Presented at the South Pacific Forum Wind Energy Workshop, Suva, Fiji, June 23-27, 1997

Making Wind Energy Work
A Case Study of Western Power's Ten Mile Lagoon Wind Farm

by

P.R.Ebert
Energy Technology & Environment Branch
Western Power Corporation
363 Wellington Street
Perth WA 6000
AUSTRALIA

Abstract: *Western Power is the principal supplier of electricity in the Australian state of Western Australia. The company services a land area of about 2.5 million square kilometres, which includes many remote and isolated communities which rely almost entirely on expensive diesel powered electricity. However, the wind resource in Western Australia is by world standards very good, so to offset the use of diesel in these communities, Western Power established a wind energy program which culminated in wind turbines being installed at a number of locations. This paper will briefly introduce the history of Western Power's wind energy developments, and in particular discuss the 2 MW wind farm at Ten Mile Lagoon, near Esperance on the state's south coast. Ten Mile Lagoon was Australia's first commercial wind farm, and began operation in 1993. This farm delivers power to Esperance's 16.2 MW diesel powered grid and provides about 12% of the area's electricity. The paper will provide the history of Ten Mile Lagoon, and discuss the planning and development processes, including the ongoing monitoring of the farm's performance. In particular, the paper will cover the performance of the farm to date and the effect the wind energy input has had on the local Esperance grid.*

1.0 Introduction

As the name implies, the state of Western Australia (WA) lies on the far western side of Australia. With a land area of over 2.5 million kilometres, WA occupies a third of the total land area of the country yet its population is little more than 2 million. Many of these people live in isolated and remote areas which makes for an interesting electricity supply network involving large interconnected and small independent systems.

Western Power* is the principal company supplying this electricity and this paper is about the steps taken to successfully incorporate wind energy into these systems. In particular it will focus on the largest wind development Western Power has undertaken, the 2 MW Ten Mile Lagoon Wind Farm at Esperance on the state's south coast. This is a very successful farm that operates on a purely commercial basis. It shows that wind energy can really work – it can be competitive, reliable and worthwhile. However, for this to happen requires not only a genuine commitment but rigorous planning and technical evaluation stages. Here the later two will be discussed in some detail, as well as a short description of other work Western Power is doing in the wind energy area.

* *See company profile on the last page*

2.0 Background

It is worth spending time looking at the electricity situation in WA and the history of the wind energy program established by Western Power.

A little more than half of the population of WA resides in the capital city of Perth, which is serviced by a large interconnected electricity system known as the South West System. This 2757 MW system, supplied largely by conventional coal and gas fired power stations, covers an area reaching 500 km north of Perth to Kalbarri, 600 km east to Kalgoorlie, and 400 km south to Albany; this system can be identified around Perth in Figure 1.

Apart from a smaller 95 MW interconnected system in the state's north-west (see Figure 1), supplied predominantly by gas turbines, the remainder of the state's electricity comes almost entirely from diesel generators. The small grids serviced by these diesels are not connected to the interconnected systems and are termed regional systems. The 27 regional systems operated by Western Power range from 16.2 MW at Esperance to 270 kW at Gascoyne Junction.

Currently, a total of 106 MW of regional system load is met by diesels, and the electricity from them is expensive - much more so than large thermal plants. The expense makes alternatives attractive,

