THE POTENTIAL OF ELECTRIC BICYCLES TO PROVIDE LOW COST TRANSPORT, MOBILITY AND ECONOMIC EMPOWERMENT IN SOUTH AFRICA.

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ABSTRACT

Electric bicycles have experienced a massive market growth over the last two years in Asia and Europe. “World demand for a lighter, environmentally friendly, high performance e-bike increases; in China alone, sales soared from under 100,000 units in 1998 to a staggering 4 million units in 2003” (Fairley, June 2005 & Golden power Battery). It is not the rich high tech first world that is leading the way in electric bicycles but the developing world, and this is for two main reasons – they are very cheap to run and convenient to use.

Cost Effective Electric Bicycles (or ebikes) offer a very attractive solution to South Africa’s transport problems and at the same time drastically reducing pollution levels. The cost and availability of transport is a basic factor in the quality of life and Africa as a whole cannot afford to miss out on the electric bicycle revolution.

This paper will present the current costs of Electric bicycles and the results of an investigation into capabilities of electric bicycles in terms of parameters such as range, speed and recharging time. It will also provide a comparative cost analysis of an electric bicycle as a means of transport. The paper will outline how an electric bicycle can provide a cheap means of transport, empowering a person both in terms of cost and mobility. Electric bicycle use will also substantially reduce pollution, decrease traffic congestion and reduce South Africa’s oil needs. If our transport regulators and municipal planners do not take into account this new technology, South Africa could lose an option to provide cheap and environmentally clean transport to its nation.

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1. INTRODUCTION

Electric bikes, or ebikes, have been around for the last 20 years but it is only in the last 5 years that they have really substantially increased sales. Ironically it is China that leads the way in electric bike usage, not the high tech West, and South Africa can learn valuable lessons on the benefits of this rapidly growing mode of transport and ensure that our national transport strategy takes ebikes into account. This paper will investigate the real performance of an electric bicycle, and its functionality. It will discuss range, weight, energy usage, power, torque, efficiency, batteries and Watt-hours required (stored energy needed). An analysis is done of the costs of transport in a car, motorbike, Taxi and electric bicycle and comparisons are given. The environmental benefits of an electric bicycle are then shown. The reduction in use and imports of fossil fuels for SA is calculated. Conclusions and recommendations are drawn to facilitate the implementation of electric bicycles in South Africa.

2. CURRENT ELECTRIC BICYCLES - TECHNOLOGY AND PERFORMANCE

Initially, ebike manufactures failed as they supplied motors of less than 250 watts which consumers found to weak and to slow. Added to this, these motors were brushed motors which further reduces the efficiency of the motor by 20-25%. The trend is now to supply larger powered brushless motors of 400 Watt which can keep an ebike traveling at 32km/hr and easily go up most hills. Over the last few years there have been a few technologies that have progressed at an unprecedented pace in terms of cost and performance and have enabled electric bicycles to come of age. These enabling technologies include: Power electronic components, Permanent magnet Brushless motors, Microprocessor controllers, Sealed Lead Acid (SLA), Nickel Metal Hydride (NiMH), and Lithium Polymer (Li-P) rechargeable batteries. These technologies now enable high performance and relatively cost effective electric bicycles to be built.

2.1 Technology

Permanent magnet Brushless Hub motor - One of the enabling technologies of ebikes is the development of permanent magnet brushless hub motors. These motors are unobtrusive, generate high torque at low speed, are highly efficient and result in a solution which needs no costly chains or gearing. The HUB motor is the inside out of a traditional motor i.e. the rotor is outside the stator with the permanent magnets being mounted on the inside of the outer HUB forming the rotor. The stator is mounted and fixed onto the axle. The motor has no brushes to wear out, and the only moving parts are the two bearings. This means they are very reliable and have an exceptionally long life time.

