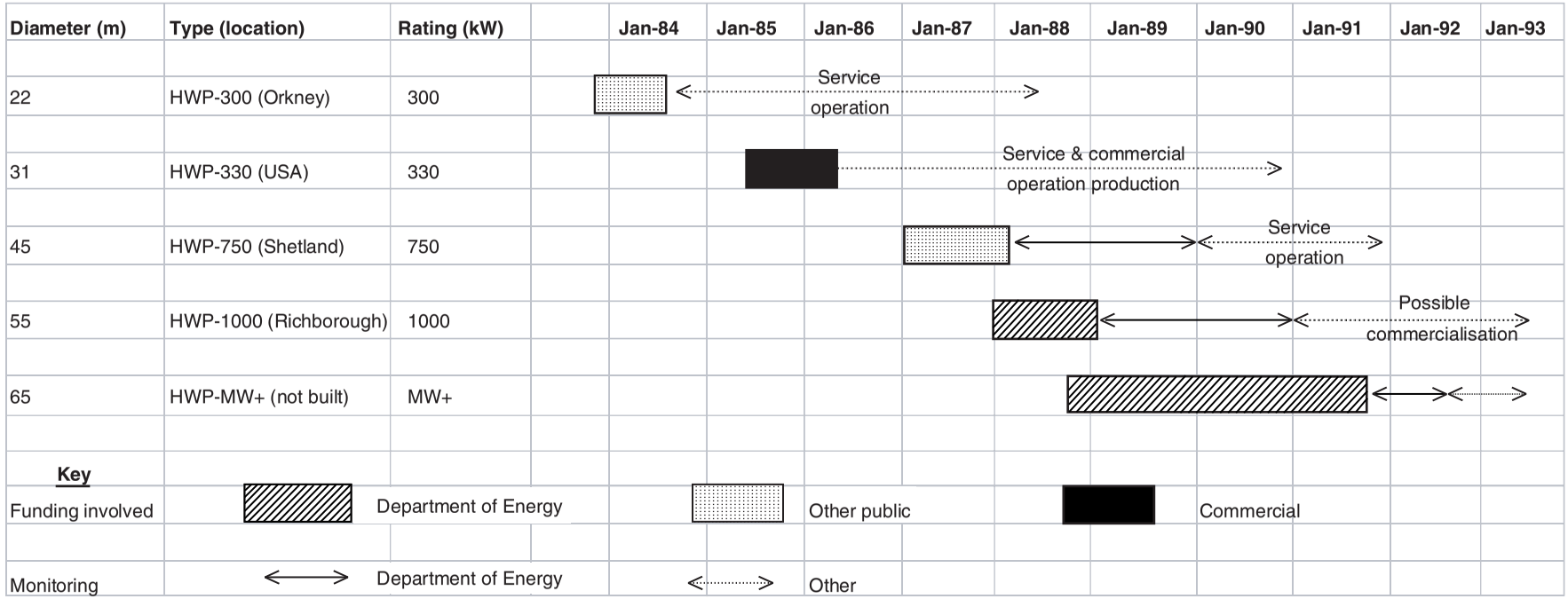


Figure 2: Large wind machine developments by James Howden and Co. (Page, Bedford, McAnulty and Maskell, 1987).

