



The power assisted bicycle: a green vehicle to reduce greenhouse gas emissions and air pollution

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Abstract

The power assisted bicycle (PAB) weighs only a few kilograms more than a bicycle and, as its name suggests, gives only power assistance. Some PABs are powered by small and dirty two stroke petrol engines; some have clean electric motors powered by on-board rechargeable batteries. The most advanced electric PABs have electronically controlled power assistance via sensors in the cranks linked to a computer chip, with automatic speed control to enable them to be safely used on shared footways. Future models could be mass produced to run on renewable energy.

There over 125 models of PABs sold throughout the world today and most are legally classified as bicycles; however, their sale and use in Australia is constrained by poor legislation. This paper describes the past, present and possible future development of the PAB as a practical substitute for most urban car trips of less than 10 km:-

1. Product development since 1950; from the early petrol powered models to “state of the art” electric models.
2. Existing markets in Japan and China; their planned use to reduce air pollution in China.
3. How power assistance that reduces physical effort by 50% makes it easier to cycle in hilly cities, to carry loads and enables the elderly to continue cycling.
4. The development of electric PABs coupled with domestic solar PV panels for recharging, or clean IC engines powered by biofuels, are both feasible.
5. Outlines a specific engineering opportunity to use Australian expertise in the design of small clean IC engines to manufacture and export PABs in Australia and developing countries.

It is concluded that when “state of art” PABs are classified as bicycles in Australia a start can be made on realising their potential for reducing greenhouse gas emissions, air pollution, petrol consumption and traffic congestion in cities.

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Key reference and abbreviations:

- PAB = Power assisted bicycle
- E-PAB. = Power assisted bicycle with a rechargeable battery and electric motor with a maximum power output of 250 watts
- IC-PAB = PAB with a polluting two stroke internal combustion engine.
- E-Bike = Chinese electric bicycle with a motor rated at around 400 to 500 watts.
- Cycle Press = Japanese publisher serving the information needs of Asian manufacturers and distributors of 80 million new bicycles, E-PABs and E-Bikes each year. Produces their International Year Book, monthly journal and catalogues in English and Japanese. E-mail: cycletyo@zb3.so-net.ne.jp

Introduction

Both the IC-PAB, and the E-PAB, when they are legally classed as bicycles, are very economical for consumers. There are no compulsory registration and insurance fees and they have very low running costs. This is why IC-PABs were popular in postwar World War 2 Europe and are used widely in China and India today. However the difference in quality and sophistication between the early model IC-PABs and “state of the art” Yamaha and Panasonic E-PABs today is like the difference between a post war Holden car and a Toyota petrol/electric hybrid car.

A “state of the art “Japanese E-PAB is a bicycle that is pedal powered for most of the trip but power assisted when starting off, climbing hills, overcoming strong wind resistance or when carrying a heavy load. The power assist is designed to maintain a safe cruising speed and to halve the effort required to get from A to B on an average trip. The batteries are designed to provide for around 30 km of travel before a recharge. The rated power output of the E-PAB motor is between 210 and 245 watts. They cannot be purchased as bicycles in Australia due to a regulatory 200 watt limit on the power output.

The safety feature of the “state of the art “ E-PAB is that the electronically controlled power assist cuts out at 25 km per hour. This automatic speed limitation, coupled with their silent operation, makes them very suitable for use on both shared footways and local residential streets with 30 kph limits. In Japan, their use is relatively safe for able bodied people and a substitute for car trips of less than 10 km. The needs of an ageing population are being met, many of whom have health problems that prevent them from driving cars. The elderly use E-PABs, many makes of electric wheelchairs and tiny low speed three and four wheeled electric vehicles on shared footways and local roads (CyclePress 2001).

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The “state of the art” E-PAB and E-Bike have the potential for making Asian urban transport systems far more energy efficient, reducing greenhouse gas emissions and reducing air pollution. The next generation of these vehicles will be powered from renewable energy resources and will be the most energy efficient form of motorised transport ever invented.

For all practical purposes tomorrow’s electric two wheelers are destined to join the bicycle and walking as the only forms of transport that emit no greenhouse gases. Some of the car companies that are producing fuel cell concept cars and petrol/electric hybrid cars are also developing E-PABs and E-Bikes with solar PV battery rechargers for public and domestic use.

In Asian countries(with the exception of Japan and Singapore) IC-PABs, mopeds, scooters, motorcycles and three wheelers with two stroke engines are a major health hazard because up to 70% of the petrol used ends up as exhaust fumes. In Asia the production of petrol and diesel powered two wheelers exceeds 25 million per year. A similar number of motor cars and commercial vehicles are produced but they are less of a problem because new cars have 4-stroke engines and catalytic converters (CSE India 2002).