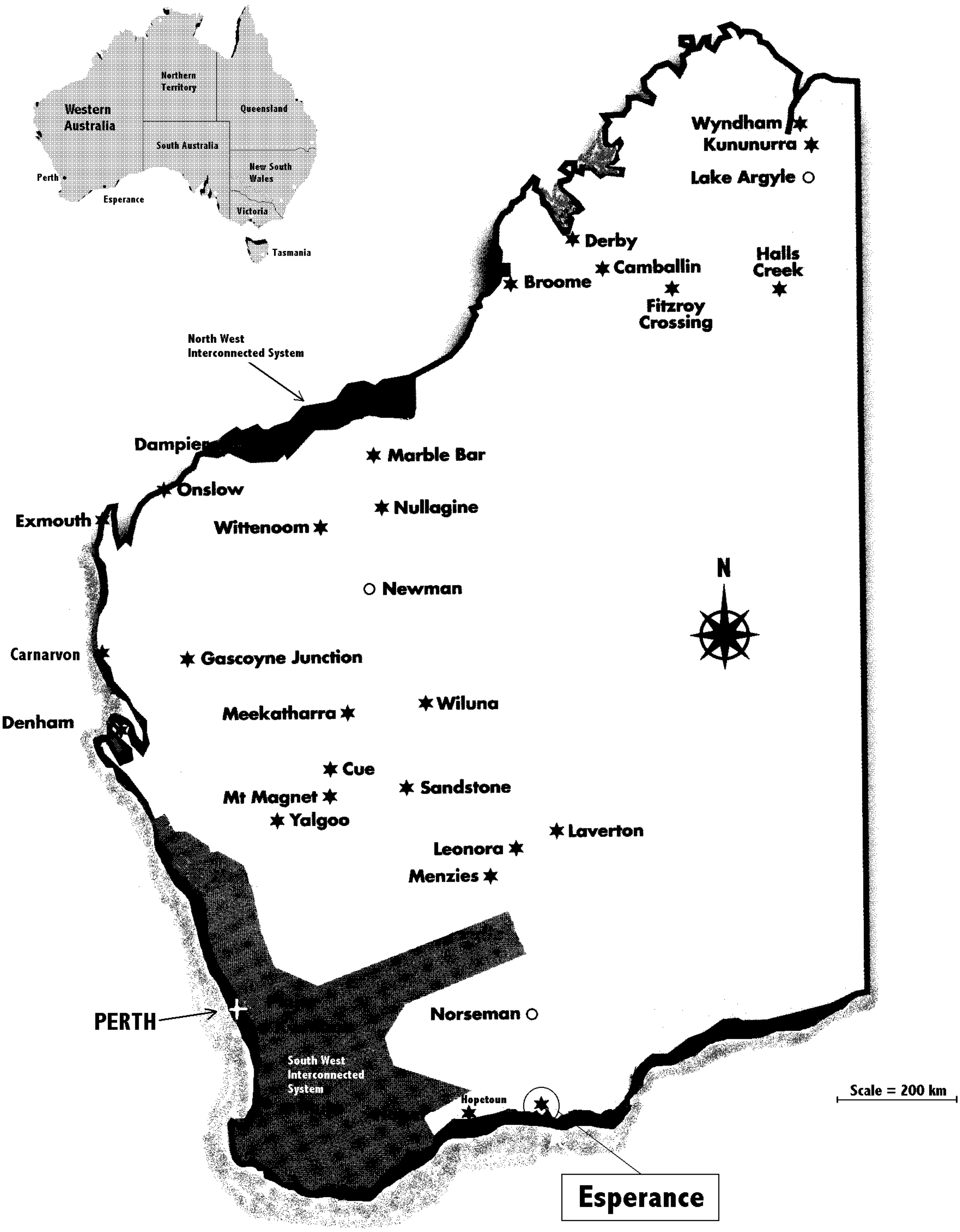

Figure 1. Detail of Western Power's generation & distribution. Regional generation systems owned & operated by Western power are shown as K; privately owned shown as O.

and as a uniform tariff operates in WA a significant business driver is lowering regional system costs. The large distances between regional centres also makes local energy sources attractive and, where competitive, renewables are an option.

Western Power began investigating renewables in the early 1970's, at which time the company was known as the State Energy Commission of Western Australia (SECWA)♣. At that time some uncertainty existed to the supply of diesel, and of the alternatives available wind energy appeared the most cost competitive and promising.

A series of research projects involving 13 horizontal and vertical axis turbines was initiated in 1978, comprising machines from 20 to about 60 kW. The idea here was to gain experience with the machine types and the nuances and basic control aspects of grid connection; the latter particularly relevant to small regional systems. Concurrently, SECWA also invested money in a number of other wind energy related research projects involving universities.

