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WOKING PARK PAFC CHP MONITORING

Phase 2: Monitoring, Performance and Operational Experience

CONTRACT NUMBER: F/03/00178/REP/2

URN NUMBER: 04/2041

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WOKING PARK PAFC CHP MONITORING

PHASE 2: MONITORING, PERFORMANCE AND OPERATIONAL EXPERIENCE

ETSU F/03/00178/REP/2

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The work described in this report was carried out under contract as part of the DTI Technology Programme: New and Renewable Energy, which is managed by Future Energy Solutions. The views and judgements expressed in this report are those of the contractor and do not necessarily reflect those of the DTI or Future Energy Solutions.

First published 2005

EXECUTIVE SUMMARY

This report covers the operation of the Woking park fuel cell CHP system from initial operation in January 2002 until September 2003. The period up to commissioning was covered by an earlier Phase 1 report.

The Woking Park 200kW fuel cell has now been operational for over a year. There have been a number of teething problems, as would be expected for a relatively new technology, even one such as the UTC PC25C phosphoric acid fuel cell, which has been tried in a variety of different environments. The Woking site is perhaps unique in the extent of its ambition in a UK context, both from CHP and private wires electricity generation perspectives, and importantly continues to develop around the fuel cell. The real lessons of the fuel cell therefore continue to be learned and this report has only produced an interim indication of its potential in this type of application.

The fuel cell supplies electricity (200kW) to the Leisure Centre and Pool in the Park at Woking via a private wires network. It also provides up to 264kW of thermal energy via low and high grade heating circuits. The high grade heat provides heat to the pool and leisure centre as well as air conditioning via an absorption chiller. The low grade heat is currently used to provide domestic hot water to the leisure lagoon. A thermal store was also incorporated into the system in 2003 to improve the usage of the hot water. In the longer term, as part of Woking Borough council's wider plans electricity will be provided over an extended private wires network to sheltered housing in the Borough, providing a secure source of revenue for the power.

The performance of the fuel cell has matched that found from the many previous installations, and its overall availability has exceeded 90%. There have been some unplanned outages, and unexpected failures of electrical systems have necessitated the running of the fuel cell at less than full load for extended periods. In particular, matching the operating voltage of the fuel cell with that of the local distribution network proved an unexpected challenge, necessitating the installation of an extra inline transformer.

Energy performance has been close to that expected, with electrical efficiencies of above 37% Lower Heating Value (LHV). The stack degradation common to phosphoric acid fuel cells was observed leading to a drop in electrical efficiency over the monitoring period. This ultimately led to a lowering of the electrical output to 195kW to counter the fall in efficiency. It is not known yet whether the rate of stack degradation will necessitate early stack replacement. Not all the thermal load has been utilised from the fuel cell. An overall efficiency of around 85% is possible, but only 57% is typically achieved, even with the thermal store. Much or all high grade heating appears to be utilised, whereas only around 10% of the low grade heat is used. This usage pattern has still been sufficient to allow CHPQA certification, which will in turn allow significant savings on energy costs through CCL exemption. However until all heat is utilised it is difficult to distinguish the fuel cell CHP performance from that to be expected for more conventional prime-movers with efficiencies in the 60% range. This in turn impacts on the overall economics of the facility.

Environmental performance has been in line with that expected for fuel cell technology with natural gas reforming. NOx and CO levels are minimal, and NOx savings relative to

reciprocating engine based CHP are estimated to be of the order of 900kg over the first 14,000 hours of operation.

The true potential of the fuel cell may well be realised when the Phase II Woking Park CHP system is operational, and the extended private wires scheme is in place. This period will be covered by a future monitoring report.

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1. INTRODUCTION

The PC25 is currently the only fuel cell cogeneration unit available commercially. It delivers 200kW of electricity at just under 40% electrical efficiency with commensurate heat, allowing total efficiencies of around 85%. Several hundred of the units are now installed around the world. The PC25C installed at Woking Park during 2001, and put online in January 2002 is the first such unit in the UK, and forms part of a groundbreaking private wires and cogeneration system which continues to develop around the fuel cell system.

The background to this project and the details of the purchasing, installation and commissioning of the system were given in the Phase 1 report preceding this one, which is now available on the DTI website[1]. That report also illustrated Woking Borough Council's highly innovative approach to energy projects, which put it at the forefront of sustainable energy implementation in the UK. This report sets out to summarise the performance and operation of the fuel cell system in its first period of operation up to October 2003.

The installation on the Woking Park site has continued to develop:

- Landscaping of the fuel cell enclosure has continued, with inclusion of a technology information display, a mural illustrating the history of fuel cells, and a newly commissioned statue of William Grove. This culminated in the opening ceremony in June 2003.

- Since the commissioning of the fuel cell system in 2002, work has continued on the private wires and on-site district heating system.

- A Thermax 500kW absorption chiller has been installed in the compound adjoining the fuel cell.

- A 100m^3 hot water thermal store was erected and commissioned in the nearby utilities compound in March 2003.

- Phase 2 of the Woking Park CHP project will install 836kWe + 978kWth of conventional CHP plant during 2003-4.

Although these aspects are not strictly speaking part of the monitoring project, their commissioning will impact on the outputs of the project, and will ultimately affect the economics of the fuel cell system in the longer term. More importantly for this phase of the project, down times and anomalies in the heat and power usage can often be traced to the implementation of these facilities.

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[1] Woking Park PAFC Monitoring Phase 1 Report, http://www.dti.gov.uk/energy/renewables/publications/pubs_fuel_cells.shtml

2. INSTRUMENTATION AND DATA GATHERING

2.1 Monitoring software

Advantica are monitoring the fuel cell by modem access of the TREND Building Management System installed at Woking Park. Specific sensors have been installed for the monitoring project and interfaced with the Trend system (Table 1). The Windows NT based 962 supervisor system is used to provide data management and visualisation through a graphical interface. Figure 1 shows a typical screen from the TREND system. The system allows collection of data at intervals ranging from every 15 minutes to several hours. Data files are stored on the system and begin to refresh when maximum file size is reached. Separate data files store the information as daily, weekly and monthly and cumulative data sets. Each of those other than the cumulative information resets to zero at the end of each daily, weekly or monthly period.

TREND Dataset	Meter	Unit
Electricity Generation	TREND Em/3+Electricity meters, CT and CTX current Transducers, voltage meters	kW, kWh
Low temperature hot water (LTHW)	Kamstrup ULTRAFLOW ultrasonic flow meter with differential temperature energy meter conversion	kW, kWh
High temperature hot water (HTHW)	“	kW, kWh
Water system	Ultrasonic flow meters	litres
Gas consumption	Gas flow meter, temperature and CV based energy conversion	m^3

Table 1. Basic TREND instrumentation

Gas flow in sm^3 is recorded within the TREND system. This is converted into Calorific Value (CV) using gas quality information obtained from Transco. CV, energy content and efficiencies within this report are calculated using lower heating value (LHV) unless stated otherwise.

Additionally, internal systems and subsystems for the fuel cell plant are available through the ONSI/ UTC RADAR (Remote Automated Diagnostics and Data Acquisition and Recording) system which is again monitored directly through a dial-up interface. This only provided Advantica with real time read access of the systems.

Figure 2 illustrates schematically the part of the Woking system which is relevant to the monitoring project.