China has ten of the worlds most polluted megacities some of which have already banned the use of mopeds and IC-PABs. The Chinese National Environment Protection Agency has issued regulations that encourage Chinese industry to produce E-PABs and E-Bikes. By July 2000 37 cities had stopped issuing motorcycle licenses and from 2002 all new motorcycles made in Chinas are legally required to have much cleaner engines.

The situation is far worse in India where 70% of the motor vehicles on the roads are two and three wheeled vehicles with two stroke IC engines (CSE India 2002). Despite the existence of emission standards no coordinated action is being taken by the government, other than in New Delhi. India, Thailand, Taiwan and Vietnam are likely to create a regulatory environment in which all new motor cycles and scooters will have four stroke engines from around 2005.

Even the latest IC-PABS are polluting but new technology in the form of more efficient engines powered by biofuels such as ethanol could be made. The Orbital Engine Corporation (OEC) in WA, has expertise in the design of small clean engines (Leighton et all 1993). A bio-fueled PAB would be a very efficient user of ethanol which could be produced from waste in Asian rural areas.

At present only China and Taiwan are emulating Japanese E-PAB development and tooling up to produce E-PABs and E-Bikes. The ecological footprint of tomorrow’s solar powered E-PAB and E-Bike is so small it could enhance the mobility of billions without irreparable environmental damage and resource depletion.

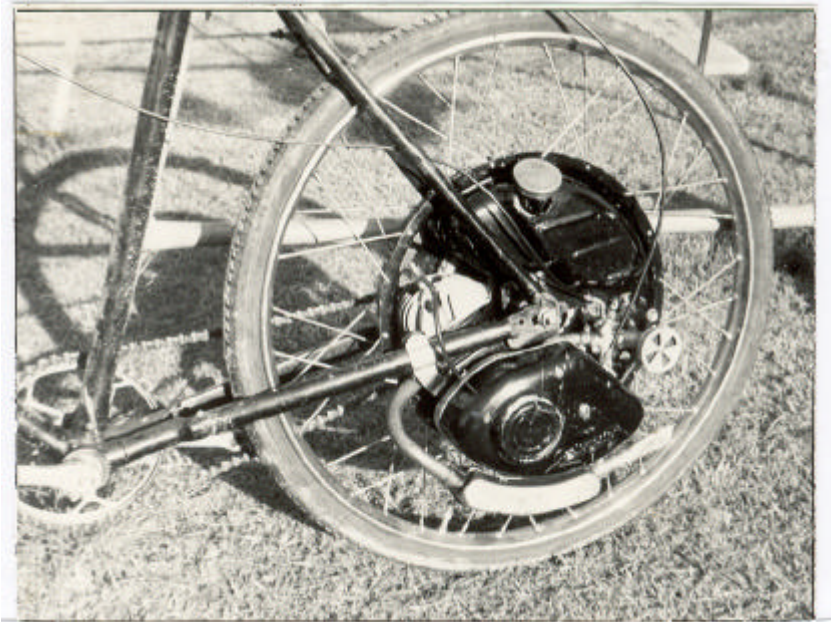
IC-PAB product development since 1900

The IC-PAB evolved from the development of the earliest European and British motor cycles which had pedal start engines and were very slow. The oldest relatives to the modern IC-PABs were the 1900 Singer motorised back wheels that were fitted into heavy duty bicycles. IC-PABs were popular for touring before 1906 but their use declined after World War 1.

After World War 2 the economic necessities of post war reconstruction in Europe encouraged the production of lighter weight IC-PABs and mopeds as economical means of mass transport. One British IC-PAB ,which was exported to Australia was the 1952 BSA model shown in figure 1.

This was typical of the models available as they were designed to be bolted onto or into an existing bicycle frame. They were PABs in the sense that you needed to pedal going uphill or to get the engine started or to overcome strong head and crosswinds; however there were no automatic electronic controls and speed limiters. Front wheel drive IC-PABs were also popular in Italy but were dangerous on England's icy roads in the winter.

Figure 1 . The BSA "Cyclemaster" motorised back wheel had a 32 cc cast iron engine built into a 27 x 1.5 inch rear bicycle wheel. It had a fuel consumption of 1.1 litres per 100 km on long runs, delivering its maximum power output at low speeds going uphill. It was safer than many PABs because it powered the back wheel and the engine's centre of gravity was low .