Controller and throttle – The controller and throttle allow the user to drive the motor linearly from zero speed to full speed. The throttle attaches to your right handle on the handle bar, and is connected to the controller. The controller is in essence the “variable speed drive” that converts the constant DC voltage from your battery to an alternating voltage with variable amplitude and frequency that will drive the HUB motor at different speeds. It basically consists of Power Electronic MOSFET transistors and a small microprocessor.

Battery – the battery has traditionally been the weakest aspect of an electric bicycle, but they are improving rapidly. When engineers first developed cheap and efficient hub motors they were surprised to see that it was the batteries that after a month’s use were failing and needing replacement. Now SLA batteries have been redesigned specifically for ebike use and 200-400 complete recharges are the norm, giving a battery life of one to two years. However, although they are very cost effective they are still fairly heavy. New batteries such as Nickel Metal Hydride (NiMh) and Lithium based batteries have been developed which have over 500 and 1000 cycles respectively and are far more robust and lighter than SLA technology. Unfortunately these battery types are currently still too expensive for mainstream use in ebikes. A summary of the batteries and costs are presented in Appendix 1. On a positive note though, the costs of lithium based batteries is been driven down rapidly by the portable electronics market (cell phones, laptops, MP3 players etc) and by research for use in electric vehicles. It is the authors' opinion that in less than five years, these better batteries will be as cost effective as SLA.

2.2 Performance

The Electric bicycle investigated is sold by Adequate Energy, South Africa. This ebike uses a three phase permanent magnet brushless HUB motor. The results of testing this HUB motor by itself on custom built dynamometer are presented in appendix 2. If the HUB motor is mounted on a standard 26" mountain bike wheel, the rpm that corresponds to 32km/h is approximately 220rpm. We can see that at this rpm, the HUB motor is delivering between 10-12Nm of torque and around 250W of power. This is enough power and torque to propel an ebike rider of weight 75kg at 30-32km/h.

Table1. Basic Results of Ebike investigated.

Bicycle:	California Mountain Bike sold by BEN bikes
Motor:	Three phase three phase permanent magnet HUB motor, incorporated into wheel, total weight 6kg.
Controller:	Three phase microprocessor PWM controlled with Hall effect feedback.
Battery:	Sealed Lead Acid, weight 12kg, 36V, 12Ah, stored energy 432Wh, 200 charge/discharge cycles.
Top Speed unassisted:	32km/h with 80kg rider
Range unassisted :	25km (Note 1)
Energy used for 25km:	205Wh (Note 2)
Range Assisted:	40-50km.
Rider weight:	80kg
Note 1	This is with no pedalling and at continuous full power on a semi **flat road.**
Note 2	Although the battery capacity is rated at 432Wh, when discharged at high current it only supplied 200Wh.

Fast, Convenient and Fun - An electric bicycle is as fast as traffic in rush hour, it is invigorating, it is fun and can be as little or as much exercise as the user wants.

Summary - The next few years will show rapid development of all the technologies used in electric bicycles, in particular the batteries. This means electric bicycles will get cheaper, faster, lighter and more efficient. In short, it is a solution that is only going to continue getting better!

3. REAL COST OF TRANSPORT - ELECTRIC BICYCLE VS. ALTERNATIVES

Table 2. Comparing cost of ebikes.

	Ebike[1]	Motorbike	Small Car	Taxi
Cost	R 3,500	R 9,000	R 75,000	
Monthly repayment	R 121.33	R 243.69	R 2,581.57	
Daily Payment[2]	R 5.60	R 11.26	R 119.24	
Average distance to work - (km)	15	15	15	
Overall running cost per 100km[3]	R 2.80	R 23.00	R 86.77	
Running Cost to work and back	R 0.84	R 6.90	R 26.03	
Total cost to travel to work and back	R 6.44	R 18.16	R 145.27	R 12.00
Effective cost of transport to work & back[4] (30km trip)	**R 3.64**	**R 12.53**	**R 82.12**	**R 12.00**
Interest Rate used	15.0%	14.5%	13.5%	
Capital repayment period (years)	3	3	4	

	Notes
1	Retail price. Assumed with a South African market of 10,000 ebikes per year
2	Assumes vehicle used 5 days a week for work.
3	Assumes cost as using SLA ebike (see Table 1). For vehicles includes petrol and maintenance according to AA SA rates
4	Basic assumption that vehicle can be sold for half the value of its initial purchase price.

