Climate Change Fuel Cell Program

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Abstract:

On April 2002 a 200KW Phosphoric Acid Fuel Cell (PAFC) Power Plant. was installed at LACTEC Institute For Technology Development, Research and Development facilities.

The power plant installed at LACTEC site is the second of its kind in the Southern Hemisphere. Its presence, not only contributed to the creation of a Fuel Cell Stationary Power market for Brazil and the rest of the region, but increased the knowledge about fuel cell technology, and marked the point of entry as a reference for the education of a new generation of applied scientists. On its first year the power plant has operated 8,558 hours achieving an availability factor of 97% and supplying 730.50MWh of premium energy.

As a second regional experience with fuel cell technology, we expect this report about LACTEC PACFC power plant performance, applications and cost-benefit evaluation will provide relevant information for future regional investments on this technology.

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Executive Summary

On April 2002 a 200KW Phosphoric Acid Fuel Cell (PAFC) Power Plant was started up at LACTEC Institute For Technology Development, Research and Development facilities.

Its presence marked the point of entry as a reference for the education of a new generation of applied scientists in Brazil measuring the impact of the Fuel cells entry into the Brazilian power market.

The project involved the acquisition of information about the fuel cell technology, performance, emissions, operational training and development of installations and maintenance procedures.

The utilization of hydrogen produced in electrolytic format to fuel the unit is one of the project objectives. This goal was not achieved because of technical causes related to the modifications required on the PAFC model PC25C and the cost involved on those modifications.

The power plant application consisted on supplying premium power to LACTEC R&D Department. Lactec laboratory uses two power systems to get the electrical power, the commercial grid and the fuel cell power plant. After the period of evaluation and considering the power plant power capacity can match the laboratory electric peak of the demand, the fuel cell power plant is thought to become the facility main electrical power source.

From the beginning of this project the use of thermal energy was not considered to be used on the current facility due to the high cost to replace the exiting system. The construction of a new laboratory facility that allows the use of power plant thermal energy suffered several delays and at the moment there is not a date for the conclusion of the work.

During this period the power plant operated 8,558 hours reaching an availability factor of 97.23%. The resulting availability factor achieved the expectations and was in accordance to manufacturer records and former experiences recorded by DoD for the same power plant model.

Six shutdowns were registered, three of them were scheduled outages and three were forced outages.

Regarding the forced outages, one was due to a problem with fuel cell brakes and the remaining two forced outages were the result of a failure of the three port modulating ball valve TCV400/480.

The resulting MTBFO of 2,853 hours exceed the manufacturer specifications and not only demonstrated the system reliability but achieved the project expectations.

To generate 730MWhrs the power plant consumed 254,530.80 m³ (8,736,988.31 cf) of natural gas.

Reaching to an average electrical efficiency of 28 % at gas LHV and 26 % at gas HHV. Compared with recorded experiences with same units it is a low result, showing the drop on the electrical efficiency at an AC power demand under the 30% of the unit capacity. In despite of the efficiency average result, it is important to remark that high efficiency values, 37% at gas LHV (35% at gas HHV), have been achieved demanding only the 50% of the power plant capacity. These figures exceed the performance recorded with other devices like gas turbines or diesel generators that can reach up to 30% or 35% of efficiency at its maximum capacity factor.

As expected no harmful emissions of NO_x, SO_x were detected, demonstrating the fact that fuel cell technology contributes to the overall benefit of the environment.

In terms of the cost benefit analysis the power plant is still an expensive alternative when compared with traditional power generation. According to the project demands the resulting cost for kWh generated, including amortization and maintenance costs, was USD 0.24084 kWh (natural gas HHV), versus to USD 0.04345 kWh conventional rate for 13.8kV medium voltage, USD 0.06779 kWh residential low voltage rate and USD 0.06340 kWh commercial and industrial low voltage rate. The main factors that affect results are application demand (electrical and thermal demand); the high cost of natural gas compared with conventional electric rates and finally the power plant acquisition cost.

The main project conclusion is that fuel cell technology demonstrated to be a reliable option for the vision of distributed power generation as an important alternative for non-polluting power generation.

The achievement of this project contributed to the regional evaluation of fuel cell technology, providing technical and commercial know how that will be applicable and very valuable when considering further regional projects.

Introduction

The Global demand for power has created a large need to develop alternative sources of energy that will become pollution free energy sources. In the case of South America and specifically Brazil, climate changes have seriously affected the environment and the supply of power to meet the growing demand. As these economies become part of the global mainstream, clean energy alternatives can be addressed by the use of Stationary Power Fuel Cells.