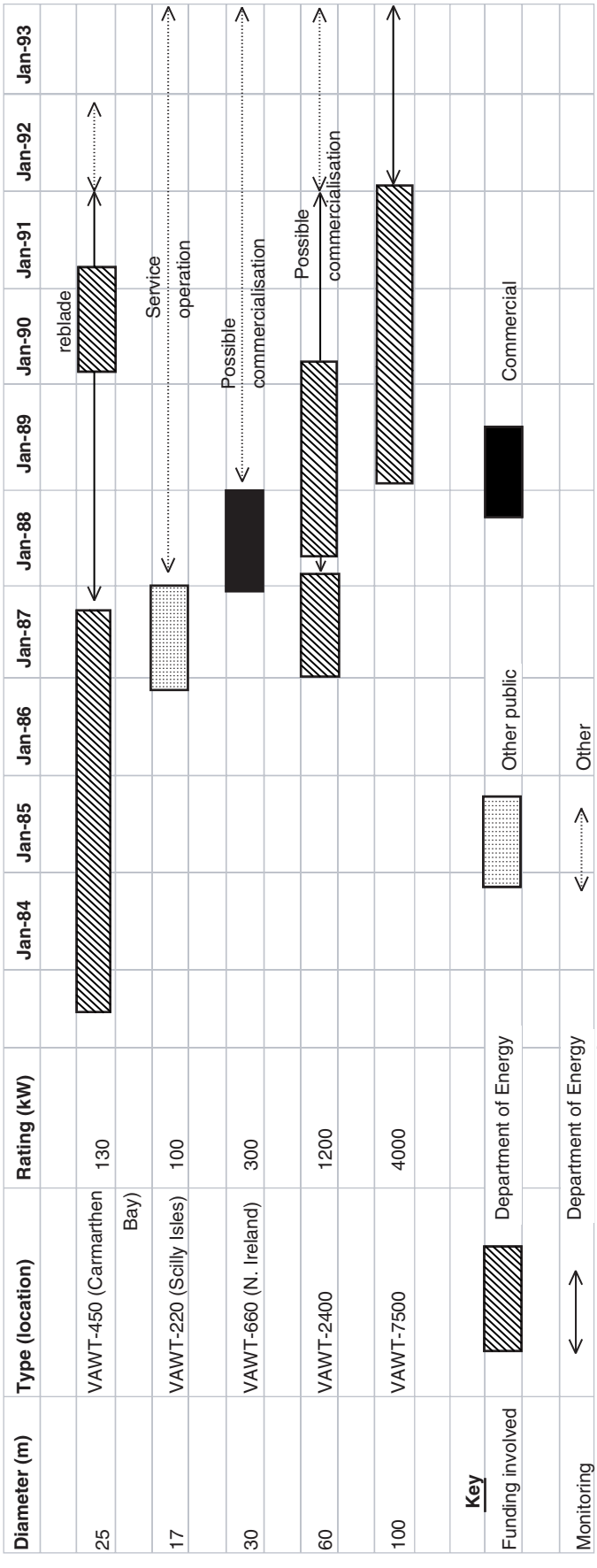


Figure 3: Large wind machine developments by vertical axis wind turbines limited. (Page, Bedford, McAnulty and Maskell, 1987).

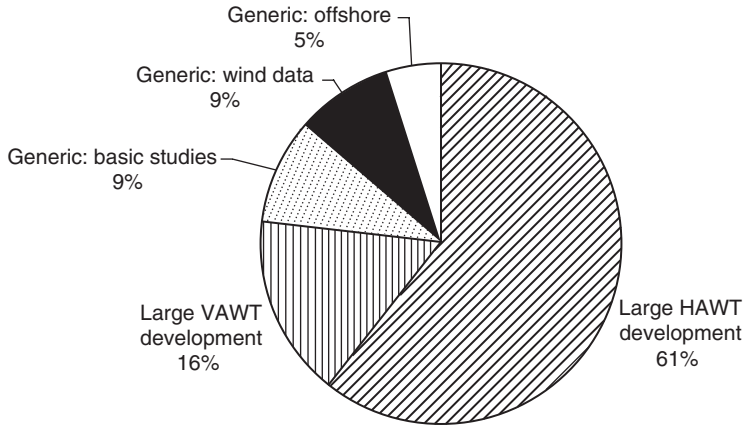


Figure 4: UK Department of Energy total expenditure on its wind energy research and development programme up to 1986.

Ltd [13]. By 1986 '*a third route* [was] *identified* [consisting] *of exploring the extent to which medium scale machines* [were to] *be scaled-up in gradual steps*'. The DoE believed that, due to the high commercial risks, to rely upon commercial investment would have severely impeded progress, and so in 1986 the DoE's main objectives for its wind power programme were altered to determine the technical feasibility of such machines for generating grid quality electricity, as well as to encourage research '*aimed at cost reductions and improved performance*' of the turbines. These two objectives were addressed by four programme strands, viz.:

- Strand 1. By gaining operating experience of the WEG 2-bladed, 60 m diameter 3 MW LS-1 HAWT on Orkney, Scotland.
- Strand 2. The testing of a 25 m diameter, variable geometry 'Musgrove' VAWT, which was to be built and tested by VAWT Ltd.
- Strand 3. The scaling-up of medium-sized wind turbine technology. This focussed upon a collaborative project between the Glasgow-based mechanical engineering company, James Howden and Co., the DoE and other partners. James Howden and Co. had already developed a number of HAWTs of sizes ranging from 22 to 45 m rotor diameter. Tests of a new prototype 55 m rotor diameter, 1 MW 3-bladed HAWT, based upon the designs of the smaller machines.
- Strand 4. Advanced design studies which would inform wind industry planning decisions after 1986. These studies included outline design and cost analyses for a 1 MW VAWT; the use of variable geometry rotors; and the feasibility of a multimegawatt HAWT.

During 1986 the government hoped that their support would lead to [14]:

- A WEG 2-bladed HAWT of between 2 to 2.5 MW capacity, which would use advanced rotor blade materials.
- Construction of a 1 MW, 55 m diameter 'stretched' Howden HAWT at a test site in Richborough, Kent.
- A VAWT variable geometry machine having provided operational performance data for about 18 months. This would allow a reappraisal of the merits of the 25 m diameter machine, informing further development of VAWT technology.
- Allow the completion of low-weight and low-cost rotor and tower design analyses based upon a 1 MW VAWT.

In 1986 the DoE was also publicly musing about long term wind power developments into the 1990s: by 1991, the idea of a demonstration wind 'park' was mooted, as it would be '*the*

culmination of the Department of Energy's programme in support of the development of large machines for UK main grid operation successful operation of the wind park could lead to a similar off-shore array demonstration in subsequent years' [14]. As Table 1 shows, the DoE expected to have a '*medium-sized machine demonstration wind park*' built by 1990 which would pave the way for a larger, multi-MW wind park by circa 1995.