At a similar time a coastal and inland wind monitoring program was established by SECWA, and enough interest was fostered within the organisation that the program was widespread and well done. WA has some of the best winds in Australia; some locations have mean wind speeds approaching 9 m/s at ten metres with very low turbulence. On the basis of the success of this monitoring program, a larger wind turbine development was proposed and approved for Salmon Beach, near Esperance in the south of the state, to provide power to the town's diesel grid.

The Salmon Beach wind farm began generating in March 1987, and this year celebrates it's tenth year of operation; Figure 2 shows a close-up of one of the turbines. The farm consists of six 60 kW Westwind, upwind, three bladed, constant speed machines that use blade stalling and tip brakes for overspeed control. Set up primarily as a research project, SECWA's investment and experience with previous turbines paid off in that a reliable and effective machine was chosen. The manufacturer, Westwind, is an Australian company which worked with SECWA in developing the turbine.

It should be noted that, at the time, turbine technology was still very much developing, especially in regard to operation on isolated and small grids. The farm was therefore quite a risk, and reflecting this is that 34% of the project funding was from a government agency, the remainder from SECWA. Nevertheless, the farm gave valuable experience with the technology - the control systems and electronics were designed and installed by SECWA for example - and proved the worth of wind power on such a system. In its first year, the farm produced almost 1 million kilowatt hours and reduced Esperance's diesel use by about 250,000 litres.

The Salmon beach farm provided the impetus and confidence to proceed with a larger wind farm and the result was the Ten Mile Lagoon 2 MW installation. It is worth noting that no legislative framework exists in Australia that encourages the use of renewable energy. While the Salmon Beach farm included a government funding component, Ten Mile Lagoon operates on a purely commercial basis, with no government support. Economics still drive the use of renewables by Western Power, though other benefits, especially in relation to "greenhouse gas" issues, are increasingly a contributing factor. For example, Western Power has a Greenhouse Co-operative Agreement [1] with the Australian Federal Government which aims to lower the production of greenhouse gases; this includes an increasing contribution from renewable energy.

Figure 2. One of the six machines at Salmon Beach.

♣ *SECWA was corporatised and changed its name to Western Power Corporation on 1st January 1995*