Sieco S.A. (Sieco) became involved with United Technologies Fuel Cell, Inc. (former International Fuel Cells, Inc.) in 1997 and have been promoting and marketing the PC25 Power Plant based on Phosphoric Acid Fuel Cell Technology in the South America region.

From the beginning, Sieco has focused on providing Premium Power Solutions to the region and on March 2001 was able to successfully execute on its efforts by bringing the first three Fuel Cell Power Plants into Brazil, the first in the South American territory.

LACTEC is a renowned R&D facility a Not-For-Profit Organization created to offer technological know-how and services to support the State of Parana , Copel Power Utility, the University of Parana and the Industrial association of Parana.

During the first operational year, project objectives were focused on the acquisition of information about the fuel cell technology, performance, emissions, operational training and development of installations and maintenance procedures.

The utilization of hydrogen produced in electrolytic format to fuel the unit is one of the project objectives.

The Power plant will operate as Grid independent/Grid connected.

Project Schedule and Installation

The project implementation began with the purchase of the unit on March 12, 2001. The purchased involved a 200kW Phosphoric Acid Fuel Cell (PAFC) model PC25C manufactured by United Technologies Fuel Cell (former IFC), capable to operate independent of the utility grid. The power plant was required with a low grade heat recovery heat exchanger and a single walled heat recovery heat exchanger.

The power plant electrical configuration was according to U.S. market standards for that reason it was necessary to procure the addition of two transformers to meet the power plant input / output requirements by the utility grid. Even though it was not required as an additional security measure, a reverse osmosis system to treat water inlet was included.

The unit was placed outdoors, adjacent to the Lactec R&D Laboratory, it was conceived to operate with natural gas, 24 hours a day, 365 days per year (except for scheduled maintenance) and its main application is to provide Premium Power to the laboratory.

The technical training at the manufacturer's facility in the USA was conducted on April 2001. Site engineering was concluded on August 2001. The Fuel Cell Power Plant was delivered to the site on June 26, 2001. Permits and site preparation were originally scheduled to be concluded on September, 2001, but the project suffered several deviations because of delays during the construction work. The site preparation was concluded on March 2002. The unit installation began on March 2002 and system first start-up took place on April 13th, 2002 reaching the maximum capacity of 200kW on the same date.

Results and Discussion

Reliability Metrics

The performance indices available at Gas Technology Institute (GTI) in Des Plaines, Illinois (http://www.gri.org/pub/solutions/dg/rel_metrics.html), were selected to measure power plant reliability.

Tables and graphs showing different reliability categories for a given period of time, applied reliability indices, their definitions and results follow:

<u>Data</u>	<u>Code</u>	<u>Result</u>
Period of Hours	PH	8802 Hours
Period April 13-2002 / April 13-2003		
System Available - Available Hours	AH	8558 Hours
System Down for Maintenance	SD	244 Hours
System Operating Service Hours	SH	8558 Hours
Reserve Standby Hours	RSH	0 Hours
Planned Outages	PO	3 Event
Scheduled Outage Hours	SOH	61 Hours
Forced Outage	FO	3 Events
Forced Outage Hours	FOH	183 Hours

Indices:

<i>Indices:</i>	<i>Formula</i>	<i>Result</i>
Period of Demand (POD) <i>Measures the time the unit was planned to operate</i>	$POD = PH - RSH - SOH$	8741 Hours
Availability Factor (AF %) <i>Measures, on a percent basis, the unit's "could run" capability. Impacted by planned and unplanned maintenance</i>	$AF = (PH - SOH - FOH) \times 100 / PH$	97.23%
Forced Outage Rate (FOR %) <i>Measures portion of downtime due to unplanned factors</i>	$FOR = FOH \times 100 / SH - FOH$	2.19%
Scheduled Outage Factor (SOF %) <i>Measures percent of time set aside for planned maintenance</i>	$SOF = SOH \times 100 / PH$	0.69%
Service Factor (SF %) <i>Percent of total period hours the unit is on-line – varies due to site-related or economic factors</i>	$SF = SH \times 100 / PH$	97.23%
Mean Time Between Forced Outages (MTBFO) <i>Measures the nominal time between unscheduled forced outages</i>	$MTBFO = SH / FO$	2853 Hours
Mean Down Time (MDT) <i>Measures the nominal duration the unit is down during maintenance events</i>	$MDT = SOH + FOH / FO + PO$	41 Hours

Operating Hours / Availability:

Until April 2003, Lactec power plant logged 8,558 operating hours, reaching an availability factor of 97.23 % during the total period of time demanded (calendar time).