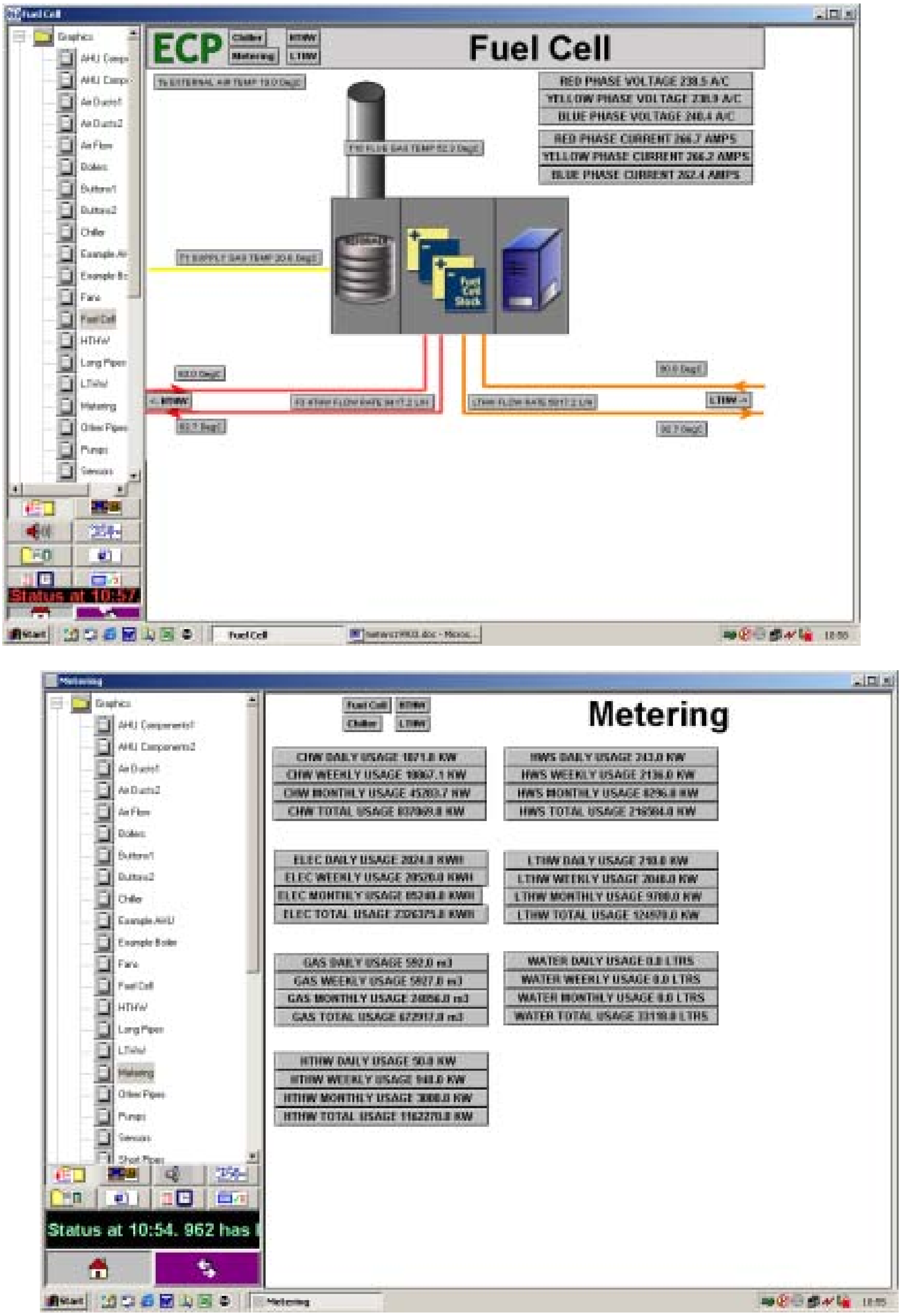

Figure 1. TREND Screendump

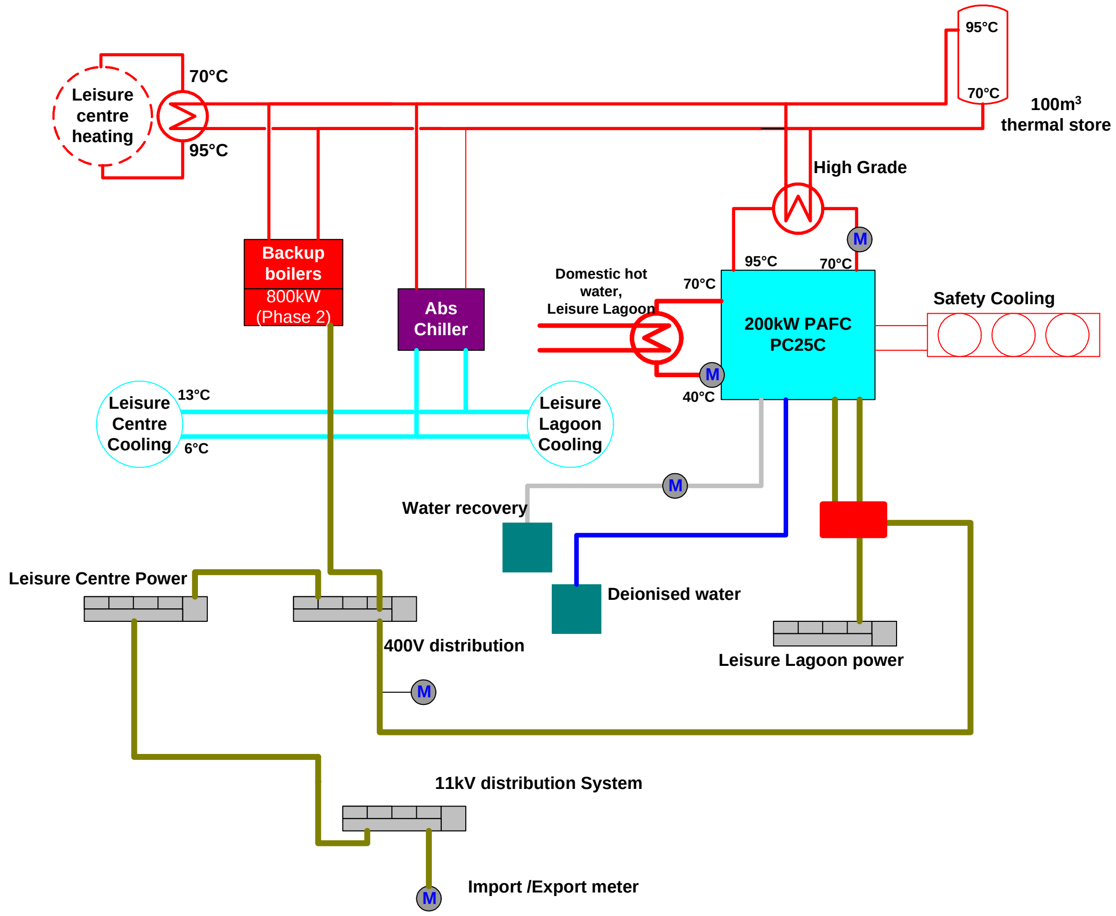

Figure 2. Schematic of Woking Fuel cell System

3. PERFORMANCE MONITORING

3.1 Gas Quality

Table 2 illustrates the gas quality for the Woking site referenced to the specification provided by UTC.

Composition	Woking (mol%)	Maximum Specification PC25 (vol%)
Methane	89	100
Ethane	5	10
Propane	1.6	5
Butanes	0.4	1.25
C5+	0.2	0.5
CO_2	1.2	3.0
N_2	2.5	4.0
Total sulphur	3 ppmV	30 max ppmV

Table 2. Gas quality Information

3.2 Availability Information

At the 30th September 2003, the fuel cell had been on line for approximately 14,000 hours and generated 2,400MWh of electricity. At present virtually all this electricity is being used on site via the private wires network at Woking Park. Likewise all heat generated is either used onsite or rejected via the fuel cell safety cooling system.