Above is a simplified comparison if one compares the cost to travel to work and back in the South African situation. It has made certain assumptions such as the average distance to work being 15 km and that the vehicle is used only to get to work and back, but it does bring to ones attention the basic actual cost to run different vehicles as a mode of transport to work. *It is highly likely that in the next couple of years 450 Watt brushless ebikes with 50 km range could retail for R2500.*

Bicycles are an even cheaper form of transport, and have not been included in this table because of its clear advantages (though ebikes complement bicycle transport). Where ebikes has advantages over bicycles is their higher speed, ease of use (in wind and hilly conditions) and longer effective range – reasons which are particularly applicable to SA conditions.

4. ENVIRONMENTAL SAVING

In Cape Town in 1997, 65% of the visible pollution was a result of vehicles (Wicking-Baird, De Villiers, Dutkiewicz, 1997), and this figure was expected to rise to over 80% by 2005 (no further studies have been done). Furthermore, with the South African Taxi recapitalization program converting the current taxi fleets to diesel, this could add to ongoing smog and pollution problem if these vehicles are not closely monitored. Already the Department of Environment Affairs and Department of Transport (in SA) is working on having mandatory emissions testing for vehicles during roadworthiness tests. In South African cities, close to 15% of green house gases are as a result of motor vehicle emissions. Every litre of fuel consumed results in 2.5 kg of CO2, not to mention other poisonous gases such as the NOX's and Carbon Monoxide.

Table 3. C02 emissions of different forms of transport.

Emissions per 100km traveled	C02	Kg
Small Motor Car	**20**	Kg
Motor Bike	**7.5**	Kg
Ebike	**1.03**	Kg
Amount of C02 absorbed by tree per annum	**22.7**	Kg
Notes		
For every litre of fuel consumed, 2.5 kg CO2 is emitted		
Assumed 8l/100km for car		
Assumed 3l/100km for motorbike		
Eskom produces 0.96 kg C02 per kWh (Eskom Annual Report, 2005)		
Assumed petrol price is R5.76 per litre (November 2005)		
Assumed need 430 Watt.hrs to travel 50 km on a bike		
Assumed charging efficiency of 80% (typical charging efficiency of SLA battery)		

As can be seen from Table 3, an ebike (using SA electricity which has amongst the highest CO2 produced per kWh) will produce approximately 20 times less C02 than a motor car and 7.5 times less C02 than a motorbike. If SA had 50,000 ebike users traveling an average of 30 km each working day, this would result in 6,160 less tons of CO2 produced per month.

Cars and motorbikes also emit noise and particulate pollution (causing smog and respiratory problems) into concentrated urban areas, and the run off from leaking oil and used oil cause countless problems to the environment. Motorized vehicles such as motorbikes and cars are most efficient the day they are bought and tend to get worse the older they are. According to the U.S. Environmental Protection Agency, 10 to 30 percent of the vehicles on the road create the majority of the pollution which is caused by age, poor maintenance etc.

Electric bikes are **the most energy efficient** means of transport known to mankind, greater even than cycling by human power (Lemire-Elmore, Justin, April 2004). In today's world of increasing energy costs, the world's leaders need to start looking at energy efficiency.

Recyclable - Every part of an ebike should and can be recyclable, including the Lead Acid, NiMH and Li-P batteries (NiCd batteries should not be used as they are not recyclable and are extremely toxic to the environment. In most developed worlds they are not allowed to be sold). More over, because of the size (less than 30kg for the total bike), recycling becomes much easier. Compare this to a 1,200 kg car with plastics, metals and foams intertwined with oil which is more difficult to recycle and generally ends its life in an unsightly dump. In an ebike, the most toxic part is the SLA battery which fortunately is recyclable. Lead acid batteries are a reasonable environmental success story of our time, with roughly 83% of all battery lead being recycled in SA. Compared to 42% of newspapers, 55% of aluminium soft drink and beer cans, and 40% of plastic soft drink bottles, lead acid batteries top the list of the most highly recycled consumer products (Joseph, Kevin).

