ADB

Project Number: 43207

Philippines: Mitigation of Climate Change Through Increased Energy Efficiency and the Use of Clean Energy

Lead Acid: A Growing Environmental Problem

Asian Development Bank

LEAD ACID: A GROWING ENVIRONMENTAL PROBLEM

I. Introduction

1. This report provides the technical, financial and environmental justifications for selecting lithium battery as a technology of choice for the e-Trike project.

II. Battery Technology

2. The default battery technology used in electric vehicle was lead acid because it was readily available and has a lower capital cost than other competing battery technologies. Lead acid battery performance has been well established and has become a common choice for batteries used in electric vehicles due to the vehicle designers' familiarity of the technology.

A. Higher Energy Density

3. For mobile battery application, a high energy density means a smaller and lighter battery size is required to power the electric device. The nickel metal hydride and the lithium batteries thrived in the cellular mobile, laptops, and PDA applications due their energy density advantage over lead acid. The table below shows the comparison made by Kokam, a Korean Company, on the lead acid, nickel metal hydride and lithium Polymer battery technologies.

Table 1. Battery Technology comparison

	Lead Acid	Ni-MH	Lithium Polymer
Nominal Voltage	2.0V/cell	1.25V/cell	3.7V/cell
Combination	6 cells = 12.0V	10 cells = 12.5V	4 cells = 14.8V
Capacity (assume)	100Ah	100Ah	100Ah
Energy	1,200 Wh	1,250 Wh	1,480 Wh
Weight	34.3Kg	15.6Kg	8.2Kg
Volume	13.4 liter	5.2 liter	3.5 liter

4. The table shows that for a typical 12V 100Ah battery, lithium batteries are around four times lighter and smaller than lead acid batteries. These advantages increase the power, range and efficiency for the electric vehicle aside from a smaller compartment and a lighter suspension to support the battery weight.

5. The high energy density of lithium batteries raised some safety issues. In the past, oxide-based electrodes were used in lithium ion batteries, which could overheat and explode, but current lithium ion batteries include phosphate, a much less volatile material that significantly increases the safety of lithium ion batteries.

B. Fast Charging Capability

6. Lead acid batteries require slow charging to efficiently and safely store energy. Typical charging time take 8 to 10 hours and usually done overnight. It is very common for lithium batteries to have slow charging time of 3 hours and can be charged faster within an hour without sacrificing its service life, charging efficiency and safety. In March 2011, Mitsubishi installed

level 3 Electric Vehicle DC Fast Charge systems in Australia that provided 50% of the i-MIEV lithium battery charge in 12 minutes and 80% charge in 30 minutes. Dr. Paul Braun and his colleagues at University of Illinois, Urbana-Champaign succeeded in building prototype batteries that can be charged within two minutes as published in The Economist March 2011.

7. The fast charging capability reduces the time that the vehicle need to stop for charging and increases the useful time that that vehicle can be mobile. The usual approach to compensate for the long charging time is to increase the battery capacity to store enough energy required to run the vehicle throughout the rest of time between scheduled charging. This required increase in capacity results to higher battery cost, size and weight.

8. The electric vehicle can have the option of a smaller battery that can be fast charge charged if there are fast charging infrastructures along the route. This is important in the operation of the e-Trike where a smaller battery will reduce the cost, size and weight and the routes are short that can be loop back to a charging station or the routes are from station to station.

C. Battery Cycle life

9. Fully charging and discharging a battery makes a cycle. The battery life is based on the number of cycles that the battery can perform until it loses its capacity to store and deliver energy. Lead Acid battery manufacturers report that the cycle life of the battery between 400 and 550 cycles, although independent testing of four brands by an anonymous manufacturer revealed cycle life of 300–400 cycles. Most e-bike manufacturers provide only 1- to 1.5-year warranties on the battery, which corresponds to roughly 110–170 cycles.

