Electric vehicles

CLSA
ASIA-PACIFIC MARKETS

Special report

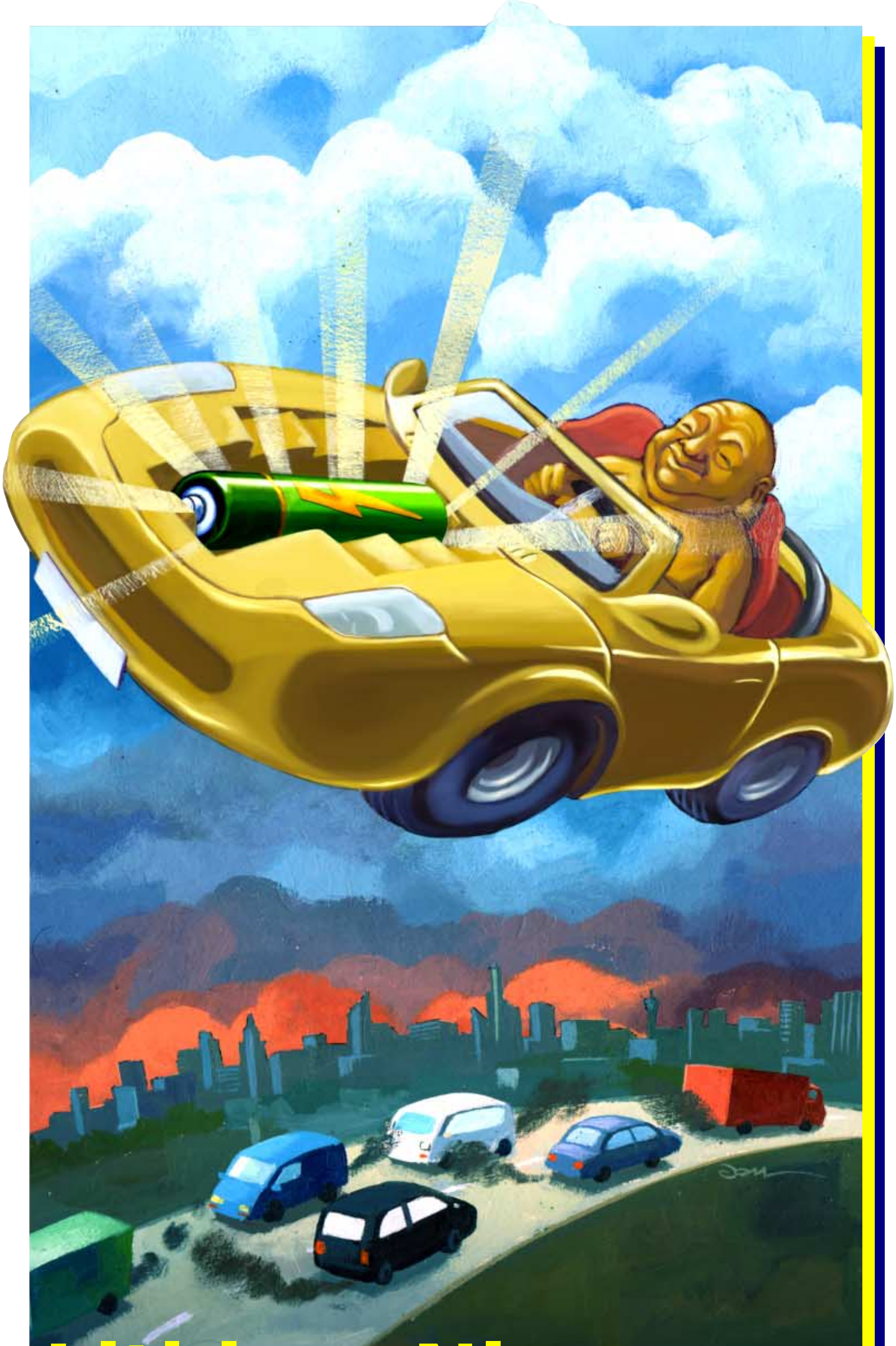
CLEAN & GREEN™

Eugene Hsiao
eugene.hsiao@clsa.com
(813) 45805988

Christopher Richter
(813) 45805288

2 June 2008

Japan
Autos



Lithium Nirvana

Powering the car of tomorrow

Automobile assemblers
Hyundai Motor (005380 KS)
Nissan Motor (7201 JP)
Toyota Motor (7203 JP)