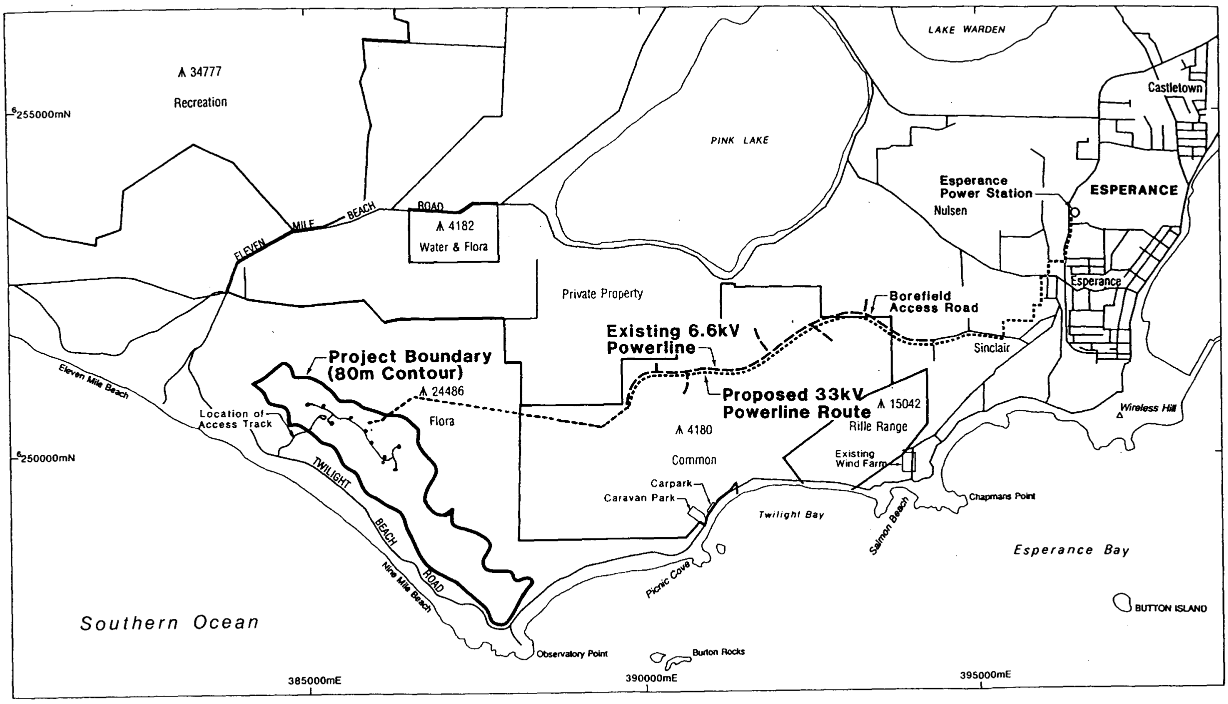

Figure 3. Detailed map of Esperance area, showing Ten Mile Lagoon Project Boundary (lower left) with final machine position and access road. Scale of map gives approximately 25km left to right, and North is up page.

3.0 Ten Mile Lagoon Wind Farm

The 2 MW Ten Mile Lagoon Wind Farm began operation in October 1993. Since then, Western Power has treated the farm simply as any other piece of generation plant and in a competitive environment that's the way it has to be. The reality is that it's contribution both to the Esperance supply and Western Power as a business has been outstanding, though we are still learning how to best incorporate wind energy into these systems. This means research is ongoing and the reader may be interested in some of the published material on the farm; those publicly available include Stann [2], Hartley [3], Rosser & Carr [4,5], and Rosser [6-8]. Only a brief description of this research work is included in the following. The reader is also directed to Western Power's internet page which includes information on Ten Mile Lagoon [9].

3.1 Initial Planning

The initial success of the Salmon Beach Farm prompted proposals for larger wind farms within Western Power and, for various reasons, a size between 2 and 3 MW was believed the most economic and was given Board approval in December 1991. Esperance was again chosen as the best site for this development due to; the average wind speed in the area which was about 7.5 m/s; unlike other regional centres, the size of the Esperance system could accommodate a farm of this size; the fact that the local diesel power station was permanently manned; and, the overall economics at Esperance were better than elsewhere.

Further monitoring in the Esperance area began in 1990, with two sites targeted and meteorological masts installed in an area to the north-west of Salmon Beach. This area was selected as it was within acceptable distance from existing electricity distribution lines, had reasonable access, and was situated on land which involved no easily identifiable issues which would prevent development. The ground was also the highest in the area, and a project boundary was defined as all land above an 80 metre contour (above sea level). The highest point enclosed by this boundary was approximately 100 metres. Figure 3 shows a map of the Esperance region showing the project boundary.

The land defined by the project boundary and in fact most of the area surrounding Esperance is of great natural beauty and somewhat fragile. It was appropriate in the planning process and indeed required by the Environmental Protection Authority (EPA), that the impact of the farm on the area should be assessed. This was done through a formal environmental assessment and investigative report [10].

This report looked at many issues including likely impacts on flora and fauna, effects of excavation and civil works, noise issues, and the possible effects on heritage sites including aboriginal sites. The report also set down guidelines for the development in terms of rehabilitation of surroundings and construction techniques. One very important aspect was the effect of the project on the visual resource. While it was impossible and simply impractical to hide the turbines, computer modelling techniques were used to assess the likely visual impact from various locations within the Esperance region. By placing transmission lines in gullies and using the natural contours to cover the access roads the impact of services visually was also kept to a minimum.