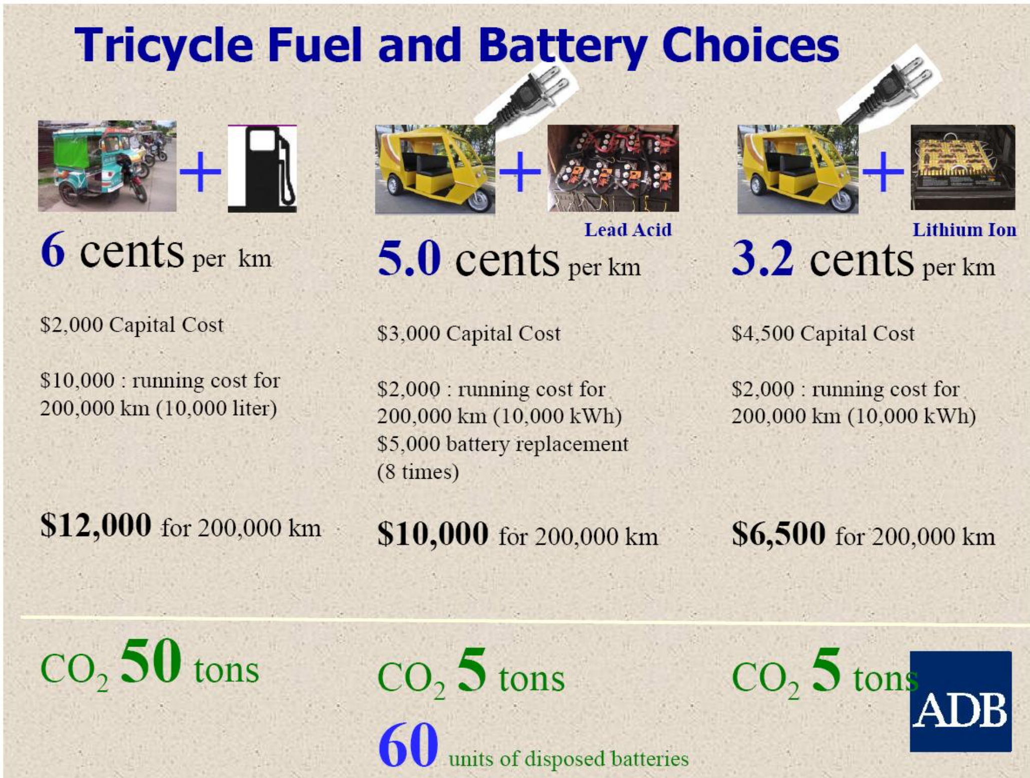
10. Lithium Ferro Phosphate ($LiFePO_4$) battery manufacturers from China claim more than 2,000 to 3,000 cycles at 80% depth of discharge while the cycle life extends to more than 5000 cycles at a shallower 70% depth of discharge. A Korean company showed test that their lithium battery still contained 70% capacity after 2,000 cycles at almost 100% depth of discharge. A Japanese battery manufacturer claims up to 6,000 for its lithium battery. These data simply shows that lithium batteries have at least 2,000 cycles at 80% depth of discharge which is four times the average cycle life claimed by lead acid manufacturers.

11. The long cycle life or lithium batteries provide advantages over lead acid in terms of life cycle cost and battery disposal. These two issues will be discussed separately in the next sections.

D. Battery Cost

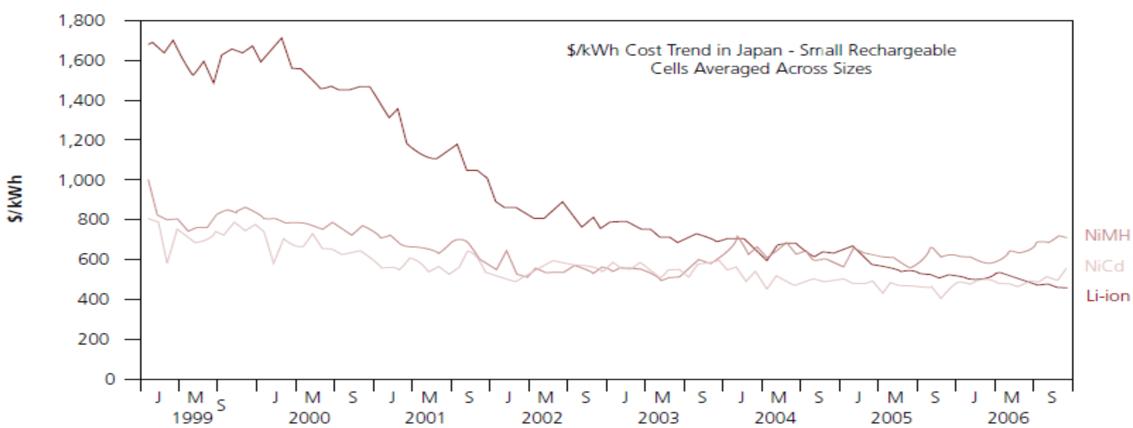
12. Battery cost is a major component in the total cost of the e-Trike. It is very common for e-Trike manufacturer and assemblers to select lead acid batteries because of its lower price and affordability of the resulting end product. However, comparing the cost per km traveled using the regular gasoline fed tricycle, e-Trike with lead acid battery and the e-Trike with lithium battery over 200,000km shows that the e-Trike with the lithium battery has a lowest cost per km travelled. The lead acid batteries were already replaced eight times during the same period that poses disposal and recycling issues. This comparison is illustrated below.