On November 2001 DOD published their experience with a fleet of 30 power plants generators, comparing reported availability rate for the PC25C model (87%), Lactec fuel cell availability factor not only achieved the expectations but also proved high system availability.

Availability Chart:

Mean Time Between Forced Outages:

During the analyzed period Lactec power plant registered six shutdowns. Three of them were a result of scheduled maintenance activities and three were forced outages. One of the forced outages was due to a problem with fuel cell brakes and the remaining two were the result of a failure of the three port modulating ball valve TCV400/4.

The resulting MTBFO of 2,853 hours exceeded manufacturer 2,500 hours records or DOD reported historical experience for the same model of 1,766 hours. The experience with the fuel cell power plant installed at Lactec not only demonstrated the system reliability but also exceeded former regional experience duplicating the registered MTBFO (1,200 hrs.).

Considering that on the former regional experience the low MTBFO was due many human mistakes when operating the power plant, the present results show also a maturity on the technical knowledge acquired by the technicians and professionals involved on the project, achieving as well one of the project main goals.

Following there is a chart with a summary of scheduled and forced outages.

Shutdowns Summary:

Event / Description	Date/Month/Yr	Load Time	Run Hours	System Down Hours
First Start Up # 9258	4/12/2002 4:16	420		
Shutdown <i>Brakes failure</i>	4/22/2002 12:17	669	249	
Restart	4/23/2002 13:17	669		25
Shutdown <i>Scheduled shutdown for maintenance purposes</i>	10/3/2002 9:45	4574	3905	
Restart	10/4/2002 18:45	4574		33
Shutdown <i>Failure of the three port modulating ball valve TCV400/480</i>	11/14/2002 14:32	5557	983	
Restart	11/20/2002 10:48	5557		140
Shutdown <i>Failure of the three port modulating ball valve TCV400/480</i>	11/20/2002 15:48	5562	5	
Restart	11/21/2002 9:51	5562		18
Shutdown <i>Scheduled shutdown for maintenance purposes</i>	2/11/2003 7:23	7527	1965	
Restart	3/12/2003 10:31	7527		27
Shutdown <i>Scheduled shutdown for maintenance purposes</i>	3/18/2003 9:00	8342	815	
Restart	3/18/2003 9:40	8342		1
Last Measuring	4/13/2003 22:02	8978	636	

Efficiency

Information published by the natural gas vendor, “Compagas”, was included to estimate the system efficiency. Following are the listed Compagas heat value for natural gas and units conversion.

Natural Gas LHV = 8650kcal/m³ = 10,06kWh/m³ = 34326Btu/m³ = 972Btu/cf.

Natural Gas HHV = 9400kcal/m³ = 10,93kWh/m³ = 37292Btu/m³ = 1056Btu/cf.

During period Lactec power plant operated at an average AC Output of 85Kw (43% of its total capacity) presenting an average electrical conversion efficiency at natural gas LHV of 28% with a maximum efficiency record of 37.9% at a 50% of fuel cell capacity (Monthly average AC demand 99kw) and a minimum of 14% at an average AC demand of 33kw (17% of power plant capacity). Considering the power plant AC output demand and the gas consuming, it is possible to prove the linear relationship up to the 50% of power plant capacity (100kw), which complies with manufacturer parameters that indicates a 57mts³/hrs at maximum capacity and 30mts³/hrs at 50% capacity (100kw). Below this point that relationship is no longer valid, affecting the unit efficiency as well. The reason for the increase on the gas consume and resulting drop of the efficiency, is because of the gas consumed at the power plant burners just to keep the operational high temperature required at the power plant reformer. At natural gas HHV, the full period average electrical conversion efficiency dropped to 26%.

Average electrical conversion efficiency for other gas engines like turbines or diesel generators ranges between 25% to 30%. When comparing these figures, it is demonstrated the power plant higher electrical conversion efficiency with the additional benefit that the power plant does not burn consumed fuel therefore, reducing polluting emissions.

The next step to achieve involves the stabilization of the power plant AC demand above the 50% of its capacity and to reach an average electrical efficiency of 35% at natural gas LHV.

Thermal efficiency is considered the ratio between heat recovered versus consumed natural gas heat content. The standard power plant model PC25C is provided with a low grade heat exchanger capable to provide 750.000 Btu/h – 220Kw/h t at 200kw/h e power rate. The heat available main utilization consist on supplying hot water to the associated site. Lactec R&D laboratory already counted with a system capable to provide hot water and because of the high cost of its replacement this application was not considered at the inception of this project. The construction of a new laboratory facility will allow the utilization of this power plant feature improving not only system total efficiency, but the economical equation. At the time of the present report the laboratory construction have not been concluded for that reason the utilization of the power plant thermal capacity is still goal to achieve.