Spending over £4 million per year on large machine developments, the DoE held the view (in 1986) that only large-scale multimegawatt machines could substantially contribute to UK energy supplies, and so wanted to support this highly commercially-risky area of development. However, such funding was justified by its successes as by March, 1986 the UK wind power programme had made substantial progress, viz. it had '*increased commitment and achievements being made by British companies and progressed with major new wind power construction projects whilst also expanding research focussed on more generic issues*' [13].

Reinforcing this view, in 1990 the Energy-Under-Secretary noted that '*a £10 million project the country's biggest wind farm would be built on Ovenden Moor, West Yorkshire*' [15]. However, by 1987 government wind power policy was becoming more cautious. Instead of planning windfarms with multi-MW machines, there was [11]:

'*a growing body of opinion in the UK which believed that it would be valuable both from a technical and operational point of view to gain experience with a modest array of successfully demonstrated medium-sized machines (circa 300 kW) before attempting to construct any demonstration array based on megawatt-sized turbines*'.

However, if all went well, projections made in 1987 described a wind farm comprising 1 MW machines as a '*reasonable*' consideration for construction sometime between 1991 and 1993.

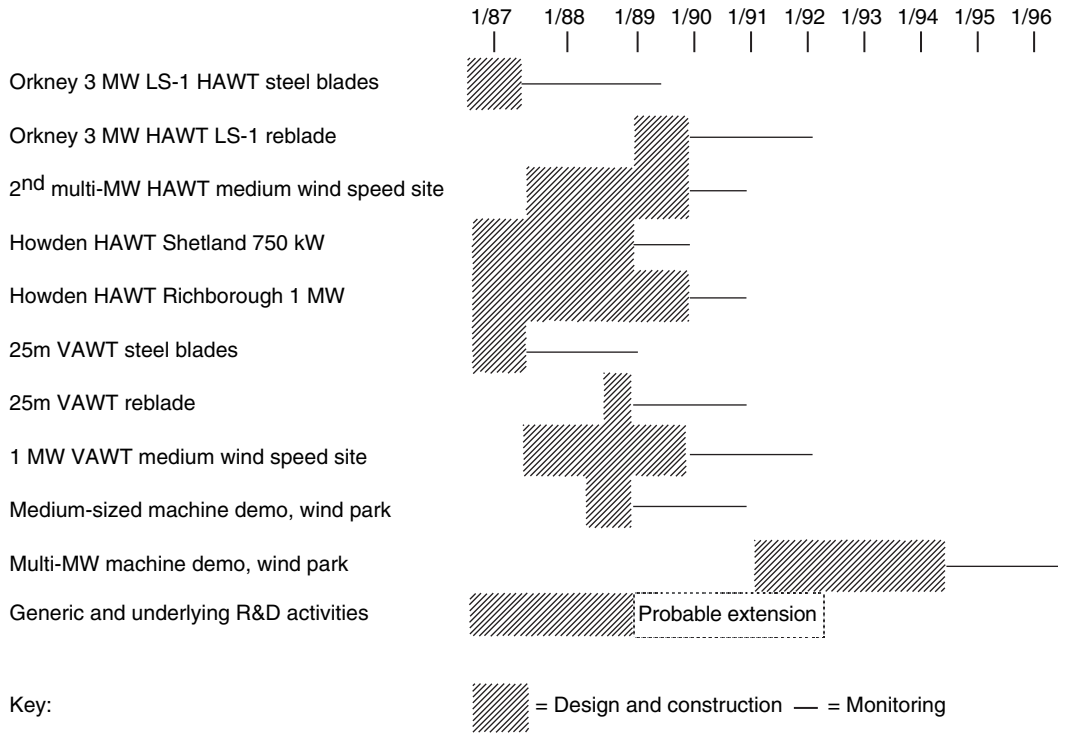
During 1988 the government's wind programme was still within its technical feasibility phase. Programme tasks therefore were still focused upon four areas, viz. studies of the resource, machines, systems, and supporting research and development, the latter being aimed at better '*understanding the technology, to obtain data for input into the machine design and development and to investigate new concepts which offer lower costs or increased energy capture*' [16].