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Usage of petrol powered IC-PABs and mopeds in Europe grew steadily in the post war years and by 1965 there were thought to be 15 million of them in total. How many of them were IC-PABs was not known as they were all legally classified and counted as mopeds. After 1965 their use declined as the sales of motor cars increased. There were also a few electrically powered E-bikes using car batteries and electric motors which were bolted on above the front wheel and driven directly onto it via a roller. These early E-Bikes, with high centres of gravity, never became popular.

In 1984 Honda introduced the 'People,' an IC- PAB with a 24cc petrol engine weighing 26 kg. In the 1980s several Taiwanese companies were making IC-PABs mainly for the domestic and Chinese markets. However the technology did not change much and was mostly based on a motorised back wheel or a 30 to 40 cc two stroke engine driving a small wheel on the top of the tyre. There were a million or so IC-PABs in use in Europe in the mid 1990s.

Outside Europe in Japan, Taiwan, Australia and New Zealand, IC-PABs with a power output of 200 or 250 watts are classed as bicycles but in most other countries they are classed as mopeds or motor cycles. In Australia the 200 watt limit remained after the road traffic regulations were reviewed in 1994.

Since 1997 there has been a growing range of E-PABs on the world market with sophisticated electronic controls and there are around 90 companies producing E-PABs world wide. Many of these companies use Japanese made drive units and electronic control systems. Over 125 models of electric PABs and E-Bikes dominate the retail market today. In 1998 there were 17 Taiwanese companies researching and developing new models for the Chinese and European market. There are also some better quality IC-PABs available on the world market and the German Sachs IC-PAB with a 30cc engine and power limiter is available in Australia.

Figure 2. The PAS Little More has (1) a stable child seat, (2) ease of control and operation with a new keyless switch design and battery remaining indicator, (3) dynamo lighting control from handle bar mounted lever, (4) battery charging time of only 2.8 hours; on a single charge will travel 38 kms over flat roads. (5) It has a 3 speed integrated gear.



Japanese E-PAB product development since 1989

The development of E-PABs in Japan grew out of the large domestic market of around 8 million bicycles a year and the a high level of bicycle use amongst the elderly. Japan has a population of 126 million of which 72 million own a bicycle. E-PABs were originally designed as an industry initiative in the late 1980s to make pedalling easier for elderly cyclists. Japan has 19 million people over 65 years of age and that will double by 2040.

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Consumer surveys by Yamaha in the 1980s showed that most E-PAB users are women or elderly males. From an ergonomic viewpoint the lower power to weight ratio of these groups was taken into account in formulating the 50% power assist concept for the second generation E-PAB released in 1989, the 'PAS Prototype' with a maximum power output of 235 watts. The Yamaha 'PAS Prototype' was a major design breakthrough with torque sensors in the cranks which are linked to the motor controls for automatic power assistance when it is needed. The basic design concept was that only half the normal pedalling effort would be necessary for most trips. Figure 2 shows *The PAS Little More*, which evolved from the *PAS prototype*, and has a retail price in Japan with exclusive battery charger of A\$1500.

The Japanese government was concerned about pedestrian safety because only 2% of cycling is done on separate bike paths; 98% is done in areas shared with pedestrians. According to the Yamaha engineers the most difficult problem in addressing these safety concerns was designing the control system so as to integrate human pedal power and the power available from the motor in the safest way possible (Cycle Press 1997). The smart computer chip developed by Yamaha prevents aggressive riders winding their E-PAB up to more than 25 kph and terrorising pedestrians on shared footways and on the narrow side streets. Above 25 kph the extra weight of the power unit and batteries also makes it more difficult to go faster than on a bicycle.

In Australia, where bikelanes are provided on main roads, E-PABs would enable a steady speed to be maintained without weaving in uphill bikelanes (as happens with a bicycle) and to reduce the speed differential between vehicles in adjacent lanes. Another advantage is that the precision power unit is connected to the chain and does not get clogged up with mud in wet weather; as did early models with drive wheels running on the top of tyres.

In 1995, after six years of development, the Yamaha E-PAB was sold nationwide. From then on many companies in both Europe and Japan became involved in E-PAB design and production; many built their own bicycle frames around Yamaha's 'PAS power unit'. However there are still some recycling issues to address, as a non profit European company (Extra Energy) found out when it tested 17 E-PABs and eight E-Bikes most of which were made in Europe. Hannes Neupert of Extra Energy seeks to promote the benefits of electric/human power hybrid vehicles through product testing and by raising concerns about battery use and disposal. He states that;

PAB technology is still far from perfect . The issues of battery recycling, solar recharging and the need for 'smart or smarter chargers', and considerable information on these subjects, including the full test results, are on our web site; www.extraenergy.org.