Thermal Output

The thermal output considered as the available heat rate, independent of thermal consumption, has relationship to the power plant AC Output Voltage. At a maximum rated power of 200kW the power plant model PC25C is able to supply 750.000Btu/h (220kW).

According to the manufacturer records from 200kW to 100kW AC Output, available heat rate drops 3% per 5% AC Output reduction. Therefore the following chart shows available heat in kW according to Lactec power plant monthly AC output average.

Emissions

The following chart shows Lactec Power Plant emissions:

As expected no harmful emissions were generated, confirming the use of fuel cell technology as a pollution free source of energy.

Cost Benefit Analysis

Currency Exchange:

During the analyzed period the Brazilian currency Real (R\$) has suffered a continuous depreciation compared with the USA Dollar (USD). Considering the currency exchange monthly fluctuation (April 2002 USD 1 = R\$ 2,28 / October 2002 USD 1 = R\$ 3.77 / April 2003 USD 1 = R\$ 3,09) a value of USD 1 = R\$ 3,15 was used for the project analysis.

Investment:

The following chart shows investment forecasted at the beginning of the project versus its result at the end of it.

Investment as Planned on March 2001

Item	Description	Cost	Percent
1	Fuel Cell & Miscellaneous	USD 840,000.00	86%
2	Installation Cost	USD 40,000.00	4%
3	First Year Fuel	USD 80,000.00	8%
4	First Year Maintenance	USD 20,000.00	2%
5	Total Planned Cost	USD 980,000.00	100%

Founding Source	Amount	Percent
6 Sieco S.A.	USD 980,000.00	100%
7 -	-	-
8 Total Funding	USD 980,000.00	100%

Investment as is, on April 2003

Item	Description	Cost	Percent
1	Fuel Cell & Miscellaneous	USD 862,650.00	85%
2	Installation Cost	USD 68,529.90	7%
3	First Year Fuel	USD 60,245.96	6%
4	First Year Maintenance	USD 22,570.41	2%
6	Total Cost	USD 1,013,996.27	100%

Founding Source	Amount	Percent
7 Sieco S.A.	USD 813,996.27	80%
8 DOE	USD 200,000.00	20%
9 Total Funding	USD 1,013,996.27	100%

Economical Analysis:

To evaluate the project economical results for the period, the capital amortization, power plant maintenance cost and natural gas consumption cost during the period compared to the cost of displaced natural gas and displaced electrical energy obtained from the cogeneration process was considered.

Second the Electrical Energy cost was compared, as a by-product of the power plant cogeneration process, versus available Electrical Energy rates into the State of Parana. The analysis determines the power plant requirements to be considered as a viable generation source.

1-Capital Amortization:

The power plant cost, plus installation cost and an amortization period of ten years was considered.

$$\text{Capital Amortization} = \frac{\text{Power Plant Cost} + \text{Installation Cost}}{\text{Amortizing Period}} = \frac{\text{USD } 862,650.00 + \text{USD } 68,529.90}{10} = \text{USD } 93,117.99$$

2-First Year Maintenance Cost:

It was equal to USD 22,570.41

3-Cost of Consumed Natural Gas:

Compagas, is the company that supplies of natural gas to Lactec power plant. The following is the listed Compagas Rate Chart and the resulting natural gas rate during the period for Lactec Power Plant.

Vol. M3 / day	Gas Rate R\$	Gas Cost With Discount (10%) R\$	Gas Cost With Discount (10%) USD = R\$ 3,155 USD
0 to 500	0.871444	0.7842996	0.248589
501 to 1000	0.732222	0.6589998	0.208875
1001 to 2000	0.627555	0.5647995	0.179017
2001 to 4000	0.575333	0.5177997	0.164120

Prices according to COMPAGAS Rates (<http://www.compagas.com.br/port/tabelaprecos.asp?tipo=1>)

The resulting rate is obtained prorating daily natural gas consumed in m3 per each rate parameter.

Example: Power plant at rated power 200kw consuming 57m3/h of natural gas.