Following submission of the report the planning process began, involving clearing the development with all interested parties and government authorities. Interestingly, during the approval process not one public objection was put forward. Time was spent in Esperance to answer public concern through information sessions and this public openness, combined with the local experience with the old farm at Salmon Beach, no doubt contributed to the lack of objections.

3.2 Development

From initial Western Power Board approval till wind farm completion took almost exactly two years. The majority of the farm development work was contracted to Australian Defence Industries (ADI), whose successful tender included the use of Vestas machines. The order to ADI was placed in October 1992. ADI took over farm design, turbine siting and procurement, and civil and construction work. All this was overseen by an in-house project team with guidance from the EPA and the Department of Conservation and Land Management (CALM).

Micro-siting was subcontracted by ADI to the Danish firm Tripod. Preliminary micro-siting was

Figure 4. One of the turbines at Ten Mile Lagoon being assembled; photo shows rotor being lifted into place.

done, however, by Western Power using the Wind Atlas Analysis and Application Program[∇] (WAsP), and a preferred turbine arrangement arrived at which corresponded well with what Tripod eventually suggested. Western Power also undertook power line construction, the installation of the diesel power station interface and control, and organised road construction with the local shire council. Other than the turbine nacelles, rotors and controllers which were supplied by Vestas, all other materials and construction (including the turbine towers) were supplied by Western Australian companies.

Figure 4 shows a photograph of one of the turbines being erected and Figure 5 the completed Ten Mile Lagoon Wind Farm.

3.5 Farm Technical Description

The farm consists of nine Vestas V27 225 kW turbines which gives it a rated power output of 2.025 MW. The turbines are three bladed, pitch

[∇] *WAsP is a product of the Department of Meteorology & Wind Energy, Risf National Laboratory, Denmark.*

Figure 5. The completed Ten Mile Lagoon 2MW wind farm at Esperance. This photo taken during farm commissioning, and since then most of the construction roads visible have been revegetated.

Regulated, upwind machines with active yaw. They employ asynchronous induction generators with switcheable windings, which allows operational rotor speeds of 32 and 43 RPM for low and high wind speeds respectively. These generators employ thyristor cut-in to control in-rush current and have a 2-stage capacitor bank to supply power factor control. The turbines have a hub height of 32m and a blade diameter of 27 metres.

The farm is located 15 km from Esperance's diesel power station. This station consists of 16.2 MW of diesel generation (4 x 1.2 MW; 1 x 2 MW; 3 x 2.3 MW; and 1 x 2.5 MW units) feeding a two bus system; one 33 kV and one 6.6 kV. The 33 kV bus serves predominantly rural loads, while the 6.6 kV bus serves the township. Ten Mile Lagoon is connected to the 33 kV bus via a dedicated above ground 33 kV feeder. Low voltage (690 V) reticulation from each turbine to the step-up transformers feeding this line is underground.

Connection of Ten Mile Lagoon at the power station included upgrading work considered necessary to guarantee system stability. This included the fitting of electronic automatic voltage regulators and governors to the diesels which replaced slower acting mechanically based units. It also included installing a Vestas Central Monitoring and Control System computer controller, which provides farm control and performance data processing via radio and telephone links.

At the time of installation, some constraints were imposed on the penetration of Ten Mile Lagoon and its interaction with the diesels. It was believed that small time scale changes in wind speed would result in uncertain farm output - large fluctuations in power output and resulting system instability problems were thought possible. The single 33 kV feeder was also believed vulnerable to faults. Therefore a policy of limiting the farm's penetration to 30% was enforced, as was making available enough spinning diesel reserve to cover the farm's output. Completing the constraints was that no diesel would operate below 50% rated power to prevent cylinder damage.

The main imperative behind the constraints was to maintain within Esperance's system Western Power's Supply Standards; a system voltage of 240V ± 3% and frequency of 50 ± 1 Hz. Consequently, at times of low system load (< 5000 kW) the farm's output was limited by monitoring and closing down machines if the wind penetration was too high. Under these constraints the farm was predicted to have an annual output of 5.3 GWhr and save 1.6 million litres of diesel. It was expected to supply about 14% of Esperance's electricity requirements.