By 1997 Japanese E-PABs, which were designed for different purposes, were coming onto the Japanese market in various wheel sizes and frame configurations. In 2001 Japanese E-PAB industry leaders were still focussing on

improving the quality of their products and the two leading manufacturers in the field, Yamaha and Panasonic, made major gains. Panasonic produced a compact lightweight drive unit and produce its "ViVi" E-PAB with an all up weight of less than 20 kg. Yamaha broke another barrier and brought production costs down. Honda also produced a lightweight E-PAB that folds up for carriage on other vehicles and weighs only 17.8 kg. Sales for 2001 went up, as shown in figure 3, as a consequence.

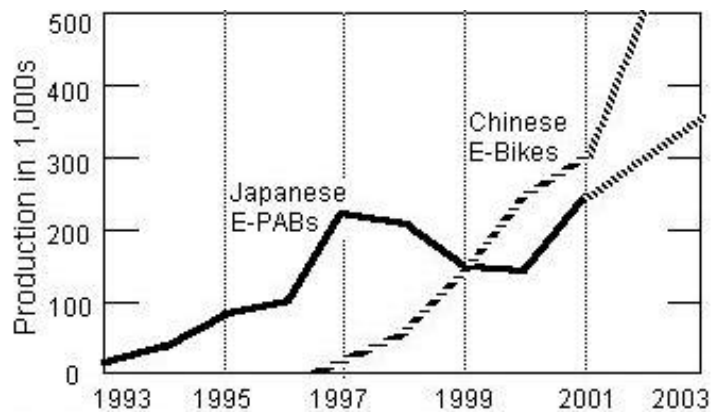


Figure 3 Production of Japanese E-PABs and Chinese E-Bikes 1993-2003

Today's niche markets for the E-PAB in Japan

In Japan there are 1.5 bicycles per household. While the level of bicycle use has declined in the last 20 years 14 % of all trips in 1996 were still made by bicycle and 17.5% of commuter trips. The E-PABs that hit the market from 1993 to 1996 were very successful because most of the 70,000 Japanese women over 50 years of age who purchased them found that pedalling the PAB was as easy as riding a bicycle had been when they were young.

Of the 950,000 Japanese who bought E-PABs in the five years from 1997 to December 2001 70% were sold to women. The three large niche markets today are listed below (Cycle Press 2001):-

People over 50 years of age bought 66% of all E-PABs. Mostly women over 50 and men over 60.

Women under 40 bought 9.4% of all E-PABs. A growing number are now using E-PABs fitted with specially designed child passenger seats (see photograph 2) or shopping baskets that are very stable.

Business men in their forties who value the time saved moving around congested central business districts bought 7.6% of E-PABs. Most of them do not want to "work up a sweat" on a bicycle and have found the E-PAB is easier and more convenient to use and park than a car.

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In 1990s the main problem for most E-PAB users was that they were too heavy for lifting up stairs into a typical Japanese home or into other vehicles. Even the small wheeled models weighed 24 to 27 kg and the large wheeled models weigh between 24 and 31 kg. The three wheeled shopping E-PABs were much heavier at 36 kg to 39 kg.(See photograph 3) The weight problem was particularly troublesome for the elderly so a lot of design effort is going into reducing the weight without increasing the price.

Figure 4 This Yamaha electric shopping tricycle has excellent stability and load carrying power. Battery charging takes 2.8 hours and it will carry the rider 35 km on flat roads. Electronic indicators show battery levels and a dynamo light is fitted that stays bright at low speeds. It comes complete with a built in front wheel lock, comfortable sprung saddle and front basket. Retail price in Japan A\$3550



Tomorrow's niche markets for the electric PAB in Japan

Since the Japan government signed the Kyoto Protocol in 2001 they have become interested in schemes to use E-PABs instead of cars to reduce greenhouse emissions and this may become an important factor in encouraging E-PAB use.

Perhaps the most interesting innovations are the uses of E-PABs to solve environmental problems in urban areas. For example In the Shimonoseki City in the prefecture of Yamaguchi a project was designed by Yamaha for the charging of batteries of 30 Yamaha "PAS" E-PABs using solar power. Yamaha

plans to promote E-PAB solar energy charging parking lots in many other areas (Cycle Press 2002).

Honda has been at the forefront of these environmental innovations and provided 200 "Racoon 24 Lx" E-PABs in April 2000 to Koga City in Ibaraki Prefecture which has built an extensive network of bikepaths. The bikes are assigned to different groups of people every 3 months to gather user comments about encouraging E-PAB use. The objective is to find out how to reduce car dependence, particularly for short trips. In 2002 battery charging stands are being provided that use solar PV panels to provide the electricity.