4. THE UK CENTRAL ELECTRICITY GENERATING BOARD, CEGB

During the 1980s the nationalised electrical supply industry for England and Wales, the CEGB operated a total of 80 coal-, oil- and nuclear-fired power stations with a combined capacity of 50 GW and therefore, was seen by some to be disinterested in renewable energy sources [17]. However, decision-makers in the CEGB realised that they needed to be '*sufficiently knowledgeable about wind energy to be able to assess its potential*' as it was likely that the wind industry would grow, especially with government encouraging industrial-scale wind power development [17]. So in order to be ready to exploit wind power's commercial possibilities, during 1978 the CEGB started its own wind power programme [18]. The first stage of the programme was aimed at issues such as meteorology, wind effects within wind farm arrays and, with the DoE's help, offshore wind resource studies. The CEGB also explored exploiting wind power from lowland sites, via the testing of a 200 kW, 24 m diameter HAWT which the CEGB had purchased from WTG Energy Systems Inc., USA. This machine was the first wind turbine to be situated at the CEGB's Carmarthen Bay test site, near Burry Port in South Wales, and was '*switched-on*' on 16th November, 1982 [19]. At a cost of £650,000, the CEGB Chairman at the time, Lord Marshall, noted that '*the wind turbine—was tangible evidence that the CEGB was interested in all forms of energy*' and that they had plans to order a larger (300 kW) wind turbine during 1983, for operation by 1985 [19].

The CEGB also wanted to select a site for a larger machine at one of 3 locations around the UK: in Lincoln, Kent or Essex. On this site, approximately 10 machines would then be erected.

Table 1. Progress chart and possible framework for the development of large wind turbines in the United Kingdom as planned for by the Department of Energy during 1986 (developed from [14]).



The CEGB also '*offered to host an internationally mounted offshore prototype wind machine*', although the viability of such a '*concept could* [not] *be established before the 1990s*'. So during the 1980s, the CEGB had to focus efforts on developing on-shore wind power technologies [19]. However, the performance of this first foray into wind power for the CEGB, the Howden turbine, was '*disappointing due to a number of technical details. The operation of the machine* [had] *been severely curtailed as a result of problems experienced with the blades and control systems*' [17, 20]. Also, '*although considerable effort* [was] *put into obtaining satisfactory operation of the machine—there were a number of technical difficulties which severely limited its operation*', resulting in the machine being in use for only 400 hours [13]. Not to be put off, the CEGB learnt from the experience and by 1987, the view of the CEGB was that '*the best commercial prospects amongst machines actually built, appear to be with medium-sized machines—in the range of 200-350 kW*' [18]. Other advantages of this size of machine (and the authors then pre-empting some of the public negativity which was to plague the UK wind industry in the 1990s), was that they were quieter and not '*too conspicuous and therefore more easily assimilated into the landscape*'. However, even with these advantages, during the 1980s it was still '*not clear—how best to exploit the onshore resource*—[as] *the large numbers needed for bulk generation are* [sic] *a drawback*' and that '*the ultimate exploitation of onshore wind energy will depend on its economic and public acceptability*' [18]. Such concerns remained at the heart of the CEGB's wind power programme.

4.1 The Carmarthen Bay Wind Power Test Programme

The wind power test site at Carmarthen Bay near Burry Port, South Wales, was located adjacent to an out-of-service CEGB coal-fired power station which had been operational between 1954 and 1984. With the A484 road to the north and the sea to its south, the wind

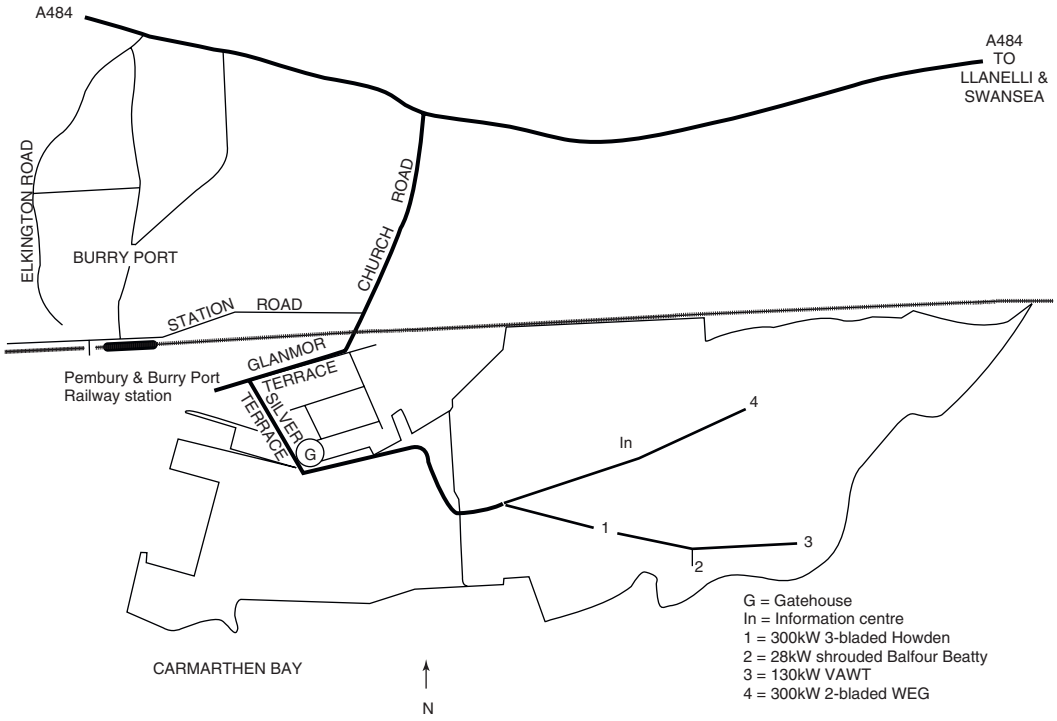


Figure 5: Map of the CEGB wind energy demonstration site, Carmarthen Bay, South Wales.