Electronics manufacturers
BYD (1211 HK)
GS Yuasa (6674 JP)
LG Chemical (051910 KS)
Sanyo Electric (6764 JP)

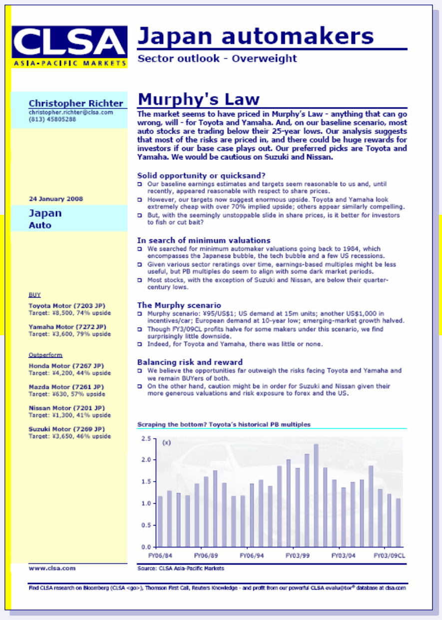
Materials and chemical
Asahi Kasei (3407 JP)
Citic Pacific (0267 HK)
Mitsubishi Chemical (4188 JP)
Mitsui Mining and Smelting (5706 JP)
NEC Tokin (6759 JP)
Nippon Carbon (5302 JP)
Toda Kogyo (4100 JP)
TonenGeneral (5012 JP)

www.clsa.com

Contents

All prices quoted herein are as at close of business 28 May 2008, unless otherwise stated

More highly charged research



Lithium Nirvana

No EV future without better batteries

As global pump prices keep pushing new highs, fuel-efficient vehicles are no longer just an eco-conscious luxury but an economically rational proposition. Battery technology is the chief bottleneck to developing mass-market electric vehicles, which we see as the long-term answer to eliminating carbon emissions and oil independence. Automakers are focusing on lithium-ion batteries to make electric vehicles a commercial reality. Toyota is our top pick to benefit from this coming shift.

Hybrids are already economically viable

The market for EVs, in the form of hybrids, is only 2% of total car sales, but has been enjoying nearly a 70% Cagr since 2000. Much of this growth can be attributed to selling hybrids as a brand rather than simply a fuel-efficient alternative. However, macro factors from fuel prices to government environmental initiatives will also make EVs economically viable. We estimate that hybrid cost premiums are already justified at current gasoline prices of US$3 per gallon.

Current batteries neither light nor powerful enough

EVs require a small and light, but powerful and cheap energy source. Standard lead-acid batteries are cheaper than nickel metal-hydride (NiMH) batteries by capacity, but have only half the energy density. Yet, nickel metal-hydride batteries are expensive - a NiMH battery capable of 40 miles of electric driving would cost US$17,000.

Lithium-ion is superior

Lithium-ion is chemically superior to other batteries. Lithium is abundant, with enough known reserves for 40 billion Toyota Prius hybrids and thus has the potential for further cost reduction. But benefits are limited by expensive cobalt-oxide cathodes, roughly 50% of total cell costs. Several companies globally are developing promising new cathode chemistries for vehicle use, with some on the cusp of mass production.

Asian companies leading the Li-ion revolution

Producing more than 80% of Li-ion cells globally, Asia provides several investment opportunities to tap into the growth of EVs. Automobile assemblers will hedge their bets across several green and fuel-efficient technologies. Electronics makers have been involved primarily through private joint ventures with auto companies. Materials and chemical firms will also see growth but typically only within subsidiaries and secondary businesses.