The availability of the fuel cell plant is obtained from the UTC web site on a rolling basis. Table 3 illustrates this information as recorded on 23rd September 2003. Figure 3, which shows power output as a function of time, gives an indication of how this availability has fluctuated with time online.

	Operating Performance		MTBFO*
	30 day	12 month	
Woking Plant	100%	90.4%	1423
UTC Fleet	91.3%	95.2%	2193

* Mean time between forced outages

Table 3. Availability Information

The relatively low value for the mean time between forced outages reflects some of the teething problems in the first year or so of operation, as well as the continued development of site, for example the commissioning of the absorption chiller and thermal store. More detail on these issues can be found in section 5 below. It is important to remember that many of the existing fleet of PC25 units have been operating for a number of years, and are often not used in cogeneration applications as sophisticated as Woking. A US Department of Defense study[2] of a fleet of PC25C units reported lifetime MTBFO of around 1594 but with substantial improvement in the most recent year of operation to 2621 hours.

3.3 Energy Performance

3.3.1 Electrical Performance

The graph of electrical output shown in

Figure 3 shows that for much of the period of operation, the fuel cell has been generating 200kW net electrical output. Approximately 13kW of additional electricity is generated which drives the fuel cell systems, pumps compressors etc, but efficiencies are quoted based on the net rather gross electrical generation.

The main exceptions to full rated output were around the annual maintenance shutdown where the fuel cell was running at 150kW due to transformer problems (see section 5) and since August 2003 where the output has been dropped to 195kW to compensate for stack

[2] M Binder, W R Taylor and F H Holcomb, Experience with the DOD fleet of 30 fuel Cell Generators, IGRC 2001

voltage degradation, which would otherwise lead to lowering of electrical efficiency. A cooling water circulation pump impellor upgrade was fitted to improve the circulation rate to the stack on 29th September enabling the output to be returned to 200kW.

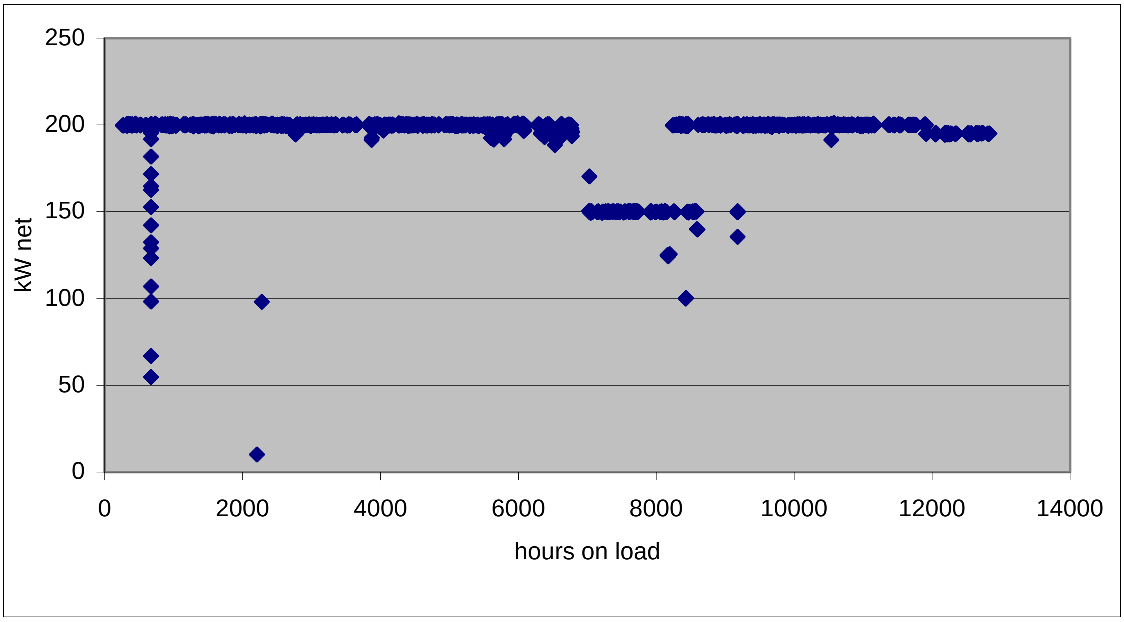

Figure 3. Electrical output of fuel cell since commissioning

The electrical performance of the fuel cell can be further expressed as cumulative electrical output in kWh. Figure 4 shows the cumulative electrical performance as well as the cumulative usage of high temperature and low temperature hot water (HTHW and LTHW); Figure 5 shows the resulting electrical and thermal efficiencies, calculated relative to the LHV of the input fuel.