Another Honda environmental initiative is the concept of "Intelligent Community Vehicle Systems" (ICVS) based on moving individual vehicle ownerships to "shared vehicle use". Honda's vision is of a transport system that is "kind to people, the city and the planet". The ICVS aims to provide a solution to environmental conservation, co-existence with nature, better use of public space, smoother traffic flow and insufficient parking space. The basic concept of this system is based on moving from the individual ownership of vehicles to the shared ownership of environmentally friendly vehicles. This includes energy efficient cars, micro buses and E-PABs used for door to door trips and to access the very energy efficient rail system.

For the future there are three niche markets that can reasonably be expected to grow and contribute to a more passenger sustainable transport system:

People of all ages using shared E-PABs at solar charging stations and apartment and office E-PAB charging and storage facilities

Employees using E-PABs to access rail stations and modal interchanges.

Young male and female bicycle riders using E-PABs to take the extra physical effort out of riding in hilly cities so that they are as mobile as cyclists riding in flat urban areas

Honda and the Japanese government are improving on the European concept of using "Car Clubs" to discourage car ownership and encourage car sharing. Five million Japanese park bikes at rail stations every workday so E-PABs will progressively move into that niche market for multi-modal travel as many users need a bicycle at both ends of their rail journey. Lightweight fold-up E-PABs are allowed to be carried on bullet trains and they can easily fit in the boot of a small car.

Chinese production of E-PABs for export and E-Bikes for domestic use

In China it is the environment policies designed to reduce air pollution that provide a secure market for E-PAB and E-Bike manufacturers. Also, the spokesperson for the Electric Vehicle Institute of the China who addressed the 2001 Electric Bicycle Summit in Taiwan the quality of 47 of the 57 brands needs improving (Cycle press 2002)

The government's main concern is to build up an industry base that in the next few years can produce E-Bikes replacements for the millions of polluting IC-PABs in Chinese cities. In the year 2000 more than 12 million Chinese purchased scooters and light weight motor cycles in addition to IC-PABs which indicates the scale of the air pollution problem.

In Shanghai, which has a population of 16 million people, (the same population as urban Australia) there were nearly a million licensed IC-PABs with dirty engine emissions so the City government decided not to issue new licenses for them but only for E-Bikes as was done in Beijing. So it is therefore not surprising that 37 Chinese E-Bike brands are now being produced in Shanghai .

According to the Chairman of the China Bicycle Association, the prospect for the immediate future is a large increase in the domestic demand for E-Bikes.

“the majority of demand is for fully battery powered machines capable of self propulsion. These will provide the bulk of sales for the domestic market. As far as the development of Japanese style “intelligent” PABs is concerned the development of such models will be geared mostly to export sales”(Cycle Press 1998).

Some heavy Chinese E-PABs which comply with the 200 watt (1/4 HP) regulations were being sold in Australian bicycle shops in 2001 and 2002.

In China, which has an economy with a high growth rate, the domestic E-Bike market will be dominated by workers, most of whom will be male. There are 360 million adult bicycle users, many of whom are upwardly mobile and wanting to enhance their mobility, who will not be able to afford a car in the next decade. Housewives and the retired will only be a small part of the E-Bike market at this early stage of Chinese economic development.

The production of E-PABs and E-Bikes in China was forecast by the national Bicycle Industry Information Centre to increase to 500,000 by 2002 and to 1.5 million in the near future (Cycle Press 2002). This exceeds Japanese E-PAB production. (see figure 2) Given the high and growing health costs of urban air pollution, it is likely that more environmental legislation will be introduced that will greatly increase the demand for both E-PABs and E-Bikes in China (CSE India 2002).

Developing markets for E-PABs and E-Bikes in Europe

From 1998 there has been a resurgence of E-PAB research and development in Europe with 11 manufacturers already involved including Mercedes Benz and four other German companies. According to one review (Neurpert 2002). E-PABs are sold under 53 brand names. There are 17 different electric motor systems but most systems are sold by Yamaha, La Prima, Merida, Sanyo, and Shanghai Elite. European E-PABs sales reached 55,000 in 2001 despite the legacy of the 1970s moped legislation (Wigan 1975) which required that PABs be classified as mopeds and subject to compulsory registration and insurance.