Figure 1: Comparison of gasoline fed tricycle, lead acid and lithium battery e-Trikes



13. The initial cost of the lithium battery has been the primary barrier in the use of this technology. Due to its longer life and higher power density, it has gained acceptance in the consumers' market. The Ministry of Economy, Trade and Industry of Japan provided the downward trend of the cost of lithium battery against NiCd and NiMH for consumers' application. The Merit Review 2009 report shows the forecast on mean price of lithium battery is 359.56$/kWh with baseline of 361.80$/kWh based on the price distribution of prices in the market and expected market penetration.

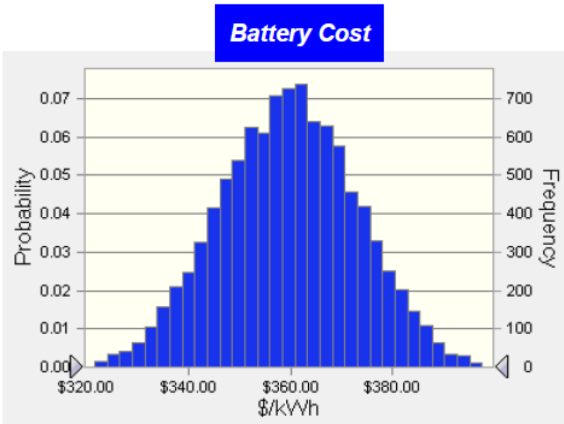
Battery Costs in Japan for Consumer Applications



J = January, kWh = kilowatt-hour, Li-ion = lithium ion, M = May, NiCd = nickel-cadmium, NiMH = nickel-metal hydride, S = September.

Source: TIAX, based on Japan's Ministry of Economy, Trade and Industry (METI) data.