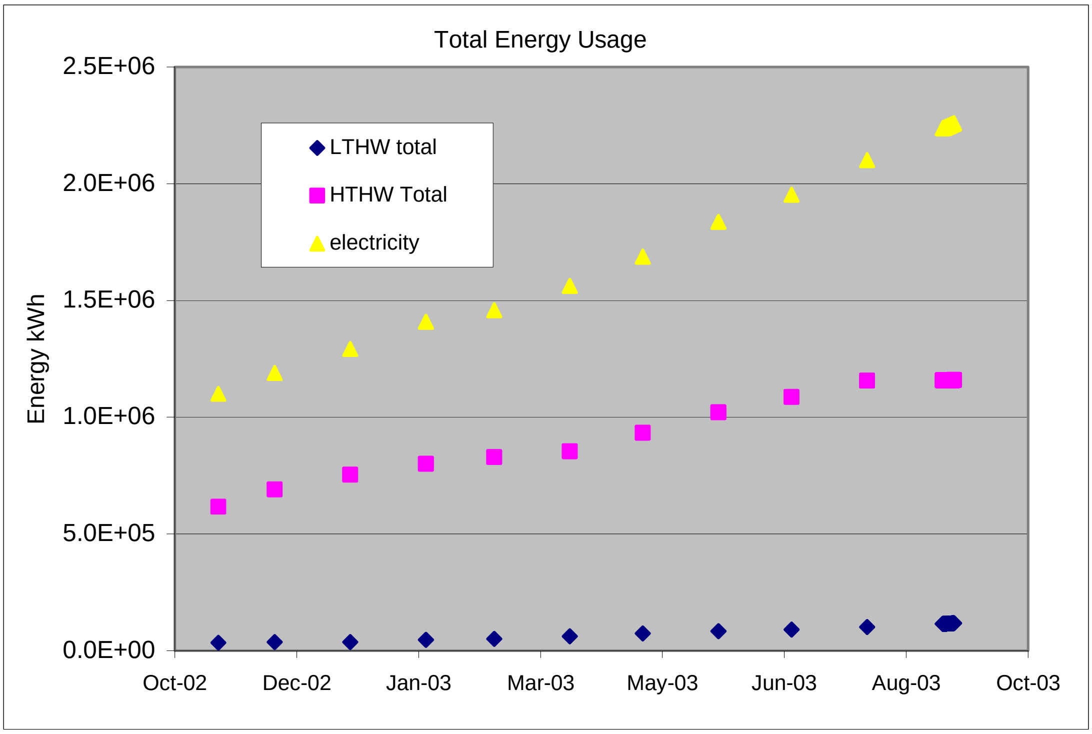

Figure 4. Energy usage from the fuel cell

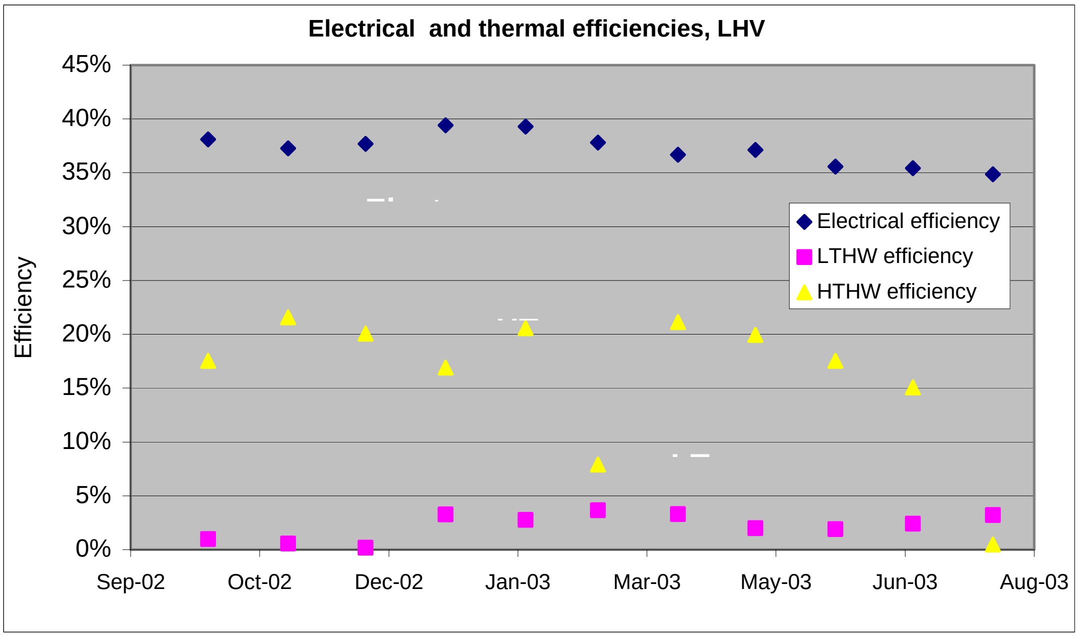

Figure 5. Electrical and thermal efficiencies

3.3.2 Heating Load

The original heat output of the fuel cell CHP was rated by UTC Fuel Cells as 205kW which was later up-rated to 264kW following the results of demonstration projects in the field. With the high-grade heat option 132kW is delivered at 70°C and 132kW is delivered at 120°C.[1]

However, the site configuration utilised the low grade thermal output (LTHW) to supply the Leisure Lagoon hot water services heat exchanger and the high grade thermal output

(HTHW) to the district heating heat exchanger circuit (which supplied the Leisure Lagoon and the Pool In The Park) at 95°C. Any high-grade heat not utilised is returned back to the low grade heat circuit (which also recovered the heat from the fuel cell internal cooling circuit) and only then if all thermal demands were satisfied is any excess heat rejected through the safety cooler. In March 2003 a 100m^3 thermal store was installed in the leisure lagoon service compound near to the fuel cell, as a separate heat recovery loop. The thermal store holds water at up to 95°C, and provides a third heat recovery loop for the high-grade heat, and was expected to smooth out variations in demand.

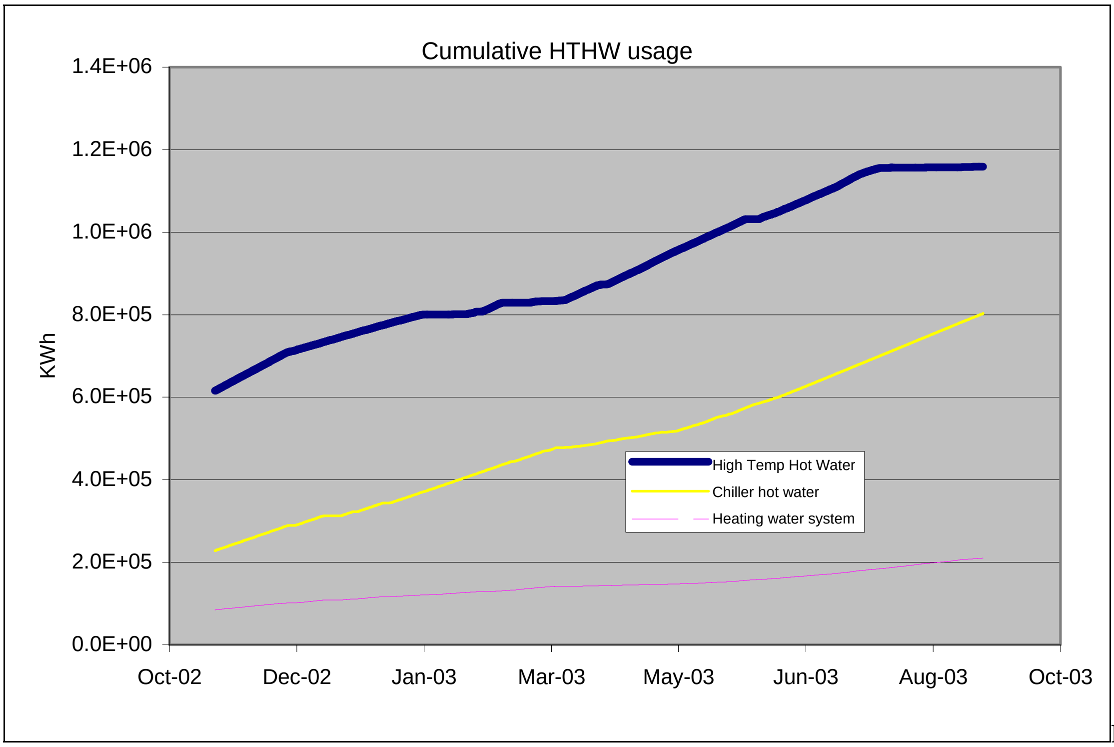

Figure 6. High temperature hot water

The thermal store is at or near full capacity for much of the time and the usage of the high temperature heat resource has typically been good. Figure 5 and Figure 6 taken together show that the high grade heat is being extensively utilised. There are some anomalies in the usage of the HTHW. The drop in March corresponds to installation of the thermal store. The apparent tail-off in late summer 2003 has yet to be explained. Before the installation of thermal store or absorption chiller, it is difficult to trace the total usage of the high grade heat as the total HTHW is significantly higher than the cumulative load from chiller hot water circuits and heating circuits. However, from early 2003, the total HTHW usage corresponds to approximately the sum of the metered quantities of chiller and heating water, with the ratio being approximately 4 to 1. It is possible that prior to this point much of the HTHW was in fact being passed to the LTHW circuit and ultimately rejected. However it should be borne in mind that these numbers can be distorted by the presence of back-up boilers in the high temperature system which supplement the heating load and the chiller hot water circuit.