<u>3.6 Technical Performance</u>

Ten Mile Lagoon has so far produced 19 GWh of electricity with an average capacity factor of 32% and availability of 98.4%. The farm has saved about 5 million litres of diesel and avoided the production of 14500 tonnes of carbon dioxide. It has therefore reached and exceeded expectations.

The turbines themselves have operated well with no major mechanical problems or maintenance issues encountered. Lightning strikes have proved somewhat rare but problematic, with one strike in December 1994 causing serious electrical damage. Measures were taken to improve lightning protection following this event. Another, more frustrating than serious problem, is communication between the Esperance power station and the farm which sometimes proves difficult. Regular turbine maintenance is carried out every six months which involves visual inspections and grease and oil changes. The twelve monthly service is carried out under the supervision of a Vestas technician who is flown in from Denmark for a ten day period.

Three years of operational experience and a system load which has grown by about 30%, have led to changes to the original farm operational criteria. At times, the farm has had an average penetration level as high as 50% - including instantaneous readings of 70% - without system stability being compromised. Interestingly, the amount of penetration and spinning reserve have become dependent on the individual power station operator. Some operators believe Ten Mile Lagoon's output is predictable and operate the diesels with a limited spinning reserve and high wind penetration. Others prefer to run with a greater safety margin and maintain the 100% spinning reserve.

Regardless of operator preference, there is a case for lowering the spinning reserve, especially when the system load is low and winds are good. Rosser & Carr [5] showed that under these circumstances the diesels at Esperance are forced to run sub-optimally and, therefore, inefficiently - diesels run most efficiently when heavily loaded. They showed that, over an extended period, the wind farm input caused a 2% drop in diesel efficiency, measured as litres/kWh.

Another study directly targeted the effects of the farm on system stability. Rosser [7] looked at variations in real and reactive power caused by the turbines - reactive power support is especially critical on small or "weak" grids. He found that kW and kVar fluctuations directly attributable to the farm were of order of that typically found on rural feeders, that is, small. He also found that the number of generating turbines, *n*, had a "smoothing" effect on fluctuations roughly proportional to $1/\sqrt{n}$. Adding more turbines did produce more power then, but fluctuations per machine decreased as *n* increased.

Western Power continues to debate the correct operational criteria for a system such as Ten Mile Lagoon. It appears the original stability concerns were unfounded, though the best levels of penetration and spinning reserve are hard to quantify. In a nutshell the problem is reliable prediction of farm power output - this in turn means accurate prediction of wind resource on short times scales which is inherently difficult. We nevertheless aim to continue research believing that the contribution from wind at Esperance can be improved.

<u>3.7 Financial Performance</u>

Before concluding, some comment should be made on financial performance which due to commercial sensitivity must remain limited. Ten Mile Lagoon cost AUS$5.8 million[⊗] to develop and at the time of installation had a payback period of 12 years. In 1995 the Australian Federal Government announced an excise on light fuel oil which doubled the cost of diesel generation in Esperance. The payback period for Ten Mile Lagoon was effectively halved, making wind energy particularly competitive in Esperance.

4.0 Conclusions

As a utility, Western Power has an obligation to meet the electricity demands of its customers as efficiently as it can, and, on diesel serviced loads, wind energy offers a means to do this. The driving force behind wind installations remains economics, and without any government lead this situation is difficult to change. It is simplistic to say, however, that utilities are blind to the environmental benefits of renewables and the need for concerns like greenhouse gas production to be recognised. Western Power recognises these things and is active in ensuring that they contribute to the direction of the business.

Ten Mile Lagoon was a successful project on both economic and environmental grounds. Its success ensured that other regional systems are actively

[⊗] *AUS$1 equals approximately US$0.78* targeted and assessed for further wind input. At the time of writing funding for a 250 kW variable speed turbine has just been approved for installation at Denham, a 1.8 MW regional system 900 km North of Perth. This turbine offers an interesting comparison with Esperance as its energy capture should be better. As it uses more flexible inverter grid connection the regulatory load should also be smaller.