$LiFePO_4$ / 3.0 Loading / 0% Fade *(short electrode, zero fade)*

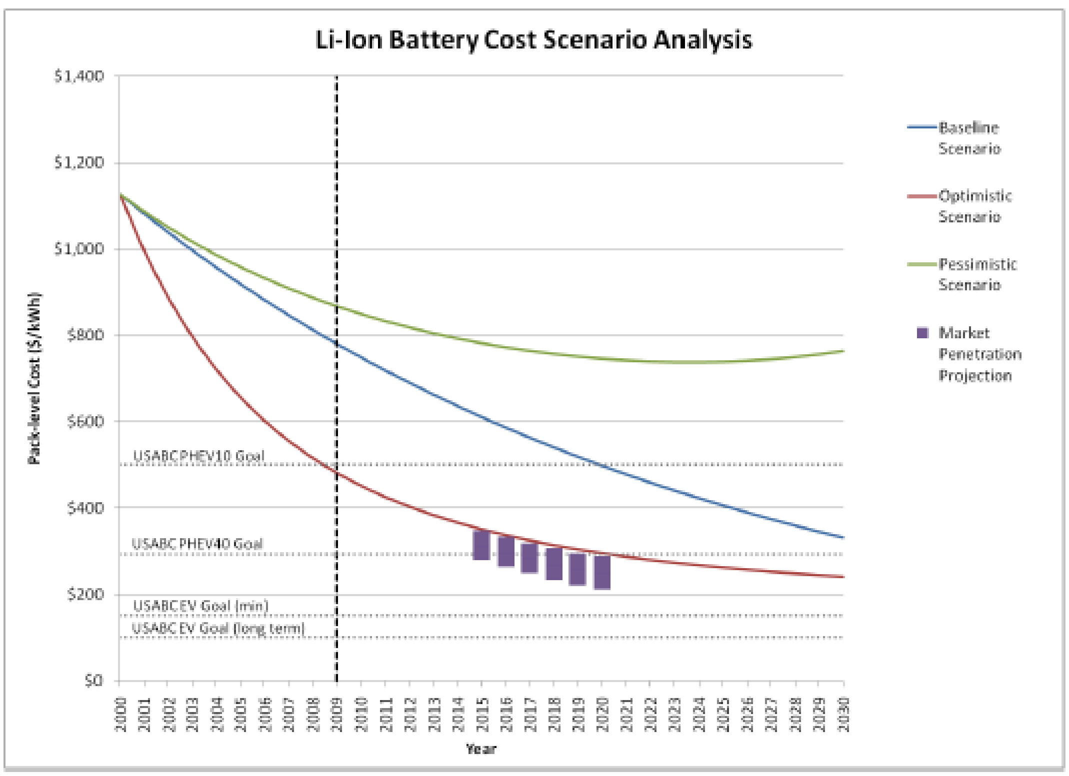


Statistic	Forecast Values $/kWh
Mean	**359.56**
Median	359.64
Standard Deviation	13.53
Minimum	313.43
Maximum	414.00
TIAX Baseline*	**361.80**

***** *The forecast value using only TIAX "base case" input parameters. This forecast value is a "single point" projection of battery cost.***

Source: TIAX,http://www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2009/energy_storage/es_02_barnett.pdf

An Evaluation Of Current And Future Costs For Lithium-Ion Batteries For Use In Electrified Vehicle Powertrains



Source: http://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/1007/Li-Ion%20Battery%20Costs%20-%20Anderson%20-%20MP%20Final.pdf?sequence=1

III. Environmental Concerns

14. According to an ADB publication[1], lead pollution is an inherent problem with electric vehicles. As long as lead acid batteries are used, there will always be pollution rates several times as high as their gasoline counterparts. It is estimated that 44%–70% of the lead from lead acid batteries in the PRC is released into the environment as waste. Groundwater and crop contamination from hazardous chemical and metals has already caused some local health problems throughout the country.

15. The Malaysian government is considering steps to contain potentially dangerous fallout from solar power systems that use lead acid batteries to store energy harvested from the sun. The biggest problem in East Malaysia, particularly Sabah, where under a government-sponsored rural electrification scheme, solar hybrid project has been rolled out to dozens of schools using lead-acid batteries. The government if pushing for a replacement programme for these batteries by conducting test using alternative technologies that do not utilize lead, a toxic heavy metal that could lead to mental retardation and breakdown of body organ functions.

16. Lead-acid batteries typically have a usable life of about 2-3 years, after which they must be sent for recycling. All of Malaysia's three lead-acid battery recycling plants, however, are located in the peninsular and transporting tons of batteries represent a logistical challenge.

17. The batteries can weigh as much as 130 kg each and one solar hybrid system alone can require a many as 80 lead acid batteries. As a result, some villagers have been dumping used and damaged batteries in rivers or leaving them neglected in backyards, possibly leaching the toxic heavy metal into fishing waters and contaminating ground water.

"I've even seen fishermen using solar hybrid lead acid batteries as anchors because they are so heavy," said YK Khor, chief technology officer of ETI Tech. His company is involved in a pilot project in Kampung Semaby, Sabah that uses lithium polymer batteries are an alternative to lead acid batteries. Khor claims that ETI Tech's home-grown lithium polymer technology is the first commercially available alternative to lead acid batteries in the world. "The problem of lead-acid batteries in not unique to Malaysia," he notes.

Figure 2: Lead acid battery can cause contamination if not properly disposed.

[1] ADB. 2009. *Electric bikes in the People's Republic of China: Impact on the Environment and Prospects for Growth.* Manila.

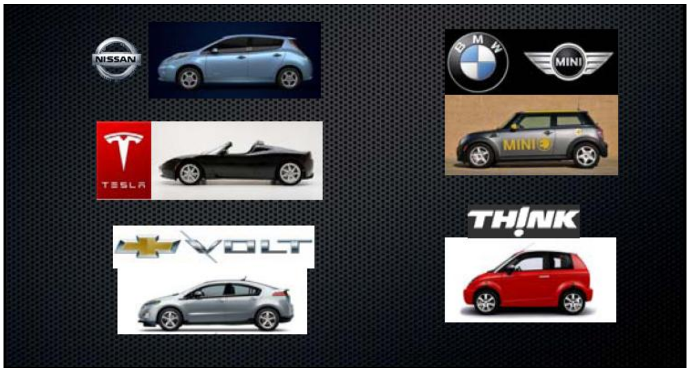
Figure 3: Electric bikes in China (Miss Electric 2011)

18. Around 90% of the electric bikes in China use lead acid batteries with 10 to 20kg of lead per bike. These lead acid batteries need to be replaced every 12 to 18 months which results to problems in mining, production and recycling.