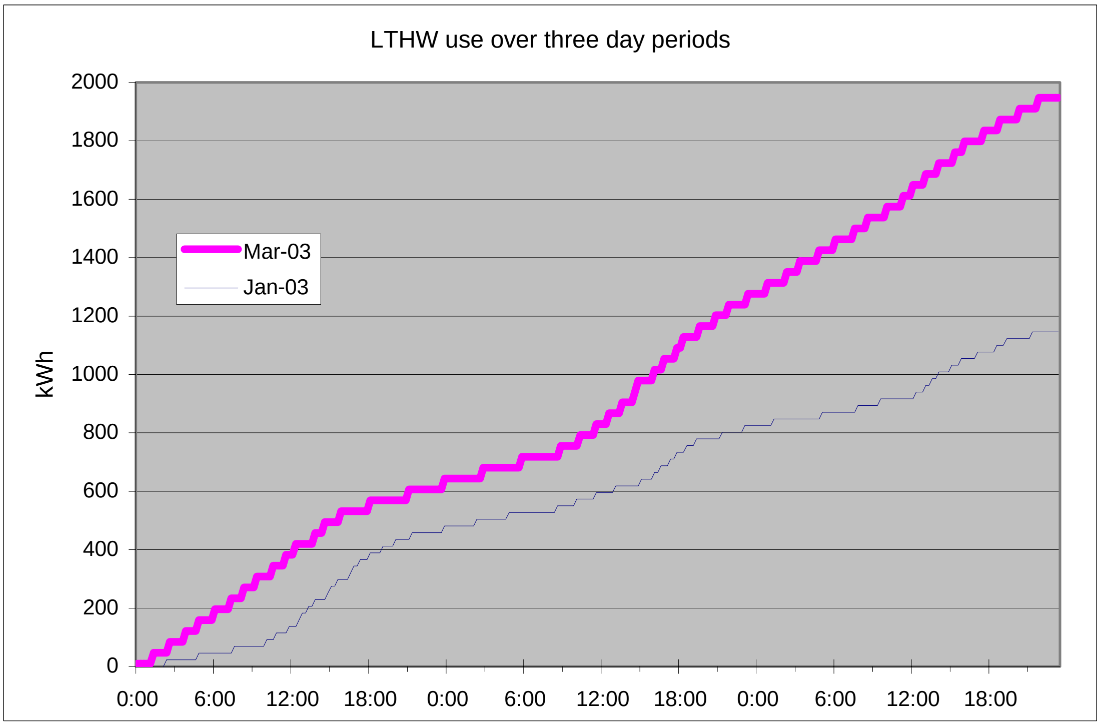

Figure 7. Low temperature hot water periodicity

Data from the low temperature heating circuit appears to indicate that the usage of this resource has remained low throughout with typically 90% of heat being rejected, meaning that the overall thermal output has not exceeded 150kW at this point, well short of the 280kW theoretically available. The usage pattern of the LTHW explains why this heating load is under utilised. As the water is used to provide hot water for the domestic system in the Leisure Lagoon, the usage is highly periodic during the day, with no use during the overnight closure period of the centre. Further use needs to be made of the low grade heat from the fuel cell both to improve the overall efficiency of the system and to justify the inclusion of the thermal store in the scheme.

<u>Stack Voltage</u>

As PAFC systems age, the electrolyte in the cell degrades and becomes depleted resulting in a fall in stack voltage. This translates into a reduction power output, and therefore requires that the fuel input is increased in order to maintain the same electrical output. At the same time, the heat production will tend to increase, leading to a fall in system efficiency. A previous monitoring project for PC25C PAFC systems recorded a fall in stack voltage of approximately 5.0% per 10000 hours. The stack voltages recorded for the Woking system are plotted in Figure 8. The voltages are the sum of 32 sub-stack voltages. It can be seen that there is a general trend of falling voltage throughout the recording period. The gradient of these points from February to September 2003 corresponds to a degradation rate similar to the 5% described above.

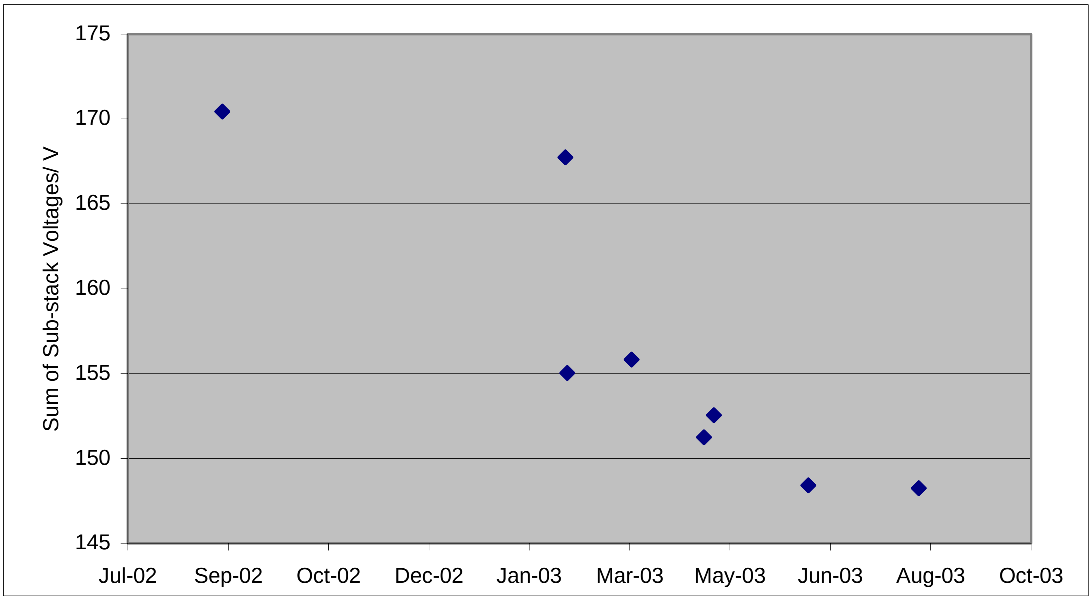

Figure 8. Stack voltage variations

Further monitoring will determine how closely this rate corresponds to the expected rate of decline. More significantly, after annual maintenance shutdown, in January 2003, a significant drop in stack voltage was observed. It is not clear why this happened, although on return to operation at 200kW output, no drop in efficiency was evident, although on the basis of previous experience a drop of 5% in stack voltage only translates to an efficiency drop of 0.8%[2]. Since early August 2003 the fuel cell output has been reduced to 195kW in order to regain electrical efficiency. It is likely that as the stack degrades, the electrical output will need to be reduced further. The alternative is that the electrical efficiency is allowed to fall, offset by heat production. If the resulting extra heat is not used (and it would appear in the LTHW circuit as fuel cell cooling water), there is a danger that the system efficiency could fall below the point at which CHPQA certification can be retained (see section 0).

3.4 CHP rating

The CHP Quality Index (QI) for power plant below 1MW output is calculated according to the formula:

$$230 \text{ x Efficiency}_{power} + 125 \text{ x Efficiency}_{heat}$$

A QI of 100 or over defines the plant as good quality CHP, gains the plant a CHPQA (quality assessment) certificate and entitles the operator to claim Climate Change Levy (CCL) exemption on fuel inputs and power outputs from the plant[3].

The Woking Park fuel cell CHP system was awarded its CHPQA certificate on the 12th June 2003, valid for this calendar year. This entitles the plant to a CCL exemption certificate. For this exemption to remain in force, a valid CHPQA certificate needs to be provided by the 30th of June each year. One condition placed on the CHPQA rating was that a heat meter needs to be provided to measure the rejected heat by 2004.

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[3] www.chpqa.com

3.5 Environmental Performance

3.5.1 Flue Gas Measurements

Flue gas measurements were made using a Land Instruments Lancom III portable flue gas analyser, which had recently been factory calibrated. The numbers in the table below are averages of values obtained from measurements at a number of points in the flue centre and around the internal radius. The flue concentrations for NOx, CO and hydrocarbons are well within specifications for the system. They are also significantly below what would be expected for other types of generation including non-fuel cell CHP and distributed generation. For example, engine based CHP would be expected to produce NOx emissions which can approach 100ppm. Even microturbines, which are perhaps the most established of the new distributed generation technologies at this scale would be expected to produce NOx emissions in the 10-100ppm range depending on load This demonstrates one of the more intangible benefits of such a system. CO_2 savings are very much efficiency dependent. The table below indicates the level of CO_2 and NOx savings for this technology over its first year of operation, against a simple base case of central generation using coal, and relative to other means of providing distributed heat and power.