5. REDUCTION IN USE OF FOSSIL FUELS

Ebikes could dramatically reduce use of fossil fuels and reduce SA's dependence on oil.

Table 4. Hypothetical savings in fuels by using ebikes.

Estimated no of Ebikes	50,000	
Average distance travelled per day (km)	30	
Petrol consumed by a car per day	R 13.82	
Litres petrol consumed by car	2.4	liters
Petrol saved per month if 50,000 ebikes	R 14.96	Rands (millions)
Petrol saved per month if 50,000 ebikes	2598	KL
Emissions saved (CO2) pm - tons	6,160	tons CO2
Power needed to charge ebikes pm	349,106	kWh
Cost of electricity pm	R 132,660	Rands
Notes		
For every litre of fuel consumed, 2.5 kg CO2 is emitted		
Assumed 8l/100km for car, 16l/100km for taxi with 8 passengers		
Assumed 3l/100km for motor bike		
Eskom (SA utility) produces 0.96 kg C02 per kWh		
Assumed petrol price is R5.76 per litre		
Assumed need 430 Watt.hrs to travel 50 km on a bike		
Assumed charging efficiency of 80%		
Electricity R0.38 per kW.hr		

In Table 4, we show what the estimated saving in fuel could be if more users were using electric vehicles. If there were 50,000 ebikes commuters every day in South Africa, 6,160 less tons of C02 per month can be emitted and almost R15 million rands less of fuel per month would be used. It must be noted that the cost of electricity would be R132,660 which is less than 1% of the equivalent cost of the petrol or diesel to the consumer, and the 349,106 kWh of electricity (costing R2.65 per user per month) would not affect electricity supply in any way especially as charging would probably not take place during peak loads. Crude oil is South Africa's single largest import, and the vast majority of the downstream products are utilised by the Transport Sector (DME, South Africa). The use of ebikes thus fits in with the DME white paper on reducing South Africa's energy needs in a positive way, and helping our unhealthy Current Account deficit.

6. CONCLUSIONS

So if ebikes are currently so much more environmentally friendly, efficient, cheap to run, and they are going to get cheaper, lighter and more efficient in the future, what will inhibit the uptake of this form of transport in South Africa?

Initial purchase price of ebike - is still out of reach of many consumers.

This is an ongoing problem within South Africa where consumer (especially the poor) cannot afford the upfront cost, even though the per trip cost is far cheaper than public transport (see Table 2). However, financing schemes similar to models run by the furniture stores could help solve this problem and the price is going to come down.

Culture – South Africa does not have a big culture of cycling. This can partially be attributed to fairly long distances 15-25km we have to travel and simply the *lack of cycle paths*. However, ebikes make traveling 25km to work a simple task. It can also be seen that when Cycle paths are put in place in South Africa, they are made good use of.

Safety – this is a big reason for not cycling, because of the danger of traffic and criminals. Both of these could be simply solved by *more cycle paths*. Cycle paths would reduce danger from traffic and encourage more people to cycle. In turn more people on the cycle path would discourage criminals.

Lack of cycle paths – this appears to be the main reason that will inhibit the use of electric bicycles in the future in South Africa.

The lack of cycle paths is the major pitfall for ebikes (and bicycles) and *unless SA commits to cycle paths*, transport for South Africans will be disproportionately expensive. It is the author's opinion that one of the overlooked reasons that China is so cost competitive in industry, is that its population has good access to low cost transport in terms of bicycles and electric bicycles. This lowers the cost of living, and improves quality of life for them.

The current market in china for ebikes is estimated at *12 million units per year* and it is still growing exponentially. SA needs to ensure that they take advantage of ebike transport, by ensuring bicycle paths are developed and consumers will then follow.