IV. Conclusion: Move towards Lithium Battery

19. According to the Industrial Technology Research Institute, 40% of e-bikes in Japan and 35% in Europe use Li-ion batteries. Advances in battery technology have made electric vehicles a more practical transportation alternative. Today's lithium ion batteries are lighter, have a greater range and a longer battery life than older lead acid batteries. The major car companies in the world doing electric vehicles are using lithium batteries because this battery technology meets the power and energy requirement of the vehicles with a lighter weight and smaller space. Lithium batteries have longer cycle life and are economically viable with the down trend in price. There is far less disposal and environmental hazard posed by lithium batteries compared to the short-lived and toxic lead acid batteries. Selecting lithium batteries for the eTrike is a logical choice from the technical, economic and environmental perspectives.

Figure 4: New Electric Vehicles use lithium batteries (Miss Electric 2011)



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2011 Electric Vehicles

Fuel Economy | Specs

	2011 Nissan Leaf	2011 smart fortwo electric drive cabriolet	2011 smart fortwo electric drive coupe
	Electric Vehicle 	Electric Vehicle 	Electric Vehicle 
Configuration	Motor: 80 kw; Battery: 24 kw-hr; Trans: Automatic (1 speed)	Motor: 30 kw; Battery: 16.5 kw-hr; Trans: Automatic (1 speed)	Motor: 30 kw; Battery: 16.5 kw-hr; Trans: Automatic (1 speed)
Manufacturer's Suggested Retail Price (MSRP)	$32,780	Not available	Not available
EPA Fuel Economy			
Miles per Gallon of Gasoline Equivalent (MPGe) 1 gallon of gasoline=33.7 kw-hr	ELECTRICITY 99 Combined; 106 City, 92 Hwy	ELECTRICITY 87 Combined; 94 City, 79 Hwy	ELECTRICITY 87 Combined; 94 City, 79 Hwy
kw-hrs/100 miles	34 Combined; 32 City, 37 Hwy	39 Combined; 36 City, 43 Hwy	39 Combined; 36 City, 43 Hwy
Fuel Economics			
Cost to Drive 25 Miles	$1.02	$1.17	$1.17
Miles on a Charge	73 miles	63 miles	63 miles
Time to Charge Battery	120v outlet: 20 hrs 240v charging station: 7 hrs	120v outlet: 12 hrs 240v charging station: 8 hrs	120v outlet: 12 hrs 240v charging station: 8 hrs
Annual Fuel Cost*	$612	$702	$702

*Based on 15,000 miles annual driving and an electricity cost of $0.12/kw-hr.

Source: US Department of Energy (http://www.fueleconomy.gov/feg/evsbs.shtml)

ENERGY

Lithium-Ion Motorcycles

Better batteries are making electric motorcycles possible, providing a cleaner alternative to pollution-spewing gas-powered bikes.

THURSDAY, JULY 19, 2007 | BY KEVIN BULLIS

Audio »

Advanced battery technologies are enabling a much cleaner alternative to pollution-spewing gas-powered motorcycles and could help promote a larger-scale move toward electric vehicles. Yesterday, an electric scooter with motorcycle-like performance made by Vectrix, based in Newport, RI, was delivered to its first customer. And next year at least two motorcycles powered by advanced lithium-ion batteries will be sold in the United States.

Electric Motorcycles: *eMoto*

eMoto was designed and built in 2008 by a team member to demonstrate that low cost EV's are possible. Using all new parts available on the internet, eMoto was designed and constructed for $3000. For more information: www.electricmotion.org.

eMoto has since been used by the EVT to demonstrate custom battery pack designs and rapid charging. In 2009 members of the EVT designed and built a set of rapid-charging enabled battery modules using A123's 26650 cells, along with a custom charger. The relatively lower power requirements of eMoto prepare the team for the demands of the higher power elEVen sedan.