energy demonstration centre was situated on the tip of the coast—*see* Fig. 5. The Carmarthen Bay site was used by the CEGB to host wind turbines made by the three leading UK turbine manufacturers, James Howden, WEG and VAWT Ltd. The site, officially named 'The Carmarthen Bay Wind Energy Demonstration Centre', also had a visitor's information centre which was visited by up to 16,000 people per year, as well as a gatehouse to aid site-security [21].

By hosting UK wind turbines, the CEGB wanted to act '*as a shop window for UK designs*' as well as offering to buy the machines, once testing had finished [13]. In total 5 wind turbines were installed and tested throughout the 1980s—*see* Table 2.

After the failed Howden machine, the next turbine to be installed at Carmarthen Bay was a shrouded-vertical axis machine, installed by Balfour Beatty Power Construction Ltd. during 1985 [23]. This was nicknamed the 'magic mushroom' from its unusual appearance. This VAWT was 6 m in diameter, the rotor comprised 5 vertical blades, spring-operated to avoid rotor over-speeding in high winds. Located around the rotor, and concentric to it, was a fixed shroud made up of 8 fixed ducts built into an annular dome—*see* Fig. 6.

The dome was so designed to increase the amount of energy that the machine could extract from oncoming wind.

Field tests began in June 1985, and after 21 months of testing it was concluded that the turbine was '*non-cost effective*' and that an '*economic analysis indicated that a cost effective machine could be achieved by reduction in material content and careful design*' [23].

5. THE MUSGROVE VERTICAL AXIS WIND TURBINE

Vertical axis turbines have been used ever since the 7th century B.C., although it was not until 1922 that the design was modernized by Savonius, a Finnish engineer [24, 25]. During 1931 Darrieus developed a unique type of VAWT, having aerofoil-shaped blades instead of the cup-shaped blades of the Savonius design, therefore employing the more efficient

Table 2. Wind turbines tested at the CEGB's test site in Carmarthen Bay, South Wales [4, 22]

Turbine Specification	James Howden & Co. Ltd.	Balfour Beatty Power Construction Ltd.		VAWT Ltd.	WEG
Year installed	1982	1985	1986	1989	1987
Rated power, (kW)	200	28	130	500	300
Blade number	3	5	2	2	2
Blade diameter, (m)	24.4	6	25	35	30
Configuration	HAWT	VAWT	VAWT-450	VAWT-850	HAWT
Hub height (m)	24	15	25	30	25

Figure 6: The Balfour Beatty Power Construction Ltd. 'magic mushroom' VAWT.

aerodynamic lift forces to pull the blades, rather than relying on the wind to push the rotor around [26].

Born in 1938, Peter Musgrove read aeronautical engineering at Southampton University as a sponsored undergraduate student supported by the aeronautical company, Vickers Dynamics Ltd. Not wanting to immediately immerse himself in industry, Musgrove remained at Southampton to undertake a PhD in microhydrodynamics. After he had completed his post-graduate research, he honoured the 'gentlemen's agreement' he had with his sponsor and so joined British Aerospace Ltd, researching flight guidance and other hi-tech engineering systems. In 1966 Musgrove gained a lecturer's post in the Engineering Department at Reading University, where he taught and researched, for the next 22 years.

Seeking stimulating undergraduate project material, during the late 1960s a colleague suggested to Musgrove that the Darrieus-type vertical axis wind turbine would prove worthy of investigation. Ultimately this undergraduate project led to developments simplifying the Darrieus troposkien (or 'egg-beater') configuration, rationalizing it into an 'H' shape and thus