7. FUTURE SOLUTIONS

If we look at some possible future Scenarios –

Trains - SA could decide to invest money on a better train system. The money would be mostly spent on foreign and relatively hi-tech companies. The whole system would have to be maintained, would have a fairly high running cost and a limited lifetime. The result is that public transport would still be more expensive than ebikes and less accessible.

Buses - Investing in many small 30-seater buses may help our public transport. However, buses have a limited lifetime and it must be noted that for the price of one 30-seater bus, 130 – 150 ebikes could be purchased and then be run cheaper than the bus. In rush hour, all 150 people would travel to work as fast as only the 30 people the bus could transport. The public bus transport would also still be more expensive than ebikes.

Bicycle paths - Alternatively SA could invest its money on massively expanding our bicycle path network. Some advantages are listed below;

- Bicycle paths *roughly* cost R160k per km as opposed to R10 million per km for a two lane road.
- Building bicycle paths is not a high tech endeavour. Minimal foundations and no heavy earth moving equipment is needed to build bicycle paths. It is a project that is ideally suited for outsourcing to *many* small BEE companies that would be contracted to build a particular section of bicycle path.
- It should be possible to install a network of bicycle paths across an entire city in less than five years. It should also be possible to find space and routes for them through almost all existing built up areas.
- Bicycle paths last longer than normal roads and have virtually no running costs. As a consequence they will continue adding value to the city, the community and the economy for many years to come with very little input. All the value remains in SA.

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APPENDIX 1

Table 1. Cost comparison of different battery types.

	Sealed Lead Acid	Nickel Metal Hydride	Lithium Polymer
Energy Density (Wh/kg)	36	65	130
Typical weight of 430 Wh battery-suitable for 50 km ebike range (kg)	12 kg	6 kg	2 kg
Typical Cycle Life[1]	250	500+	800+
Charge Time[2]	4.5 hrs	3.5 hrs	3 hrs
Self-discharge/ month	5%	25%	3%
Replacement cost of battery[3]	R 462	R 1,676	R 2,633
Approximate cost per 100km using ebike[4]	R 3.69	R 6.70	R 6.58
Electricity cost per 100km using ebike[5]	R 0.46	R 0.42	R 0.36
Total current cost per 100km for ebike	R 4.15	R 7.13	R 6.94
Potential total cost per 100km for ebike[6]	R 2.80	R 4.54	R 4.17
Notes			

1	Cycle life assumes 100% depth of discharge, and battery capacity is less than 80%
2	Typical charge time, newer technologies halving this time
3	Current SA retail prices inclusive of VAT. Prices will decrease with volumes
4	Assumes battery is replaced with 80% capacity. In reality cost will be 20-30% lower as users will carry on using batteries at the expense of range
5	Current Electricity cost 40 cents/kWhr; calc also takes into account charger losses
6	Assumes battery price drops 25%, and that users use battery until 60% of original capacity
7	Based on AA South African rates for a 1500cc-1800cc petrol engine, and petrol price of R5.76/l (Nov 2005)

The above table compares the current batteries available and shows the relative cost per 100 km traveled. What is particularly interesting is that even if electricity prices tripled, because of the relatively small cost of the electricity part, the cost of transport would barely increase. Compare this to car transport which would cost R60 per 100km at current prices for petrol (note 7) (R 87 per 100 km if maintenance is included according to AA rates) and even motorbike transport which would cost over R18 per 100km (R25 per 100 km including maintenance) which would be comparable to the above scenario.

What is important to take note of, is that the cost to transport could be less than R3.00 per 100km traveled per person (if one takes the SLA example which is predominately used in China), far cheaper than any other form of transport available, even public transport.