This year when the European Union (EU) reclassified electric bicycles with a maximum power output of up to 250 watts as bicycles, it will greatly encourage E-PAB use. For safety reasons the EU requires that all E-PABs be fitted with electronic controls that progressively reduce the power output with increasing speed and cut off the electric power assist when a speed of 25 km/hour is reached. E-PABs meeting these EU requirements are now being produced in quantity in Japan, Taiwan and Europe.

EU member states, who previously had a chaotic array of legislation for E-PABs and E-Bikes, will replace their individual regulations with the EU regulations. This will result in stable free market conditions for all producers of E-PABs inside and outside of Europe. It is predicted that a EU market for 2 million E-PABs per year is possible in a few years (Neurpert 2002). Mercedes-Benz may be one of the contenders for this market as they have produced a very good E-PAB that appeals to young adults.

It would be prudent for the Commonwealth and state governments to bring the Australian Road Rules and State traffic Acts and regulations into line with the new EU regulations so that Australian consumers have the choice of buying "state of the art" Japanese and European E-PABs, with a power output of 205 to 245 watts.

Bikeway networks for the use of E-PABs and E-Bikes in hilly urban regions

The economic justification for using bicycles and E-PABs in OECD countries is to make better use of car fleets. The Dutch car fleet is so much more efficient today than is Australia's partly because bicycle trips substitute for around 8 billion kms of short car trips. 28% of all trips made by people over 11 years of age in the Netherlands are made by bicycle. This level of bicycle usage is partly due to Dutch cities being flat and partly due to the safe bikeway networks in all Dutch cities (Parker 2001).

Most cities elsewhere in the world are not flat and have grown much bigger than Dutch cities, with growth along motorised transport corridors. In these cities the use of bicycles is limited by the physical effort required to get from A to B. Trip lengths are longer and most cities have sprawled beyond the plains and valleys

and are spread across hilly terrain. If bikeway networks existed E-PABs could theoretically overcome both these constraints and could be used to enhance personal mobility in much the same way as bicycles do in flat cities. Modern multi geared bicycles are a help in climbing hills but, as recent experience in Japan shows, housewives and elderly cyclists start to give up cycling when it becomes too strenuous; but they have demonstrated that they will use E-PABs.

Even in the most hilly parts of Sydney the more powerful E-Bikes could enable people to cycle much more than they do now. Provided that safe back routes to rail stations and secure bicycle parking at stations and model interchanges were available the E-PAB and E-Bikes could make it much more convenient to use public transport and effectively enlarge rail catchment areas. From a strategic transport planning perspective investing in bikeway networks would be cost effective in hilly Australian cities if they enabled E-PABs and E-Bikes to be safely used instead of cars (Parker 1999).

Our less fortunate Asian neighbours have rapidly growing populations and a massive movement of people from rural areas into cities which by the year 2030 will house 75% of their populations. The predicted population increases in China, India, Pakistan, Bangladesh and Indonesia are of just over one billion people by 2030. Once the problem of oil depletion described in the next section is shown to be a threat to their national security, the use of E-PABs and E-Bikes will not be a matter of choice or to deal with urban air pollution, but of dire economic necessity.

Oil depletion and the need for PABs powered by renewable energy

World wide there is a need to decouple the growth in fuel consumption from economic growth as quickly as it is feasible to do so. Oil is a finite resource and there is a geologically determined physical limit to the quantity of cheap oil that can be produced each year from existing oil reserves. The world is not going to run out of fossil fuels for a long time. There are a lot of greenhouse intensive sources of oil which many nations are willing to exploit. This will reduce the worlds capacity to produce food in the equatorial regions where most of the world's poor live by accelerating climate change. A human tragedy is unfolding because cheap oil is not being conserved for assisting food production. Most developed nations do not have an oil conservation program in place and they ignore the following three oil depletion issues:

1. World wide there are no more major frontier regions left to explore besides the earth's poles; and for several years for every new barrel of oil discovered four barrels of oil have been consumed. The world's super giant and giant oil fields are dying off; and sometime in this decade there will be a shortfall in world oil production of several billion barrels a year (Campbell & Laherrere 1998). OPEC's oil production will peak in 12 years and North North Sea oil production is dropping now, and will decline sharply by 2005 (Australian Energy News 2001).

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2. Production of non-conventional crude oil has been initiated, at great cost, in Venezuela's Orinoco belt, in Canada's Athabasca tar sands and in ultra-deep waters and has increased greenhouse emissions as a consequence.

3. Worldwide no major primary energy rival can possibly take over from conventional oil before it becomes scarce, costly and unavailable to poor countries. There is no known energetically equivalent replacement for oil.