Playing the theme

	Code	Market cap (US$m)	Price		PE (x) 2007	PB (x) 2007
Automobile assemblers						
Toyota Motor	7203 JP	165,525	¥	5,020	9.3	1.4
Nissan Motor	7201 JP	38,173	¥	883	7.5	1.1
Hyundai Motor	005380 KS	17,403	won	81,800	13.2	1.0
Electronics manufacturers						
BYD Auto	1211 HK	3,273	HK$	12.46	14.1	2.1
GS Yuasa	6674 JP	1,381	¥	393	54.0	1.9
Sanyo Electric	6764 JP	4,566	¥	255	40.0	59.9
LG Chemical	051910 KS	6,967	won	95,700	10.1	1.9
Materials and chemical companies						
Citic Pacific	267 HK	9,232	HK$	32.80	6.7	1.2
NEC Tokin	6759 JP	381	¥	351	-	4.0
Mitsubishi Chemical	4188 JP	10,126	¥	703	5.9	1.2
Toda Kogyo	4100 JP	183	¥	395	-	0.7
Nippon Carbon	5302 JP	591	¥	522	16.9	2.6
Mitsui Mining and Smelting	5706 JP	1,918	¥	350	25.6	1.1
Asahi Kasei	3407 JP	8,102	¥	604	12.1	1.3
TonenGeneral Sekiyu	5012 JP	5,264	¥	974	82.9	2.6

Source: Bloomberg

Main Street electrical parade

Path to zero emissions requires advanced battery technology in EVs

Rising oil prices and an environmentally focused ethos are increasing the demand for fuel-efficient electric vehicles (EVs). While electric cars have existed for more than a century, it was not until the hybrid Toyota Prius that there was any commercial success. Now major automakers and several niche players are expanding into cutting-edge EV powertrains, such as plug-in hybrids, diesel hybrids, as well as pure-electric and fuel-cell vehicles. Each of these technologies promises to lower or eliminate emissions and decrease fuel dependency. However, regardless of the engine, there is a common technological problem that the market has yet to overcome: the battery.

Figure 1

GM EV1: The EV of the past . . .

Source: General Motors

Figure 2

Nissan Pivo2: . . .and the future?

Source: Nissan Motors

Hybrid justification

Hybrid is an EV evolution rather than revolution

The promise of EVs has existed for several decades, yet in the wake of the failed GM EV1 in the late 1990s, many were led to ask 'who killed the electric car?' Much of the problem stemmed from the high technology costs required to jump from gasoline-fuelled internal combustion engines (ICEs) to pure electric power. Despite such limitations, latent demand for ecologically friendly and fuel-efficient automobiles has led to the success of hybrid electric vehicles (HEVs), which achieved substantial sales growth for the past decade.

Past CLSA Forum Keynote Al Gore has plenty to say

> I drive a hybrid. Tipper and I got a Lexus hybrid. And we have a couple of Priuses in the family with our children. And I encourage people to make environmentally conscious choices because we all have to solve this climate crisis.
>
> Al Gore (Larry King Live, CNN)

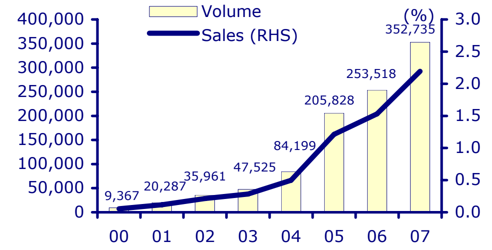
HEVs have gained popularity since the introduction of the Toyota Prius in 1997 and Honda Insight in 1999. While Toyota is still the leading producer of hybrids globally, other major competitors such as Nissan, Ford and GM have also released consumer hybrid vehicles, reflecting an increased acceptance of this alternative. HEV purchases have bucked the US downturn in auto sales, not only due to rising fuel prices and stringent global emissions standards, but also in part due to popular media coverage.

Hybrid growth booming in the past five years

Since 2000, new-hybrid-vehicle sales in the US have enjoyed a Cagr of 68% while gradually gaining a greater share of total auto sales. Though at present, hybrids only account for 2% of total US light-vehicle sales, the number of new models from all makers is steadily increasing, with several more to be released in late 2008. Recent industry forecasts predict hybrid vehicle sales to reach 2.2m-4.5m units worldwide by 2013, accounting for 10-20% of both the US and Japanese markets. Hybrid growth is predicated on several factors, but primarily rising fuel costs, environmental initiatives and public awareness.