Consume: 57m3/h * 24 = 1.368m3/day

$$\text{Rate} = \frac{(500\text{m}^3 * \text{USD } 0.248589) + (500\text{m}^3 * \text{USD } 0.208875) + (368\text{m}^3 * \text{USD } 0.179017)}{1,368\text{m}^3} = \text{USD } 0.215360\text{m}^3$$

During this period the Lactec Power Plant consumed 8,988,671.1 cubic feet of natural gas, equal to 254,530.9m3 at an average rate of USD 0.2367 m3. Resulting on a total cost of USD 60,245.96

Lactec Power Plant Consumed Natural Gas Cost Chart:

Fuel Cell Avg. Gas Rate	Fuel Cell Avg. Gas Rate	Fuel Cell Nat. Gas Consume	Fuel Cell Nat. Gas Cost
R\$ 0.74677m3	USD 0.236694m3	254,530.85m3 (LHV)	USD 60,245.96
R\$ 0.74677m3	USD 0.236694m3	254,530.85m3 (HHV)	USD 60,245.96
R\$ 0.02176Kbtu/h (LHV)	USD 0.006896Kbtu/h (LHV)	8,736,988.31Kbtu/h (LHV)	USD 60,245.96
R\$ 0.02002Kbtu/h (HHV)	USD 0.006347Kbtu/h (HHV)	9,492,036.68Kbtu/h (HHV)	USD 60,245.96
R\$ 0.07423kWh (LHV)	USD 0.023528kWh (LHV)	2,560,558.77kWh (LHV)	USD 60,245.96
R\$ 0.06833kWh (HHV)	USD 0.021657kWh (HHV)	2,781,841.63kWh (HHV)	USD 60,245.96

4-Cost of Displaced Natural Gas due to Thermal Utilization:

Since there was no thermal utilization, no saving as displaced natural gas cost was registered during the period.

5-Cost of Displaced Electrical Energy due to fuel cell generation:

In Brazil, the National Electrical Energy Agency (ANEEL) regulates and determines the electrical energy rates. For this analyzed period ANEEL had enforced two regulations that determined the electrical energy rate. Following are the listed rate charts used.

Conventional Rate	ANEEL 226 July 2001 to June 2002		ANEEL 226 July 2001 to June 2002	
	Demand R\$/kW	Consume R\$/kWh	Demand USD/kW	Consume USD/kWh
A4 (13.8V Medium Volt.)	R\$ 6.960	R\$ 0.10195	USD 2.2060	USD 0.0323
B1 (Residential Low Volt)		R\$ 0.19781		USD 0.0627
B3 (Comm. & Ind. Low Volt.)		R\$ 0.18500		USD 0.0586

Conventional Rate	ANEEL 336 July 2002 to Date		ANEEL 336 July 2002 to Date	
	Demand R\$/kW	Consume R\$/kWh	Demand USD/kW	Consume USD/kWh
A4 (13.8V Medium Volt.)	R\$ 7.720	R\$ 0.11312	USD 2.4469	USD 0.0359
B1 (Residential Low Volt)		R\$ 0.21949		USD 0.0696
B3 (Comm. & Ind. Low Volt.)		R\$ 0.20527		USD 0.0651

Lactec power plant generated 730,495 kWh during period, 189,447 kWh under the first rate period (ANEEL regulation 226) and 541,048 kWh during second one (ANEEL regulation 336). The applicable rate for Lactec Data Center is the A4 (13.8V), so the resulting electrical energy savings were:

Elec. Saving = (kW Demand * Months * Demand Rate USD/kW) + (kWh Generated * Consume Rate USD/kWh)

Displaced kWh Rate = Total Electrical Energy Cost / kWh Generated

Rate	kWh Generated	Months	Demand		Consume USD/kWh	Total Cost USD	kWh Rate USD
			Demand kW	Rate USD / kW			
A4 Aneel 226	189,446.60	3	200	2.2060	0.0323	7,445.35	0.03930
A4 Aneel 336	541,048.70	10	200	2.4469	0.0359	24,292.69	0.04490
Total	730,495.30	13	200			31,738.04	0.04345

6-Results:

During this period the power plant cost vs. savings did not generate any net savings because of the utilization of natural gas to generate electrical and thermal energy. In fact, the result shows loses that reached USD 144,196.32 (gas HHV). At the same time the resulting power plant electrical energy cost was far from being competitive with the electrical rates available on the State of Parana. The results are described on the next chart.

Considering the application low demand, an analysis was also prepared estimating costs and savings under different demand cases to identify those where the power plant application into the Brazilian power market would generate a positive result. As shown on the next second chart, considering displaced electrical energy at 13.8V rate (A4) the power plant does not generate any savings. Neither when considering the potential benefit of ANEEL regulation 21/2000 that states requirements for cogeneration devices, allowing benefits that reaches to a 50% discount on natural gas cost. Besides at a maximum demand and getting the benefits of ANEEL 21/2000, the power plant electric energy cost, can be competitive with Residential Low Volt Rate (B1) and Commercial & Industrial Low Volt Rate (B3), but not with 13.8V rate (A4).