	Air	Centre of flue	Quadrants at half radius			
			1	2	3	4
CO / ppm	0	3	3	4	5	5
O_2 / %	20.9	18.5	18.3	18.7	17.9	19.2
C_xH_x/ppm	0	30	40	40	50	50
CO_2 / %	0.21	1.59	1.66	1.46	1.86	1.23
NOx / ppm	0	1	1	1	2	1

Table 4. Emissions measurements

Estimated emissions savings at 14000 hours		
Fuel cell vs	NOx saving	CO_2 saving
Microturbine CHP	83kg	For gas fired CHP technologies at similar overall efficiencies, CO_2 emissions will be similar
Reciprocating Engine CHP	920 kg	
Central Generation, coal, 37% electrical efficiency	5000kg	2200 tonnes

Table 5. Emissions savings

3.5.2 Noise Measurements

A noise survey of noise levels produced by the hydrogen fuel cell installation at has been taken using using a type 1 Cassella CEL Ltd integrating sound level meter, type CEL-573.C1. An electronic calibrator was used to check the calibration of the meter at the beginning and end of the survey.

Equipment	Type	Serial Number	Certificate number	Calibration date
Calibrator	CEL 284/2	4/07920926	7829	26th June 2002
Sound Level Meter	CEL 573C1	3/0891596	7328	26th June 2002

Table 6. Equipment calibration details

During the survey the ambient conditions were: 19°C, overcast with occasional rain, wind speed <1m/s. Although the microphone was sheltered from rain as far as possible, the light rain may have affected some of the early measurements.

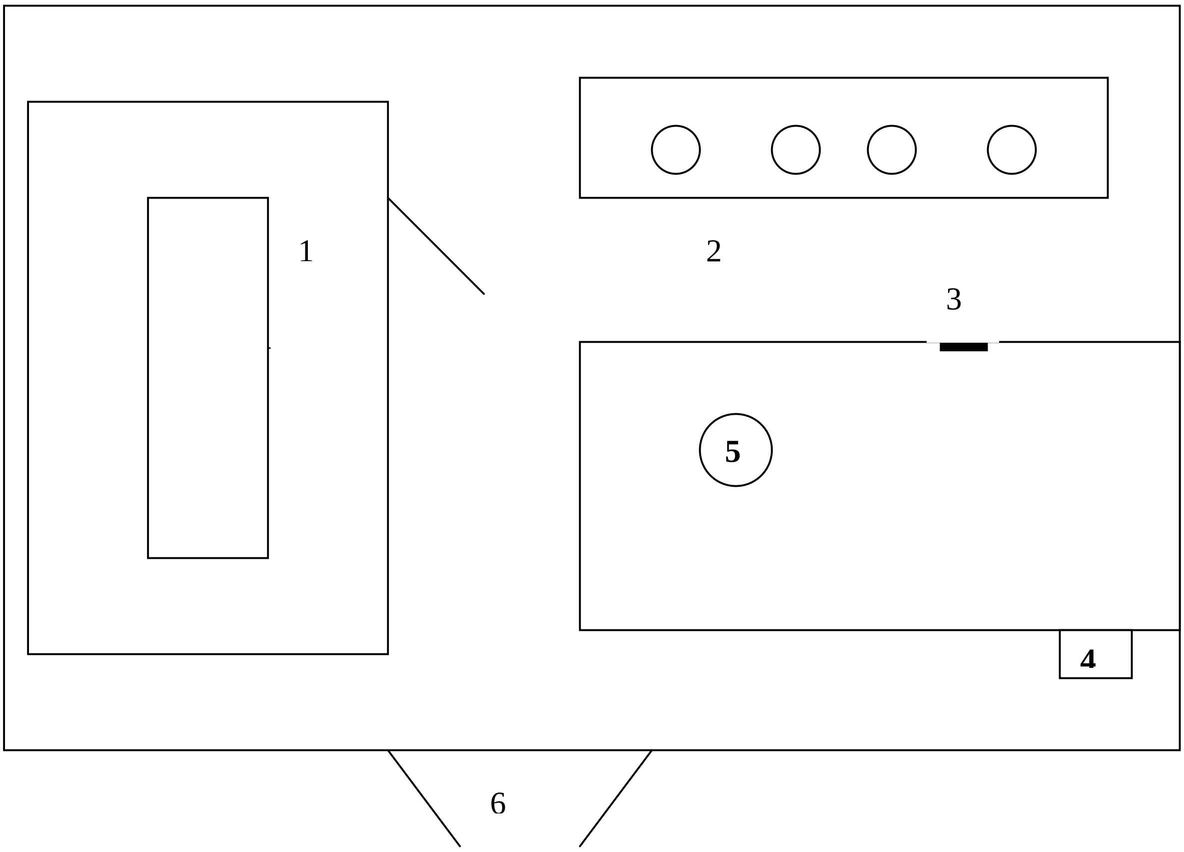
The fuel cell runs continuously and at the time of the survey the cooling fans were also running continuously due to the requirement to dump heat.

Sound level meter measurements were taken at locations identified as principal noise sources as shown in Figure 9, and were of a duration deemed suitable in order to obtain a representative A-weighted equivalent continuous sound pressure level (L_{eq} or L_A) reading. The results of these measurements for each noise source and for three locations outside the main fuel cell enclosure are given in Table 7 below.

Location	**Leq (dBA)**
1. Adsorption chiller pumps	78
2. Cooling fans	77
3. Fuel Cell rear air intake	80
4. Fuel Cell front air vent	75
5. Roof vent	77
6. In front of main enclosure door: doors open doors closed	 65 54
7. 10m from enclosure 1 door open 2 doors open doors closed	 52 55 57 – 58
8. 30m from enclosure doors open doors closed	 50 - 52 57
9. Leisure centre roof chiller fans	81

Table 7. Table of A-weighted equivalent sound pressure levels (Leq)

Figure 9. Noise Measurement Locations



7: 10m directly in front of main enclosure door (near public pathway)
8: 30m directly in from of main enclosure door (in park)
9: Chiller fans on leisure lagoon roof

3.5.2.1 Discussion

The following has been found from the survey:

- The principal noise source directly associated with the fuel cell is the rear air intake (3) producing 80.4 dBA, Third-band octave analysis shows that the maximum noise levels are in the lower frequencies between 50 to 160 Hz. Low frequency noise reflected from the wall of the leisure centre may be audible to passers-by or residents at quiet times. It is understood no complaints have been received and this is supported by the fact that there are no significant tonal elements. Measures to reduce noise are not necessary provided complaints are not received. In the unlikely event that a source of complaints be attributed to the fuel cell a recommended course of action would be to fit a baffle to the rear intake to direct noise downwards to the ground.

- The leisure lagoon cooling fans produce a similar noise level of 80.7 dBA. However the third-octave analysis shows significant low frequency tonal elements (BS 4142 section 8) at 16 Hz and 63 Hz. This supports the identification of these as the likely source of a complaint by a local resident.

- Measurements taken in front of the main enclosure doors (location 6) show a 10 dB attenuation when the external doors are fully shut, suggesting the acoustic enclosure is effective at ground level.