A global oil crunch is on the horizon according to oil giant BP (Bourne, G 2002) even though oil is still being produced at twice the level that it was in 1960. Indeed at the First International Workshop on Oil Depletion in Uppsala this year a prominent energy-sector investment banker from Houston who advises President Bush, stated that:-

"I have studied the depletion issue intensely for too long now to have any remaining doubts as to the severity of the issue. But I am still amazed at the limited knowledge that exists, even in the U.S. or within our major oil and gas company's senior management about this topic and its dire consequences" (Simmons 2002.).

The depletion of Australian oil reserves is also a problem according to Woodside's Managing Director (Akehurst 2002):

"Australia has been consuming oil three times faster than it has been discovered. Projections by Australian Government forecasting agencies indicate that Australia is facing a rapid decline in liquid petroleum production over the next decade. Liquids self-sufficiency is expected to decline from an average of 80-90% over the past decade to less than 40% by 2010. The economic implications for Australia are significant including a rapid deterioration in Australia's trade deficit on liquid hydrocarbons (from a surplus of \$1.2 billion in 2000/01 to a projected deficit of \$7.6 billion by 2009/10).

The general view within the oil industry is that Australia has low oil prospectivity and fields yet to be discovered are of small to medium size and becoming more technically demanding eg heavy oil or deep water. Yet the belief persists that new vehicle technology in form of the hybrid petrol/electric car, the Hyper Car or the fuel cell powered car will cope with any future oil depletion problems. That is not true because the mass production of hyper cars or fuel cell powered cars will take the best part of five years to create workable designs and another five years to set up production lines on a big enough scale to have any effect. By the time these cars are being mass produced around 10 million more cars will have been sold in Australia and 200 million more world wide.

The hybrid petrol/electric car could be mass produced in great numbers by 2005 but weighs in at around one tonne; and mostly will carry only one occupant with large indirect energy costs in its manufacture and in the roads built to drive it on. Why not also plan for the mass production of 20 kg E-PABs at the same time to use instead of cars for trips of less than 10 km? Biofuels such as ethanol could be used in PABs with clean internal combustion engines. Photovoltaic cells have

been used to charge E-PAB and E-Bike batteries. PABs clearly have more potential to efficiently use renewable energy resources than cars.

The average life of car in the world car fleet is around 15 years. Of the 530 million cars on the world's roads in 2002 half of them will still be on the roads by 2009, so there is no chance of reducing the dependence on oil. By 2005 it would be prudent for Australia to be mass producing PABs running on renewables as well as small hybrid petrol/electric cars. Another scenario is that a few years later the world's car production may be cut right back as a result of a 1930s type economic depression which will be triggered by increasing oil prices. This paper suggests that the development of green vehicles is a risk management strategy and an energy security issue that needs much more research.

A technically exciting future for the E-PAB and E-Bike

Hopefully all countries with the resources to do it will be integrating their electricity from coal, gas, wind and solar sources by the year 2005. The key to being able to efficiently utilise solar PV on the supply side will depend on reduced demand for mains AC electricity. Even so a cautionary approach to solar PV is necessary because, while the use of solar PV can be economically justified to power a 25 kg PAB that replaces a car trip, it could never be justified for powering electric cars or replacing conventional power stations because it is currently the most expensive form of renewable electricity. According to Diesendorf:-

Its generation cost (solar PV) is over 30 cents per kilowatt-hour (kWh), that is, at least 4 times the cost of large-scale wind power at excellent sites and at least 5 times the cost of generating electricity by burning biomass (e.g. bagasse) at appropriate sites. There is no doubt that increasing the market size and hence the volume of production would bring the price of PVs down, but existing, commercial PV technology is still too inefficient and expensive to reduce the cost by a factor of four...(Diesendorf 1999).

The prospect for powering electric motorcycles with solar battery recharging is little better than for electric cars. However, E-PABs and E-Bikes use so little energy to recharge their batteries they should be sold as part of a package, complete with a PV 24 Volt DC battery charging system coupled to solar panels. The efficiency of the total package in substituting for car trips would justify the higher kw hour cost of solar PV because only a small area of solar panels is required with a low installation cost.

Within ten years the development of domestic solar power systems for DC powered appliances (as well as for recharging the E-PAB 24 volt DC batteries) is feasible in both urban and rural areas. There is no necessity to connect these appliances to the AC grid; this will reduce the demand on it and the need to use large brown coal powered generators. Incentives are needed for utilising

solar energy in the more efficient DC powered appliances otherwise these appliances will not be available when mass produced low cost domestic solar PV panels become available.