Figure 3

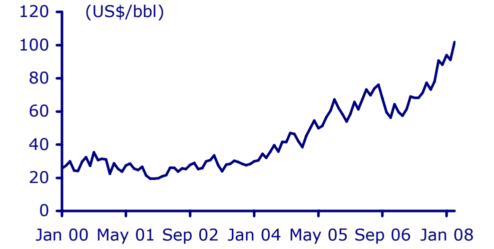
US hybrid sales



Source: CLSA Asia-Pacific Markets, WardsAuto

Figure 4

Crude oil (1M)



Source: Datastream

Better mileage at a cost

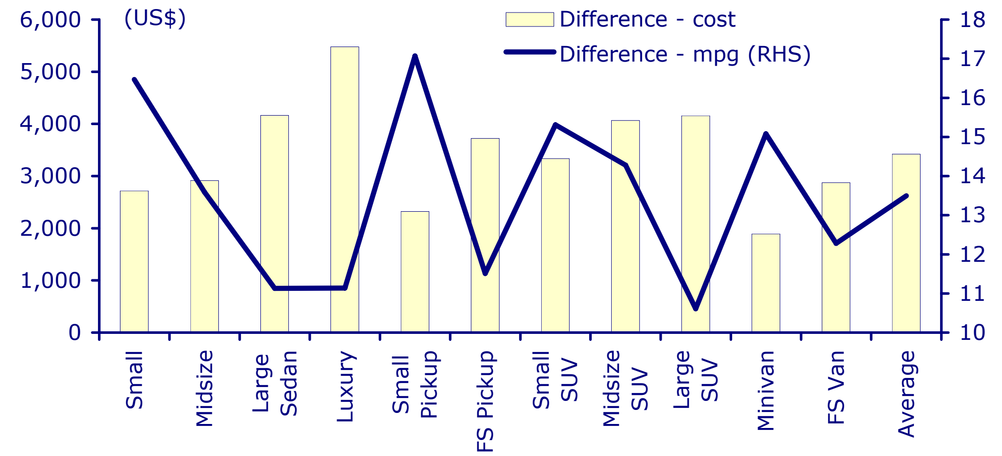
Pay for what you save at the pump tomorrow

Fuel prices will have an increasingly positive influence on hybrid sales growth, especially in the current period of high crude-oil prices. In terms of efficiency, a hybrid vehicle on average provides an extra 10-15 miles per gallon (mpg) compared to its gasoline ICE equivalent depending on the vehicle type and size. As oil prices continue to rise, the higher cost of about US$2,700 for small passenger vehicles can be better justified by the superior gas mileage of hybrid vehicles.

Fuel prices will have an increasingly positive influence on hybrid sales growth

Figure 5

Price/fuel efficiency of hybrid versus conventional vehicles



Source: CNW Marketing Research

US$100 oil? Hybrids worth it today

In order to judge the affordability of hybrid vehicles vis-à-vis rising fuel costs, we have sampled different current model hybrids with ICE equivalents.

- We have assumed a 10-year vehicle lifespan with 10,000 miles a year at a 55:45 city-to-highway driving ratio, and were able to determine the proforma ownership cost savings for each car.

Hybrid Civic premium justified at US$3/gallon

- Average US gasoline prices already exceed US$3 per gallon, and is nearing US$4 per gallon. At these prices, small cars such as the Honda Civic should be able to justify the added hybrid-system premium over the vehicle lifespan.
- If pump prices were to rise to US$4 throughout the vehicle lifespan, then nearly all current hybrids would be economically viable.
- Note that this does not include any subsidies or tax incentives, potentially making practical cost savings even more immediately achievable.

Figure 6

Hybrid cost savings - Pump-price sensitivity

	Vehicle type	Hybrid EV			Standard ICE			Price premium (US$)	End-of-life savings (US$/gallon)			
		Price (MSRP) (US$)	City (mpg)	Highway (mpg)	Price (MSRP) (US$)	City (mpg)	Highway (mpg)		2	3	4	5
Honda Civic 08	Small car	22,600	40	45	19,510	25	36	3,090	(940)	135	1,210	2,285
Toyota Prius vs Corolla 08[1]	Small Sedan	21,500	48	45	16,415	26	35	5,085	(2,574)	(1,319)	(64)	1,191
Toyota Camry 09	Full-size Sedan	25,350	33	34	21,225	21	31	4,125	(1,964)	(884)	197	1,277
Ford Escape 08	Compact SUV	26,640	34	30	21,880	20	26	4,760	(2,034)	(671)	692	2,056
Toyota Highlander 08	Midsize SUV	33,700	27	25	28,750	18	24	4,950	(2,763)	(1,669)	(576)	518
Lexus RX350 vs RX400h 08	Luxury SUV	41,280	27	24	37,400	18	23	3,880	(1,680)	(580)	520	1,620