making it more efficient and easier to manufacture. To avoid over-speeding the first Musgrove turbine design had an integrated reefing system which automatically feathered the blades in strong winds. During 1975, Musgrove and his Reading-based research team investigated the potential of UK wind power, particularly aiming at enhancing wind turbine efficiency and effectiveness [27, 28]. Funding given in 1976 from the Science Research Council enabled Musgrove to appoint a PhD research student, Ian Mays (who is now Managing Director of Renewable Energy Systems) to further develop the Musgrove-VAWT. The research built upon previous work undertaken in Britain by the ERA and others, for British wind research up until 1960 see for example [3, 29–33] for American wind power research developments see for example [34] for a description of the Russian Balaclava plant see [2, 35]. The early experiments which Musgrove and his small team undertook at Reading University during 1976 and 1977 *'validated the basic concept*' and led to a successful application being made to the UK government for financial support for a feasibility study to consider scaling-up the Musgrove turbine [5, 36]. As a result, half of the £200,000 DoE funding ear-marked for wind turbine development in the late 1970s was used to develop two different types of turbines, including the feasibility of scaling-up a '*laboratory scale*' prototype 'Musgrove' VAWT into a '*multimegawatt vertical axis wind turbine*'. Research and development into this had started during 1978, the results of which encouraged—*the Department of Energy to invite industry to carry the project forward with design studies for a medium sized machine, 25 m in diameter, as a stepping stone to a multimegawatt sized unit*' [37]. This initial VAWT design and development work was carried out by a consortium comprising British Aerospace Aircraft Group (Bristol), Taylor Woodrow Construction Ltd and Reading University. However, as large wind tunnel testing was prohibitively expensive, the largest Musgrove turbine built and tested at Reading University had been limited to 3 m in diameter. Upon conclusion of the tests during 1979, the DoE decided that to test the design fully, a life-sized trial was required. However, the DoE wanted a '*consortium quite separate from the UK horizontal axis wind turbine design group, and* [so] *Sir Robert McAlpine and Sons Ltd. were asked to take over project leadership in mid-1979*' [36]. The new consortium, which also included Aircraft Designs (Bembridge) Ltd., Engineering and Power Development Consultants Ltd and NEI Cranes Ltd., put to the DoE in 1980, a wind power development plan which aimed to develop a 4 MW, 100 m diameter prototype machine by 1986. The detailed plans for the first phase of this programme, i.e., the development of a 25 m diameter VAWT, was agreed by the DoE, and by 1983 funding of £3.5 million was made available [36]. Three contracts were subsequently entered into by VAWT Ltd and the DoE, to ensure funding for the following VAWT work [37], i.e., to :

1. Construct a 25 m diameter prototype VAWT.
2. Test and monitor the prototype VAWT for at least 2 years.
3. Carry out preliminary studies leading to the design of a multimegawatt VAWT unit.

By 1984 VAWT Ltd. were well underway with the design of the VAWT-450 (130 kW capacity). Also, the tower and '*manufacture of the major components*' of the machine had made '*substantial progress*' [12]. By January 1986 the manufacture of the rotor blades, struts and cross-arms of the 25 m Musgrove machine was almost complete, with the assembly of the rotor scheduled for the following April. By 28th November, 1986 the completed machine was inaugurated by the Under-Secretary of State for Energy, thus becoming the third turbine to be installed at Carmarthen Bay. [37] outline the work undertaken, whilst Table 3 gives the specification for the VAWT-450. The VAWT-450 turbine had 18 m long vertical blades and could produce up to 130 kW in an oncoming wind of 11 m/s (*see* Fig. 7).

Table 3. Specification of the first VAWT, the VAWT-450, wind turbine [22]

Element	Details
Rotor diameter	25 m
Rated power	130 kW
Swept area	450 m^2
Rated wind speed	11 m/s
Blade length	18 m (tip to tip)
Rotational speed	Variable up to 27 rpm
Blade aerofoil section	NACA 0015
Blade chord	1.25 m
Tower height	25 m
Shut down windspeed	30 m/s via automatic reefing system

Figure 7: The VAWT-450 (130 kW) machine (blades shown as reefed; in operation these become vertical). The gear-box and generator were at ground level.

In order to protect the machine from spinning out of control, as well as being a way to control the power output, the machine's automatic computer controlled "reef" the blades (i.e., blade elements folded to reduce swept area, as in Fig. 8) so enabling safe operation in wind speeds to 30 m/s. In faster wind speeds, the machine would 'shut down' by ceasing rotation and being braked. The 25 m tower was built from post tensioned pre-cast concrete rings and the rotor was steel with glass reinforced plastic fairings [38]. Electric generators and other equipment were housed in a plant room at the base of the tower. With more than 200 sensors recording operational data, the computer system was also used to monitor the machine's performance [13]. Also during 1986, a review of '*the commercial and technical potential*' of the VAWT was commissioned by the DoE to consider the operational experience gained from the VAWT-450 prototype. Other work was also underway by VAWT Ltd and funded by the DoE, to explore the scaling-up of the VAWT-450 into a land-based 1 MW machine, as well as a multi-MW offshore machine.

Figure 8: Foreground: the VAWT-850 (500 kW) machine during assembly, with the rotor attached to the cross-arm on the ground. Background: the VAWT-450.

Simultaneously to their investigation of the VAWT-450 at Carmarthen Bay, VAWT Ltd built a 17 m diameter, 100 kW VAWT demonstration project on the Isles of Scilly, with part-financing from the European Commission [13]. Another similar machine was built in Sardinia [7]. The Isles of Scilly were chosen because there was then no undersea electricity link to the UK mainland and so islanders relied upon expensive diesel generators for their electricity needs and for desalinisation.

During 1988, preliminary design work on a larger VAWT (the VAWT-850) was started [16]. Tests had shown that the reefing system was unnecessarily complex (as power control was automatically achieved by the natural passive-stalling of the aerofoils, even in strong winds with the blades remaining vertical). The reefing mechanism was not included in the design for the second machine (*see* Fig. 8).