COST Vs. SAVINGS ANALYSIS

Based on system effective demand for the period

Case	Elec. Cap. Factor	Thermal Util.	Displaced kWh	Displaced Gas kBtu	Capital Amortization USD	First Year Maintenance USD	Nat. Gas Cost USD	Nat. Gas Savings USD	Electrical Savings A4 USD	Net Savings USD
Lactec Fuel Cell Cost / Savings Analysis for the Period, based on effective demand										
Nat. Gas LHV	43.00%	0.00%	730,495.30	0.00	93,117.99	22,570.41	60,245.96	0.00	31,738.04	-144,196.32
Nat. Gas HHV	43.00%	0.00%	730,495.30	0.00	93,117.99	22,570.41	60,245.96	0.00	31,738.04	-144,196.32

POWER PLANT ELECTRICAL ENERGY RATE vs. UTILITY GRID ELECTRICAL ENERGY RATES

Based on system effective demand for the period

Case	Elec. Cap. Factor	Thermal Util.	Displaced kWh	Displaced Gas kBtu	Capital Amortization USD	First Year Maintenance USD	Nat. Gas Cost USD	Nat. Gas Savings USD	kWh Generated Cost USD	A4 (13,8V Medium Volt.)	B1 (Residential Low Volt)	B3 (Comm. & Ind. Low Volt.)
Lactec Fuel Cell kWh Generated Cost for the Period, based on effective demand, compared with utility grid available rate cost for the same period.												
Nat. Gas LHV	43.00%	0.00%	730,495.30	0.00	93,117.99	22,570.41	60,245.96	0.00	0.24084	0.04345	0.06779	0.06340
Nat. Gas HHV	43.00%	0.00%	730,495.30	0.00	93,117.99	22,570.41	60,245.96	0.00	0.24084	0.04345	0.06779	0.06340

COST Vs. SAVINGS ANALYSIS

Estimations according to different demand percentages.

Case	Elec. Cap. Factor	Thermal Util.	Displaced kWh	Displaced Gas kBTu	Capital Amortization USD	First Year Maintenance USD	Nat. Gas Cost USD	Nat. Gas Savings USD	Electrical Savings A4 USD	Net Savings USD
Lactec Fuel Cell Cost / Savings Analysis considering a typical Demand										
Nat. Gas LHV	90.00%	40.00%	1,540,440.00	3,667,826.96	93,117.99	22,570.41	96,324.16	31,840.79	60,244.87	-119,926.90
Nat. Gas HHV	90.00%	40.00%	1,540,440.00	3,667,826.96	93,117.99	22,570.41	96,324.16	29,308.00	60,244.87	-122,459.69
Lactec Fuel Cell Cost / Savings Analysis considering a 100% Demand										
Nat. Gas LHV	100.00%	100.00%	1,711,600.00	9,169,567.39	93,117.99	22,570.41	125,932.69	75,372.71	65,862.49	-100,385.89
Nat. Gas HHV	100.00%	100.00%	1,711,600.00	9,169,567.39	93,117.99	22,570.41	125,932.69	70,052.59	65,862.49	-105,706.01
Lactec Fuel Cell Cost / Savings Analysis considering a 100% Demand and getting a 50% Benefit on Natural Gas cost as a result of applying to ANEEL 21/2000										
Nat. Gas LHV	100.00%	100.00%	1,711,600.00	9,169,567.39	93,117.99	22,570.41	62,966.35	75,372.71	65,862.49	-37,419.54
Nat. Gas HHV	100.00%	100.00%	1,711,600.00	9,169,567.39	93,117.99	22,570.41	62,966.35	70,052.59	65,862.49	-42,739.67

POWER PLANT ELECTRICAL ENERGY RATE vs. UTILITY GRID ELECTRICAL ENERGY RATES

Estimations according to different demand percentages.