APPENDIX 2

HUB rpm	Voltage Input	Current Input	Electrical Power In	Torque Nm	Mech. Pout	Eff. %
	(DC Volts)	(DC Amps)	(Watts)		(Watts)	
263	36	0.7	25	0.0	0	0
255	36	2.0	70	1.6	44	62
252	36	2.6	94	3.1	82	88
248	36	3.8	137	4.6	120	87
239	36	5.0	178	6.1	152	85
234	36	6.1	218	7.6	185	85
229	36	7.2	259	9.0	216	83
222	36	8.3	299	10.7	248	83
218	36	9.4	338	12.0	274	81
212	36	10.5	378	13.5	299	79
207	36	11.6	418	14.8	321	77
203	36	12.9	464	16.4	349	75
195	36	14.4	518	17.9	366	71
189	36	15.3	551	19.3	382	69
184	36	16.4	590	21.0	405	69

Figure 1. Dynamometer Testing of HUB motor from Adequate Energy.

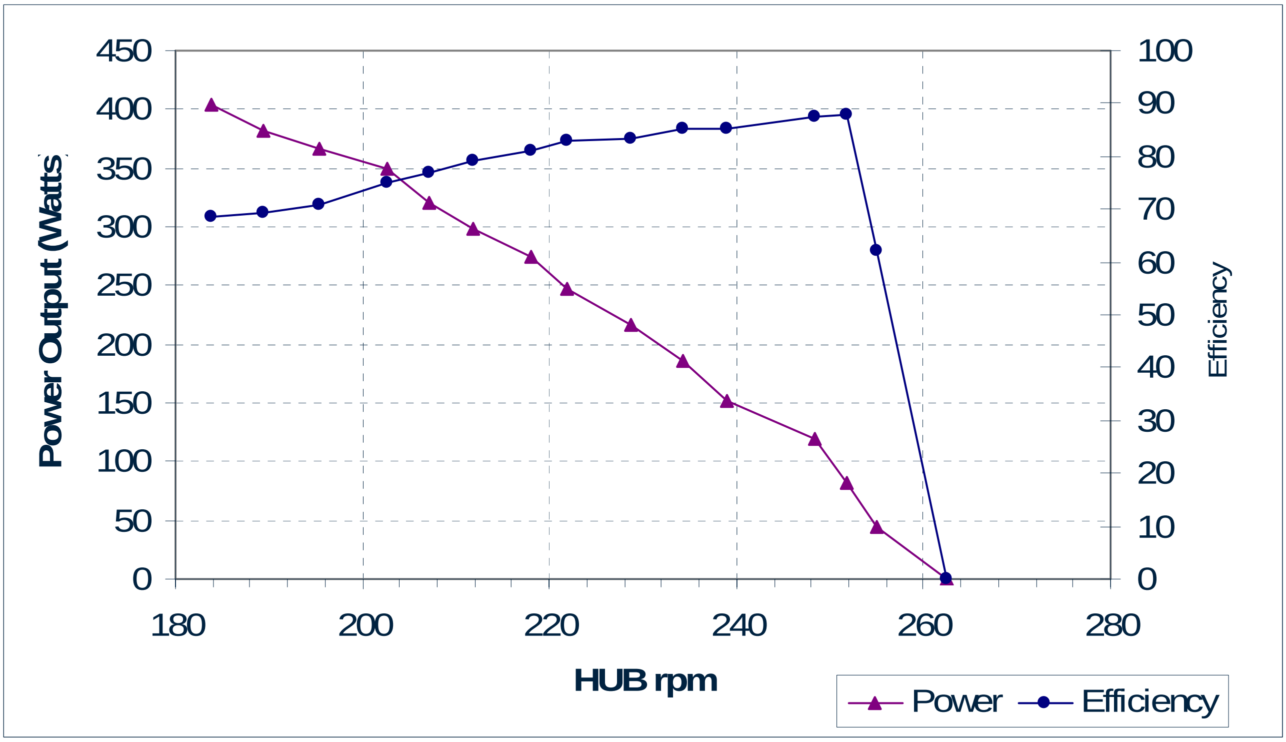

Figure 2. HUB motor Power Output and efficiency versus HUB rpm.