The VAWT-850 was a larger machine, with a rated capacity of 500 kW, again with 'H'-shaped blades [16]. The machine was at the time, Europe's biggest vertical axis wind turbine, standing approximately 45 m (140 ft) high, and with a rotor diameter of about 38 m (115 ft) [39]. It was installed at the Carmarthen test site during 1990, with tests starting in August. This machine operated only until 26th February, 1991 when one of the blades broke, due to an error in the manufacture of the fibreglass blades [7, 40]. This led to reports in the local press of the '*massive wind turbine—plung*[ing] *to the ground*'! [40, 41]. Nationally, the Independent newspaper noted that the turbine had been '*the victim of a gust that tore down one of its blades and with it the dreams of many an environmentalist*' [21]. The VAWT-850 design was also prohibitively costly, since the concrete tower and supporting structure had to cope with large cycling fatigue-loads as the blades rotated [38].

Another turbine to be built and tested at Carmarthen Bay was a 2-bladed WEG HAWT, shown in Fig. 9. It was one of the first WEG turbine to use a steel tower, rather than concrete.

During 1991, National Wind Power, (NWP) was formed as a joint venture between the CEGB and the parent companies of WEG. The responsibility of the Carmarthen Bay test site

Figure 9: The WEG 2-bladed HAWT (300 kW).

was then transferred to NWP. However by the early 1990s the test site had served its purpose. Windfarms (notably the Delabole windfarm, developed as a private venture by farmer Peter Edwards, i.e., without government research and development support), were being built and so the Carmarthen Bay test site was closed in late 1990s and the machines removed! The land is now a coastal park, the nearby power station having also been demolished.

6. CONCLUSIONS

The Carmarthen Bay wind power programme provided a '*shop window*' for the electricity supply industries, government, and the public to view the performance of what were then novel, large wind turbines. Without this facility, UK companies would not have gained the valuable experience of operating a range of different cutting-edge horizontal and vertical axis wind machines. The UK's wind power test programme of the 1970s, 1980s, and 1990s was therefore an example of how government and industry worked together to push technological development. The Carmarthen Bay tests have also left a valuable legacy that is still shaping worldwide wind power development.

The fact remains however, that subsequent history shows that no UK manufacturer of wind turbines continued with a successful run of commercially marketed machines, neither in Europe nor elsewhere. Danish wind turbines dominated the later UK market, as elsewhere, to be joined mostly by German manufactured machines. There were but a few US manufactured machines. The success of Denmark, Germany and Spain in both manufacture and installing capacity on their own networks is surely due to their policy of feed-laws, rather than giving development grants to specific companies. The UK relied on supporting a small group of UK companies, rather than encouraging a market. Whatever the success or otherwise of particular UK manufactured machines, their possible success was doomed by lack of UK market support.

Post script: Dr Musgrove, later joined National Wind Power and was awarded a special lifetime achievement award at the BWEA's 24th Annual conference in 2002.

ACKNOWLEDGEMENTS

The author thanks Dr Peter Musgrove (now retired) and Dr Simon Powles, RES Group, who provided much insight and valuable information (including photographs) during the compilation of this article.

REFERENCES

[1] Putnam, P. C. (1948): *Power from the wind*, D. Van Nostrand Co. Inc., USA.

[2] Golding, E. W. (1949): *Large scale generation of electricity by wind power – preliminary report.*

[3] Golding, E. W. (1959): *Wind power research in Great Britain*, British Electrical and Allied Industries Research Association, Leatherhead, Surrey.

[4] Savonius, S. J. (1931): *S-rotor and its applications*, Mechanical Engineering, 53, 333–338.

[5] Sectorov, W. R. (1934): *100 kW from Russian winds*, Electrical World, 103, 540–541.

[6] BWEA (British Wind Energy Association), (2003) *BWEA 1978–2003 and beyond: celebrating 25 years of the British Wind Energy association*, London.

[7] Cameron-Brown, C. A. (1926): *Windmills for the generation of electricity*, Institute for Research in Agricultural Engineering, Oxford University.

[8] BWEA (British Wind Energy Association), (1983): *Wind directions*, BWEA Newsletter, Vol. II (3), London, p. 2.

[9] Bullen, P. R., Mewburn-Cook, A., and Read, S. (1987): *The performance of a novel shrouded vertical axis wind turbine*, Proc. Ninth British Wind Energy Association Wind Energy Conference, Galt J. (Ed), Edinburgh, pp. 215–219.

[10] Mays, I. D. and Rhodes, H. (1984): *Progress with the UK vertical axis wind turbine programme*, European Wind Energy Conference, Hamburg, 130–137.

[11] Price, T. J. (2006): *Edward Golding's influence on wind power*, Wind Engineering, 29(6): 513–530.

[12] Twidell, J. W., Burton, T., Gauld, R, and Fern, D. (1995): *Recommissioning and managing the 3 MW wind turbine on Orkney*, Scotland, Proc 1995 Solar World Congress (Budapest), International Solar Energy Society.

[13] Anon. (1990): *Wind turbine, Carmarthen Bay*, The Times newspaper, 20th August, London, Home News Section.