- Measurements taken in the centre of the park show that there is no measurable difference in noise levels at these locations with the main enclosure doors open or closed.

- It was not possible to take background noise level measurements ($L_{A90,T}$, the A-weighted sound pressure level of the residual noise at the assessment position that is exceeded for 90 % of a given time interval, T) as this requires measurement of the residual noise (i.e. fuel cell and fans not running). However, Leq measurements taken at two locations in the park 10 and 30m from the fuel cell (locations 7 and 8) show no measurable difference. This suggests the fuel cell when in continuous running mode does not contribute to ambient noise in the park. It cannot be said that this is case at other locations, other weather conditions or different operating conditions (for example intermittent operation of fans) where noise spill from the open roof of the enclosure may be audible.

- Background noise measurements taken in the park (which can be assumed to be representative of residual noise at the fuel cell location) were in the range 49 – 51 dB (LA_{90}, 5min). This is a fairly typical suburban noise level.

As the fuel cell has been running for some time now and no complaints have been received it is unlikely this will cause complaints provided the plant is properly maintained to ensure resonance (and therefore tonal elements) is kept to a minimum.

3.6 Stack Water

The single byproduct of the fuel cell stack operation is high purity water. It was reported in the Phase I report that Woking Borough Council intended to obtain a certificate of purity for this water from the Drinking Water Inspectorate, prior to investigating the use of the water as drinking water. The purity of the water has been confirmed. However in operation, the fuel cell system recycles much of the produced stack water to the fuel processor for the steam reforming reaction, and actual water output is dependent on temperature. This means that in total, up to the beginning of September 2003 (almost 14,000 hours of operation) only about 30,000 litres of water has been obtained from the system via the plume suppression system, well short of the 650,000 litres theoretically produced by the stack. This water has been disposed of to drain.

4. OPERATIONAL ECONOMICS

The Phase 1 report[1] gave a calculation of the expected payback period for the fuel cell system, based on factory gate, installation and commissioning costs with expected energy savings from a predicted usage pattern. This now needs to be revisited in light of the actual usage patterns and the observed performance and degradation of the fuel cell.

Section 3.5 gave an indication of the expected CO_2 savings obtained from the fuel cell so far and section 3.4 stated that the fuel cell has also received CHPQA certification as good quality CHP. These latter two occurances will potentially lead to an increasing benefit in terms of CCL and levy and future emissions trading advantages. However, for any CHP system operating with similar efficiencies and with similar heat load utilisation, the CO_2 and CCL benefits will be the same. This can similarly be applied to revenues which can be obtained from selling electricity (and heat) across private wires schemes. The economics must therefore be judged on the basis not only of the simple payback period, but also the cost of the system relative to other CHP systems.

In the Phase 1 report a payback period of just over 16 years was calculated, based on a simple estimate of energy cost savings against the Woking Borough council budgeted cost. If a similar payback calculation is done now, but assuming actual maintenance costs rather than those predicted (see section 5), the payback period has if anything extended slightly.

Estimating annual energy costs and usage profiles is the most difficult part of the evaluation of CHP systems, and for Woking, the first year of operation only begins to give an indication of how these will develop. Plans to export electricity over an extended private wires network will only come to fruition in 2004. At that point a more detailed analysis of costs and revenues will enable an illustration of how this scheme compares to the economics of centrally supplied electricity. It should be emphasised again that as long as a portion of the heating load is being lost, the likely overall operational efficiencies of the fuel cell system will compare to other forms of CHP. This will change significantly where the CHP system is being run to provide heat load and extra electricity is exported. The electrical efficiency of the fuel cell is very similar to that expected for engine based CHP. A full economic evaluation will be produced with the phase 3 report, at which point the entire CHP scheme will have been running as part of an extended private wires network for some time.

	Woking Fuel Cell CHP	Engine Based CHP	Microturbine CHP
CAPEX Installed (kW)	5000	750	2000
Electrical Efficiency	37	37	30
Maintenance (£/kWh)	0.02	0.006	0.006

Table 8. Relative Economics of Fuel Cell CHP

If the fuel cell were used to supply electricity to sheltered housing, assuming electricity usage levels of 6kWh per day, approximately 780 houses could be supplied. Revenues would be approximately £6.50 per residence per week for heat and power (i.e. less than 10% of minimum pension income, as required to combat fuel poverty). This translates to a total income of £263,000 per annum, set against fuel cell energy costs of £42,000. Also to be factored into this equation would be the cost of providing the private wires infrastructure and the cost of transporting electricity across the local distribution network to the private wires schemes. However, all these costs are diluted by their occurrence within a significantly larger CHP scheme. It is expected that when the full scheme is operational around 500kW of electricity will be available for export.

5. OPERATIONAL EXPERIENCE

Section 5.1, provided by BTU Heating, reflects the operation and maintenance of the unit, primarily during its first year to January 2003. However, there have been no major additional developments since then.

5.1 Report by BTU Heating Limited

BTU Heating Limited were responsible for the design, installation, commissioning and now for the operation of what is the UK's first commercial fuel cell system. The fuel cell itself was manufactured by UTC. Commissioning took place in December 2001, and the fuel cell has been run only in the grid-connected mode since then. The operational duties have consisted of routine inspection, planned maintenance and reactive breakdown maintenance.

Routine Inspection

This consists of weekly checks at which time a general inspection of the fuel cell is undertaken to determine any visual defects or malfunctions. Any operating anomalies are reported to the manufacturers who remotely dial into the power plant to investigate.

> *The time taken to complete this inspection amounts to two hours per week for one man.*

Planned Maintenance

On a monthly basis the fuel cell stack voltages are recorded and these are e-mailed to the manufacturer.

> *This takes two hours for two men.*

On a quarterly basis the four nuclear grade resin tanks are exchanged, as is the charcoal tank. See explanation to follow.

> *This takes two men nine hours to complete. The resin and charcoal costs approximately £1k per exchange.*

On a quarterly basis the air filters are exchanged.

> *This takes one man five hours to complete. The filters cost approximately £0.1k per exchange.*

On an annual basis the fuel cell system is overhauled.

> *This takes two men between three and four days to complete. The cost of parts and consumables associated with the annual maintenance amounts to £2.9k*

Reactive Breakdown Maintenance

Call out response time is important, as it is vital that the fuel cell stack temperature is maintained. This is therefore required to be within one hour.

The unit can operate in idle mode (no generation) for long periods, typically up to one week, but it should not be allowed to shut down.

Details of spare parts recommended for accumulation on site were requested from the manufacturer in the US. There was no specific or standardised guidance on this at company level overall and therefore the company engineer for this project advised what Woking should hold, in his view. Spares were subsequently purchased to a value of £20k.

5.1.1 Operators General Comments

During the first year of operation the fuel cell has provided reliable energy production, the run hours reaching 8100 at the end of the first year in January 2003.

The main factor affecting fuel cell performance has been that external grid voltage conditions has been outside the operating limits acceptable to the fuel cell. The fuel cell operates at 400 Volts plus or minus 10%. The grid network operates at 415 volts plus 10% minus 6 %. Therefore if the grid condition goes more than 6% over design the fuel cell operation is automatically interrupted. In such circumstances, there is no opportunity for recourse with the supply network as the grid condition has remained within its acceptable tolerances.

When the fuel cell suffers an interrupt, it stops generating immediately and trips to idle mode. In such circumstances, the circuits remain active although no generation occurs. Over one period, the logs were indicating that the unit was tripping to idle up to 26 times per day. To resolve the problem, an inline transformer was installed to reduce the voltage peaks seen by the fuel cell by 7%. This addition had an installed cost of £15k, but has fully resolved the problems associated with fluctuating grid conditions.