Case	Elec. Cap. Factor	Thermal Util.	Displaced kWh	Displaced Gas kBTu	Capital Amortization USD	First Year Maintenance USD	Nat. Gas Cost USD	Nat. Gas Savings USD	kWh Generated Cost USD	A4 (13,8V Medium Volt.)	B1 (Residential Low Volt)	B3 (Comm. & Ind. Low Volt.)
Lactec Fuel Cell kWh Generated Cost, considering a typical Demand, compared with available utility grid rate costs.												
Nat. Gas LHV	90.00%	40.00%	1,540,440.00	3,667,826.96	93,117.99	22,570.41	96,324.16	31,840.79	0.11696	0.03911	0.06805	0.06364
Nat. Gas HHV	90.00%	40.00%	1,540,440.00	3,667,826.96	93,117.99	22,570.41	96,324.16	29,308.00	0.11861	0.03911	0.06805	0.06364
Lactec Fuel Cell kWh Generated Cost, considering a 100% Demand, compared with available utility grid rate costs.												
Nat. Gas LHV	100.00%	100.00%	1,711,600.00	9,169,567.39	93,117.99	22,570.41	125,932.69	75,372.71	0.09713	0.03848	0.06805	0.06364
Nat. Gas HHV	100.00%	100.00%	1,711,600.00	9,169,567.39	93,117.99	22,570.41	125,932.69	70,052.59	0.10024	0.03848	0.06805	0.06364
Lactec Fuel Cell kWh Generated Cost, considering a 100% Demand and getting a 50% Benefit on Natural Gas cost as a result of applying to ANEEL 21/2000, compared with utility grid available rate costs.												
Nat. Gas LHV	100.00%	100.00%	1,711,600.00	9,169,567.39	93,117.99	22,570.41	62,966.35	75,372.71	0.06034	0.03848	0.06805	0.06364
Nat. Gas HHV	100.00%	100.00%	1,711,600.00	9,169,567.39	93,117.99	22,570.41	62,966.35	70,052.59	0.06345	0.03848	0.06805	0.06364

The combination of many factors affected the economical results. These factors can be summarized under the following categories:

Related to the Application:

- Effective installation cost was 70% more expensive than forecasted cost.
- Low Electrical Capacity Utilization (43%)
- Limited availability of Thermal Loads (0%)

Related to the Brazilian Energy Market:

- The cost difference between natural gas and electrical energy rate, demands a high efficiency for the electrical generation from the gas utilization in order to turn it equal to conventional electrical market rates. As shown, project displaced electricity rate was USD 0.04345 kWh; the natural gas rate was USD 0.023528 kWh just in order to equalize both rates the power plant should reach to 54% efficiency and that is without considering any amortization or maintenance costs factors. The small difference does not provide the necessary savings to support maintenance cost and amortization rate, being the result that the electrical generation from the power plant is more expensive than conventional electrical rates.

Related to the Power Plant

- The high cost of acquisition creates a high amortization rate per year.

Conclusions:

According to the evaluation of the results we conclude that the power plant has demonstrated to be a reliable system that complies with premium power supply requirements.

In terms of efficiency, the power plant has demonstrated to perform better than other technologies when referring to electric energy generation. The power plant considerable thermal output represents an additional advantage and its utilization on applications with available thermal loads not only improves the system efficiency but also contributes to the economical viability of the project results.

It was also demonstrated that the use of fuel cell technology greatly contributes to the improvement of the local environment by not releasing harmful emissions.

At this time the commercialization efforts to promote fuel cell technology presents a barrier due to the expensive cost of the equipment compared with traditional sources of power generation, becoming competitive when critical factors are considered as a measure of success.

The achievement of this project has without a doubt contributed to exposing fuel cell technology to a new continent, providing a source of regional evaluation, technical education and expertise and a path to commercial opportunities that will be applicable on future projects.

We can conclude that fuel cell technology provides a reliable option for the maturing concept of distributed generation as an important alternative for environmental clean power generation.

Statistics:

Period Summary Statistics: April 13, 2002 through April 15, 2003.

Hours of Operation:	8558Hours	Electric Efficiency:	28.5%
Total Electric Output:	730.50MWhrs	Thermal Efficiency:	0.0%
Average Fuel Cell Output:	85.0kW	Total Efficiency:	28.5%
Total Heat Recovered:	0.0MMBtu	Electric Capacity Factor:	42.51%
Heat Recovery Rate:	0kBtu/Hr	Availability:	97.2%
Input Fuel:	8,988,671Cubic Feet		