[14] Musgrove, P. (2004a): *Private interview*, Reading.

[15] Bedford, L. A., Halliday, J. and Milborrow, D. (1986): *A review of wind energy in the United Kingdom*, Proc. Eighth British Wind Energy Association Wind Energy Conference, Anderson, M. and Powles, S. (Eds), Cambridge, pp. 1–12.

[16] Bird, R. and Allen, J. (1977): *The prospects for the generation of electricity from wind energy in the United Kingdom*, Energy Paper 21, HMSO, London.

[17] Milborrow, D. J. and Surman, P. L. (1987): *CEGB wind energy strategy and future research*, Proc. Ninth British Wind Energy Association Wind Energy Conference, Galt J. (Ed), Edinburgh, 9–13.

[18] Musgrove, P. (2004b): *Letter plus additional information*, Reading.

[19] Nuttall, N. (1990): *Government boost for long-term wind energy*, The Times newspaper, London, 10.

[20] Page, D. I., Bedford, L. A., McAnulty, K. F., and Maskell, C. W. (1987): *A progress report on the UK Department of Energy's wind energy programme*, Proc. Ninth British Wind Energy Association Wind Energy Conference, Galt J. (Ed), Edinburgh, 1–8.

[21] Anon. (1987): *Vertical axis wind turbine – 25 m diameter research prototype*, Technical brochure, VAWT Ltd., Hemel Hempstead.

[22] Peace, S. (2004): *Another approach to wind*, available from www.memagazine.org/backissues/jun04/features/apptowind/apptowind.html, accessed 3rd July, 2006.

[23] Price, T. J. (2005): *James Blyth—Britain's first modern wind power pioneer*, Wind Engineering, 29(3): 191–200.

[24] Craig, J. W. (1998): *UK DTi wind programme area – review and current priorities*, Proc. Nineteenth British Wind Energy Association Wind Energy Conference, Hunter, R. (Ed), Edinburgh, pp. 23–28.

[25] Darrieus, G. J. M. (1931): *Turbine having its rotating shaft transverse to the flow of the current*, United States Patent, 1,835,018.

[26] Golding, E. W. and Stodhart, A. H. (1949): *The potentialities of wind power for electricity generation (with special references to small scale operation)*, British Electrical and Allied Industries Research Association Technical Report W/T16.

[27] Musgrove, P. (1976): *The variable geometry vertical axis windmill*, Proc. 1st Int. Symp. Wind Energy Systems, Cambridge, BHRA, Cranfield, UK.

[28] Musgrove, P. and Mays, I. (1978): *Development of the variable geometry vertical axis windmill*, Proc. 2nd Intl. Sym. Wind Energy Systems, Amsterdam, BHRA, Cranfield, UK.

[29] Anon. (1991): *Centre turbine wreckage probe*, South Wales Evening Post, p. 3. [30].

[30] Golding, E. W. (1953): *The utilization of wind power in desert areas*, British Electrical and Allied Industries Research Association, Leatherhead, Surrey.

[31] Coopey, R. (1991): *The white heat of scientific revolution*, Contemporary Record, 5(1): 115.

[32] BWEA (British Wind Energy Association), (1982): *Wind energy for the eighties*, Lipman, N., Musgrove, P. and Pontin, G., (Eds), Peter Peregrinus Ltd., Stevenage.

[33] Milborrow, D. J., Invernizzi, A., Grastrup, H., and Overdijk, J. (1986): *Electricity from the wind-current projects*, European Wind Energy Conference, Rome, 65–73.

[34] Bevan, E. G., Bedford, L. A. W., and Page, D. I. (1986): *The development of wind generated electricity in the United Kingdom – a framework for the future*, European Wind Energy Conference, Rome, Italy, 7–9, pp. 151–155.

[35] Golding, E. W. (1955): *The generation of electricity by wind power*, 1st edition, Spon, London.

[36] Anon. (1982): *Power from the wind*, Central Electricity Generating Board (CEGB), Press Release.

[37] Anderson, M. B., Groechel, K. M., and Powles S. J. (1987): *Analysis of data from the 25 m variable geometry vertical axis wind turbine*, Proc. Ninth British Wind Energy Association Wind Energy Conference, Galt J. (Ed), Edinburgh, p. 333–339.

[38] Powles, S. (2004): *Personal interview*, Llanelli.

[39] Meir, R., Page, I. D., and Bedford, L. A. (1988): *The UK Department of Energy wind energy programme*, Proc. Tenth British Wind Energy Association Wind Energy Conference, Millborrow D. J. (Ed), London, 5–8.

[40] Prestage, M. (1991): *Dream of power has gone with the wind*, The Independent newspaper, 3.

[41] Bevan, E. G., Derwent, R. G., and Bedford, L. A. (1985): *Wind energy: a promising renewable energy source for the United Kingdom*, Proc. Seventh British Wind Energy Association Wind Energy Conference, Garrad A. (Ed), Oxford, pp. 1–5.