The other difficulties experienced with the fuel cell have been due to operating problems with the components of the set. For example the onboard UPS has failed four times during the year, which brought about its complete replacement on two separate occasions. The reason for the failure remains unknown.

The replacement of the ion-exchange resin in the water treatment circuit every three months was not predicted. The fuel cell has a water circulation system for cell cooling purposes. The conductivity level of the inlet water within this system must be maintained at or below 1 micro siemen. In order to achieve this, the fuel cell has a water treatment system on board which comprises one charcoal cylinder and four nuclear grade resin filters, piped in series. A control system monitors the water quality within the fuel cell and raises an alarm when the conductivity level starts to increase. The alarm provides one week's notice to the operatives to change the resin before the fuel cell automatically sets back to idle. At Woking the alarm has activated every three months.

The fuel cell will operate in idle mode for two hours with the resin cylinders out of circuit. Experience has shown that it takes two hours to exchange the cylinders and, consequently, five pre-charged cylinders must be available for exchange on-site in order for the activity to be completed without shutting down the cell stack. It cannot be carried out without the availability of pre-charged replacement cylinders on site. Replacement cylinders of this type are not readily available in the UK.

On occasions when the fuel cell has shut down (UPS failures) the re-start procedure has taken one man five hours to complete and has required two full bottles of nitrogen gas for each re-start. It is therefore necessary to maintain eight nitrogen bottles on-site at all times. The nitrogen costs for the first year of operation have exceeded £1.2k.

On each occasion that the fuel cell has shut down to idle, requiring an engineer's attendance, it has been possible to call up the maintenance staff in the US with little difficulty. They have dialled into the site for information and offered excellent support to the local engineers. Typically the procedure has been to call them, leave a message and a return call has been made within the hour at any time of the day or year.

The annual maintenance inspection was not particularly well supported by UTC from an instruction and documentation perspective. There was no specific guidance on particular tasks and where to locate particular items. As a consequence, BTU engineers spent three days determining the specific task requirements for the power plant installed at Woking. Subsequently annual service inspections will be completed without this requirement.

Following the annual service involving a period of eight days during which the fuel cell was turned off, operating faults with component items were experienced when the system went back into operation. Each time the fuel cell does shut down, it is a day's work for an engineer to re-start it and resolve the operating defects which, in most cases, simply required a re-calibration of an item or a replacement printed circuit board.

It is BTU's view that the operating faults experienced after the service are not uncommon following a lengthy period of shut down.

5.2 Overview of BTU's Report

The report in the above section reflects the fact that this particular product is offered for sale without a fully geared-up maintenance and support programme, which is somewhat surprising. For the annual maintenance, for example, information is provided on how to perform all tasks, but not on which are actually required. Advice was then provided from BTU's contact at UTC on the basis of recommendation rather than standard procedures. There was some discrepancy between information provided on how to perform tasks and the task itself, when undertaken, and there was also some confusion over labelling, all of which took several days to sort out and involved numerous telephone calls to UTC. The impression formed by BTU was that they were dealing with a prototype. There was no clear guidance at the outset on the likely maintenance budget, spares holding requirement or maintenance needs.

There is no doubt that personal support to BTU by UTC staff has been excellent, given the relative locations: 'we have never been left on our own'. However, there would clearly seem to be considerable cost savings to be made through more comprehensive service and maintenance documentation for customers. BTU, having now gone up the learning curve, has created its own manual and logbook for quarterly, six monthly and annual requirements. It is interesting that, with more than 100 worldwide installations over the last ten years, the customer support process is still at such an under-developed stage.

The early commissioning phase was troublesome, with a number of shut-downs, but BTU's view was that subsequent operation for the first year was very successful, with the exception of the voltage stability problems referred to. However, costs were £35k to the 8100-hour point, against an initial estimate by BTU of £20k.

At a more detailed level, the following problems have been encountered:

- there were problems with some of the resin bottles developing splits.
- There has been water ingress into the fuel cell housing and some of the internal pipes have rusted since they had not been painted.
- When the side doors are open for maintenance, there is no shelter from the rain, either for personnel or the internals. Some sort of fold-out awning could be incorporated.
- There have been some pump failures and it has not been clear whether the pumps can be satisfactorily refurbished or replaced with units not of UTC supply.
- There were health and safety issues with the resin bottles, which are supposedly a one-man replacement task, but are in fact too heavy, with reference to UK regulation.
- Water quality in the cooling circuits has been a problem due to the various metallic materials used in the pipes: stainless steel, copper, aluminium, etc. The BTU view is that, if one part of the circuit requires low conductivity, it should be separate from the rest. As it is, water quality engineers indicate that there are likely to be pinhole leaks before too long, in several places. Water treatment costs are £8k per annum.

In mid 2003, it was noted that the stack voltage has dropped, as part of the anticipated deterioration. Output has now been downgraded by 5kW to 195kW.

The bottom line is that the system does work and work reliably, but not without considerable back-up. There is clearly a need for a more streamlined maintenance programme to be developed by UTC, and better quality engineering to be used for balance of plant items such as pipework.

6. CONCLUSIONS AND LESSONS LEARNED

The Woking Park 200kW fuel cell has now been operational for over a year. There have been a number of teething problems, as would be expected for a relatively new technology, even one which has been tried in a variety of different environments. The Woking site is perhaps unique in the extent of its ambition in a UK context, and importantly continues to develop around the fuel cell. The real lessons of the fuel cell therefore continue to be learned and this report has only produced an interim picture of its potential in this type of application.

A number of important conclusions can be highlighted

- Previous operational experience has been in many cases confirmed. The availability of the system has been high, over 90%, as reported in general for other installations in the field. For most of this time 200kW electrical output has been achieved.

- Stack degradation has been observed, as expected, leading to falls in electrical efficiency. Whether these will be sufficient to lead to early stack replacement remains to be seen. However, they have already been sufficient to lead to an overall fall in electrical output of 5%. This needs to be taken into account when estimating economic viability.

- The economics of the system are highly dependent on the availability of loads for the low and high grade hot water. An overall efficiency of over 85% is available from the fuel cell. As yet utilisation of efficiencies over 60% have not been realised. The fuel cell is capable of standing out from the current array of CHP technologies in terms of its overall efficiency but so far the Woking installation cannot be distinguished from them because of the relatively low requirement for low-grade heating on site.

- Maintenance costs have been higher than expected. This may be associated with a settling in period, but the second and subsequent years of operation will give a clearer picture. There have been more parts failures than expected, down-times for maintenance were higher than expected, and the planned maintenance proved more labour intensive than planned. Water conductivity issues give some cause for concern, and corrosion of pipe-work in the first year was unexpected. A more detailed maintenance manual would be extremely useful.

- External grid voltage conditions were found to be outside the operating limits acceptable to the fuel cell. The unit operates at 400 Volts plus or minus 10%. The grid network operates at 415 volts plus. This caused regular tripping of the system into an offline state and was solved by installation of an inline transformer. This needs to be borne in mind before installing the fuel cell into other UK distribution networks.

- The fuel cell has undoubtedly made significant savings in polluting emissions relative to virtually any other available technology. In particularly emissions of nitrogen oxides are substantially lower than for any other power generation technology operating in the UK. Additionally its CHPQA rating will allow it to make significant operating gains through CCL exemption. Future operation within the wider Woking CHP system and private wires network will allow a degree of quantification of the benefits of this technology. This future performance will be the subject of a phase III report