MONTH	Operating Hours	Calendar Time	KWHRS	Average AC Output kW	Nat. Gas Consume Cubic Feet	Nat. Gas Consume Cubic Feet/Hrs	Nat. Gas Consume Cubic Meter	Nat. Gas Consume Cubic Meter/Hrs	Heat Recovered KBTUHS	% Availability	Avg. El. Eff. Nat. Gas LHV	Avg. Therm. Eff. Nat. Gas LHV
Apr-02	426	451	50,143.20	115.1	568,817.1	1,334.9	16,107.1	37.8	0.0	94.5%	30.9%	0.0%
CTD	426	451	50,143.20	115.1	568,817.1	1,334.9	16,107.1	37.8	0.0	94.5%	30.9%	0.0%
May-02	742	742	115,314.10	157.5	1,163,119.0	1,567.9	32,935.9	44.4	0.0	100.0%	34.8%	0.0%
CTD	1169	1194	165,757.30	138.8	1,734,731.1	1,483.5	49,122.1	42.0	0.0	97.9%	33.5%	0.0%
Jun-02	715	715	23,689.30	33.2	573,597.0	802.3	16,242.5	22.7	0.0	100.0%	14.5%	0.0%
CTD	1889	1914	189,446.60	103.1	2,311,217.1	1,223.3	65,446.4	34.6	0.0	98.7%	28.8%	0.0%
Jul-02	740	740	33,824.30	44.7	633,158.0	855.8	17,929.0	24.2	0.0	100.0%	18.8%	0.0%
CTD	2634	2659	223,520.80	88.1	2,948,895.1	1,119.5	83,503.4	31.7	0.0	99.1%	26.6%	0.0%
Aug-02	738	738	39,712.20	63.0	647,305.0	877.1	18,329.6	24.8	0.0	100.0%	21.5%	0.0%
CTD	3377	3402	263,233.00	84.4	3,599,087.1	1,065.8	101,914.8	30.2	0.0	99.3%	25.7%	0.0%
Sep-02	672	672	45,508.90	95.4	691,000.0	1,027.5	19,566.9	29.1	0.0	100.0%	23.1%	0.0%
CTD	4098	4122	309,525.10	86.0	4,322,911.1	1,055.0	122,411.2	29.9	0.0	99.4%	25.1%	0.0%
Oct-02	321	354	38,688.90	135.5	885,123.0	2,757.2	25,063.9	78.1	0.0	90.6%	15.3%	0.0%
CTD	4424	4482	349,213.80	90.3	5,217,478.1	1,179.4	147,742.5	33.4	0.0	98.7%	23.5%	0.0%
Nov-02	558	716	88,445.90	126.7	833,425.0	1,494.4	23,600.0	42.3	0.0	77.9%	37.3%	0.0%
CTD	5371	5587	483,849.80	97.5	6,060,331.1	1,128.3	171,609.5	31.9	0.0	96.1%	28.0%	0.0%
Dec-02	739	739	72,096.80	93.6	678,281.0	918.0	19,206.8	26.0	0.0	100.0%	37.3%	0.0%
CTD	6115	6331	556,446.50	97.0	6,743,168.1	1,102.7	190,945.3	31.2	0.0	96.6%	29.0%	0.0%
Jan-03	739	739	36,937.30	50.0	680,549.0	921.1	19,271.0	26.1	0.0	100.0%	19.1%	0.0%
CTD	6859	7075	593,633.90	89.5	7,428,326.1	1,083.0	210,346.8	30.7	0.0	96.9%	28.1%	0.0%
Feb-03	640	666	32,456.20	42.9	588,405.0	920.0	16,661.8	26.1	0.0	96.0%	19.4%	0.0%
CTD	7503	7746	626,340.20	81.4	8,021,362.1	1,069.0	227,139.7	30.3	0.0	96.9%	27.4%	0.0%
Mar-03	739	740	72,830.50	97.7	676,874.0	916.1	19,166.9	25.9	0.0	99.9%	37.8%	0.0%
CTD	8247	8491	699,670.60	83.7	8,702,823.1	1,055.2	246,436.5	29.9	0.0	97.1%	28.2%	0.0%
Apr-03	306	306	30,324.90	99.5	281,235.0	919.2	7,963.7	26.0	0.0	100.0%	37.9%	0.0%
CTD	8558	8802	730,495.30	85.0	8,988,671.1	1,050.3	254,530.9	29.7	0.0	97.2%	28.5%	0.0%

Information Source

- i. Cogeneration Case Studies of the DoD Fuel Cell Demonstration Program
(Presented at the IQPC F-CELL Stationary Conference London, UK - February 29,2000)
- ii. Experience with the DoD Fleet of 30 Fuel Cell Generators
(Presented at the 2001 International Gas Research Conference –IGRC 2001- November 5-8, 2001)
- iii. Gas and Electricity Rates on South America (Protecnica IAPG Magazine, N°4 August, 2002)
- iv. UTC Fuel Cell (www.utcfuelcells.com)
- v. DoD Fuel Cell ERDC-CERL (www.dodfuelcell.com)
- vi. Companhia Paranaense de Energia – COPEL - (www.copel.com)
- vii. Companhia Paranaense de Gas – COMPAGAS - (www.compagas.com)
- viii. IAPG Argentine Institute of Petroleum and Gas (www.iapg.org.ar)

Photo Gallery

"Fuel Cell on Site"

Fuel Cell and Cooling Module

Fuel Cell On Site

Fuel Cell On Site

Cooling Module

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