[1] No direct comparison to Toyota Prius, Corolla used as approximation. Source: CLSA Asia-Pacific Markets, Edmunds.com

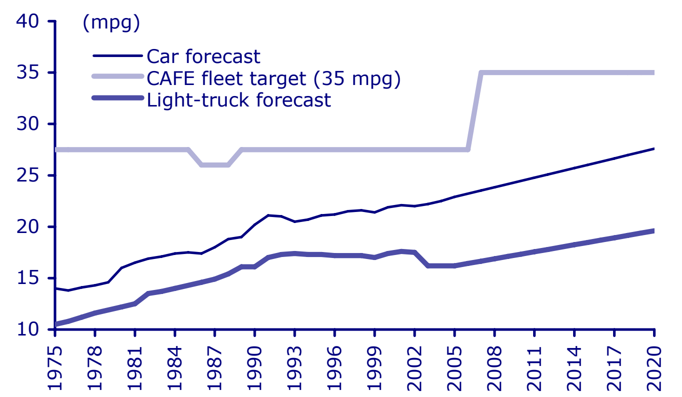
Government regulations forcing automakers to minimise emissions

Fuel ecology and fuel economy

As a result of growing fears over global warming and oil dependency, world governments have taken an assertive role in vehicle regulations. Governments have enacted tighter fuel-economy standards such as the Corporate Average Fuel Economy (CAFE) regulations in the US which requires an average of 35mpg for all passenger vehicles by 2020. By our estimates this is 27% higher than the current projected improvement for cars, and 78% higher for light trucks. Similarly the EU has agreed on a plan targeting a 20% decrease in greenhouse-gas emissions by 2020. Hybrids have an inherent emissions advantage from well-to-wheel. When comparing the relative total emissions from various drivetrains, hybrids have shown to produce less than half the emissions of a standard gasoline ICE.

Figure 7

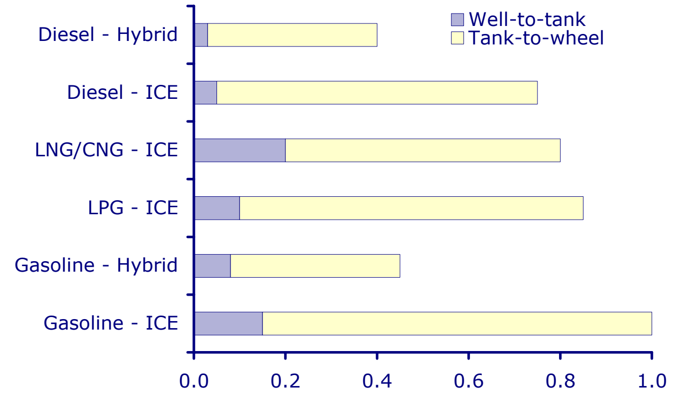
Aggressive US CAFE target



Source: CLSA Asia-Pacific Markets, US DOE

Figure 8

Relative well-to-wheel emissions



Source: Toyota Motors

What about biofuels?

There is much debate regarding the ecological and economic effects of using biofuels as an alternative to fossil fuels. While the answer to this complex and political question is outside the scope of this report, studies show that from a well-to-wheel perspective biofuels provide significant carbon reductions. However, impacts on food prices and the environment are highly controversial.

Hybrids will always have lower emissions than an ICE equivalent

The total impact of biofuels including generation needs to be considered. By-products of production such as deforestation, land use and indirect emissions actually lead to a net increase in greenhouse-gas emissions. Regardless, biofuel adoption will not damper electric-vehicle growth. Hybrid engines, by definition, can be run with alternative fuels, diesel or any other fuel, and will always be less polluting and more fuel-efficient than an ICE equivalent.

Environmental status symbol

Prius owners drive to make a statement

Another and arguably more compelling explanation for rising sales in hybrids is their role as an environmental status symbol. A CNW Marketing Research survey reveals that 30% of Prius owners cite 'making a personal statement' as a top reason for purchasing a hybrid vehicle. This beats out 'fuel economy' and 'lower emissions,' in spite of rising fuel costs and emissions restrictions. From a marketing perspective this has become a critical issue for automakers. 'Distinctive styling' was also cited more often than lower emissions as a reason to purchase a Prius. Consumers look to be visibly associated with the environmental cause and are willing to pay a price premium even before the recent surge in oil prices.