Western Power is also considering a wind input into it's South West System. While it is probably some time before wind energy can compete directly with coal and gas fired generation in WA, the remarkable drop in costs of turbines, a growing interest in "green electricity" schemes and a recognition of greenhouse issues may make this input possible. Monitoring continues at a number of locations with suitable infrastructure and wind resource, though particular issues associated with urban wind energy developments - such as community and land access issues - will require greater effort.

Interestingly, the benefits to the community of Esperance from Ten Mile Lagoon have been large. Western Power ensured the general public could visit the wind farm, and installed a weatherproof display at the site and opened the access road to the general public. Approximately forty thousand people visit the farm every year – which for a remote site is particularly impressive – and while most of these people visit other attractions in the area there is no doubt that the farm is a major tourist asset. Wind energy can not only work for utilities then, it can work for the community that uses them.

5.0 Acknowledgements

The author expresses thanks to colleagues from the Energy Technology & Environment Branch and Regional Power Division of Western Power for comments on the draft of this paper. Mr Brian Hampson from Esperance power station provided technical support and this was appreciated.

6.0 References

[1] "Greenhouse Co-operative Agreement; a cooperative agreement between Western Power Corporation and the Commonwealth of Australia", Western Power Corporation, September, 1996.

[2] Stann, I. (1991) "Pushing wind to the limit", Proceedings of the 1991 Australian and New Zealand Solar Energy Society Conference, 5-7 December, Adelaide, South Australia, Australia.

[3] Hartley, J. (1993) "Esperance 10 Mile Lagoon Wind Farm", Proceedings of the 1993 Australian and New Zealand Solar Energy Society Conference, T. Pryor (ed.), December 1-5, Fremantle, Western Australia, Australia, pp. 147-152.

[4] Rosser,M. & Carr, M. (1994) "Wind as a Diesel Fuel Saver – Australia's First Commercial Wind Farm", CADDET, Vol. 1, 95, pp.8.

[5] Rosser, M. & Carr, M. (1994). "Australia's First Commercial Wind Farm – Ten Mile Lagoon", Proceedings of the Electrical Engineering Congress, November 24-30, Sydney, NSW, Australia, pp. 293-298.

[6] Rosser, M. (1994) "Ten Mile Lagoon Performance Analysis", Proceedings of the Asia pacific Wind Energy Centre Workshop, July 4, Monash University, Melbourne, Australia.

[7] Rosser, M. (1995) "Fluctuations in Real and Reactive Power from a 2 MW Wind Farm Interconnected with a 14 MW Diesel Power Station", Proceedings of the Australasian Universities Power Engineering Conference, 29 September, The University of Western Australia, Perth, Australia, pp. 1-7.

[8] Rosser, M. (1994) "2 MW Diesel Integrated Wind Farm – Research Results", Proceedings of the 1994 Australian and New Zealand Solar Energy Society Conference, G. Morrison, D. Prasad & M. Watt (ed.s), 30 November-3 December, Sydney, Australia, pp. 553-556.

[9] Western Power's renewables internet page is at; *http://www. wpcorp.com.au/envir/renew.htm*

[10] "Consultative Environmental Review - Proposed Esperance Wind Farm. For The State Energy Commission of Western Australia", Consultative report written by Dames & Moore Consulting Environmental Engineers, Job Number 08038-171-071, June, 1992.

Western Power

Western Power is the principal supplier of electricity in Western Australia, serving 725,000 customers. It generates 72.5% of the state's electricity including 2852 MW on two large interconnected systems, and 106 MW on small regional grids. It has a workforce of 3,500 and fixed assets of AUS$2.7 billion. Western Power was formed by the Corporatisation of the State Energy Commission of Western Australia (SECWA) in January 1995.