Adapting existing Australian expertise in engine design to create biofuelled” PAB manufacturing industry

There is the potential for Australian companies to manufacture bio-fueled PABs using the clean electronic ignition two stroke engines that are available in WA. The Orbital Engine Corporation (OEC) in WA is one of the leading independent automotive research establishments in the world. The OEC has expertise in the design of small clean two stroke engines (Leighton et al 1993) which are used in marine outboard motors, jet skis, Piaggio-engined scooters, and NSR motor cycles. The Chinese authorities have now adopted OEC designed clean electronic ignition, two stroke engines for all new motor scooters made in China (Johnstone, B 1998).

The direct injection orbital engine, when using petrol, produces less pollutants than the four stroke engine. A tiny 25 cc or 30cc OEC two stroke PAB engine precision built with high quality materials and specifically designed to use ethanol, or a blend of ethanol and petrol, would produce a very small volume of air pollutants. As OEC designed engines for scooters and light weight motorcycles already exist, it is reasonable to assume that the opportunity exists in Australia to manufacture an even smaller engine.

Tomorrows bio-fueled IC-PAB may prove to be a competitor to the “state of the art” E-PABs. It certainly will be a few kilograms lighter and will not rely on mains electricity to charge it batteries. When the oil crunch comes and fuel is much more expensive than today there will be a market for bio-fueled PAB’s in rural areas of the developing world. The production of 95% proof ethanol in villages using relatively low cost labour to run stills is feasible. Ethanol can be made by the fermentation of sugars made from harvest residues, agricultural waste, and sugar cane and distilled in 3 stages.

Ethanol can be used as a fuel and blended with petrol or diesel. Commercially it is likely to be made from plantations of specially selected shrubs or trees grown on marginal land which has low value for anything else. In Australian Blue Mallee plantations, on the millions of hectares of land that has already been damaged by salination, theoretically at least a million tonnes of ethanol a year could be produced by 2010. This would displace fossil fuels, as well as helping to rehabilitate the bush both ecologically and economically (NELA 1996). Ethanol will in 5 to 10 years cost less to produce than petrol so its production should be encouraged.

Conclusions and recommendations

There is a need to enable Australia to survive the major depression which may be induced by the depletion of indigenous and world oil reserves as early as 2006 and will certainly occur by 2016. As a risk management strategy green products like the E-PAB and E-Bike could be mass produced to help move the world and Australia beyond oil. In the next 20 years they could be used to substitute for many car trips and thereby reduce demand for oil. To create ecologically sustainable cities that encourage E-PAB and E-Bike and bicycle use we must also start building urban bikeways now.

Given a government commitment to develop green vehicles it is likely that the Australian market for E-PABs would initially be dominated by female buyers and older men as it is in Japan today. Furthermore extensive product development in Japan has proven that extra power output is clearly necessary for female and elderly users in moderately hilly urban environments. To create an Australian regulatory environment suitable for encouraging E-PAB use one simple regulatory change needs to be made.

- Increase the 200 watt regulatory limit to 250 watts in line with both the Japanese and EU regulations.

Once that is done the issue of whether or not 250 watts is enough power for those wishing to use an E-PAB safely and without too much effort in the very hilly parts of cities like Sydney and Brisbane need to be resolved. This can be done by commissioning a consultant or cycling organisation to do the following:-

- Study and test an E-Bike with a 400 watt power output and a quality Japanese made E-PAB to compare their capability for safely riding up hills in an urban environment by elderly male and female test riders. The models recommended for testing are the "Lafree" E-Bike made by Giant weighing 29 kg with 400 watt power output and two E-PABs that weigh around 20 kg; the Panasonic "ViVi" and the Yamaha "PAS Super Light U" (which is designed for women wearing skirts to mount and dismount easily)

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In the medium term E-PABs and E-Bikes could be powered by batteries recharged from Australian made photovoltaic cells mounted on the roof of the house or garage of their owners. Investing in tomorrow's industry to produce an E-PAB with batteries charged from small arrays of photovoltaic cells or a bio-fueled IC-PAB is a sensible oil depletion risk management strategy. It is recommended that the ATRB should commission three studies:-

1. Commission a university to develop a prototype solar PV battery recharging installation for a Japanese E-PAB, and to test it over a period of one year and produce a feasibility study and detailed costings for factory production.

2. Commission the Orbital Engine Company (OEC) to produce a feasibility study for the production of two bio-fueled PAB engines. One 400 watt engine would use ethanol and the other a rich ethanol/petrol blend of fuel.

3. Commission a report on the potential domestic and export markets for Australian made E-PABs and E-Bikes and ethanol fuelled PAB's or ethanol fuelled PAB engines

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