GM understands that perception is everything

> . . . every Toyota has a little bit of Prius in it. The iconic Toyota vehicle is the Prius. The iconic GM vehicle is the Hummer H2. So that creates the impression that Toyota is frugal, GM guzzles. Toyota loves the environment, GM pillages the environment. Perception becomes reality.
>
> GM Vice Chairman, Bob Lutz (US News and World Report)

The Prius and other green cars have become conspicuous pop-culture icons oft flaunted by celebrities and featured on popular US television such as Curb your Enthusiasm, Family Guy and South Park.

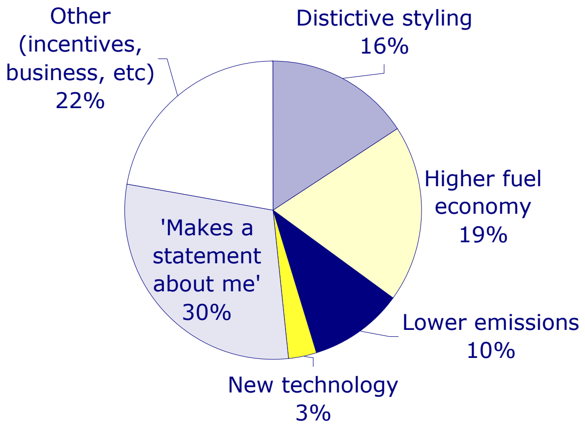
Hybrids: Popular enough to be funny

> In addition to [the Prius] being obviously economical and environmentally friendly, they drive great and are just plain sexy.
>
> Actor, Will Ferrell (New York Times)

Popularity may have driven hybrid sales in the past, but current fuel-price levels provide an economic incentive to lead demand into the future.

Figure 9

Top reasons to purchase a Prius



Source: CNW Marketing Research

Plug-in electric vehicles - Coming soon

Plug-in could mean never fuelling for short distances

The plug-in electric vehicle is widely predicted as the next step in the EV market. Conceptually, the biggest benefit of plug-in vehicles is the ability to perform short- to medium-range driving without burning any fuel. This potentially provides a readily realisable solution to energy/ecological concerns without any significant economic infrastructure costs. In practice there are two types of plug-in vehicles in development: hybrid plug-ins and pure-electric vehicles.

Hybrids with a punch

Big 2010 plans from Detroit and Toyota-city

The plug-in hybrid electric vehicle (PHEV) has garnered much attention as the most readily available solution applying plug-in technology. Both General Motors (GM) and Toyota have made official announcements that they hope to release a plug-in hybrid by 2010. There have also been some notable efforts to sell plug-in conversion kits for current hybrid vehicles but these systems are not yet cost-efficient enough to be widely practical. To date, there has not been a commercially released PHEV due to technical obstacles and impractical costs of the battery.

Figure 10

Plug-in Hybrid Prius

Source: Toyota Motor

Figure 11

GM Volt: Plug your cars in for Detroit

Source: General Motors

EVs mostly use existing technology, with notable exception of batteries

With the exception of the battery, there are no significantly new components to be used in PHEVs. The only other major differences between hybrid systems and ICEs are the additions of an electric motor and regenerative braking systems. These systems are already well-understood in current hybrid designs and have been practically implemented for over a decade. The most significant technological success of current hybrid vehicles is more likely the adoption of sophisticated drivetrain management systems that maximises vehicle efficiency and maintains battery performance and safety.

Waiting in the wings

Battery costs still too expensive for PEVs

Automakers still have hopes to develop pure-electric vehicles (PEVs), though facing even greater battery technology and cost limitations than plug-in hybrids. This has not stopped niche makers from providing options using more immediately available technologies such as the US$100,000 Tesla Roadster released this year. The cost of the Li-ion battery pack in the Roadster is estimated to be US$20,000 with a total weight of 450kg. This is significantly higher than the current hybrids at US$2,500 and 55kg, making the packs used in the Tesla PEV impractical for standard passenger cars.

No shortage of PEV concept vehicles

Automakers such as Nissan, Mitsubishi and GM have stated their intention to release plug-in PEVs and have developed various vehicle concepts such as the Nissan Denki Cube, Pivo2, Mixim and the Mitsubishi i-MiEV. Nissan, in particular, has been aggressive in pursuing a PEV as part of its goal for zero-emissions vehicles. However these concepts will all need better batteries before becoming a practical reality.

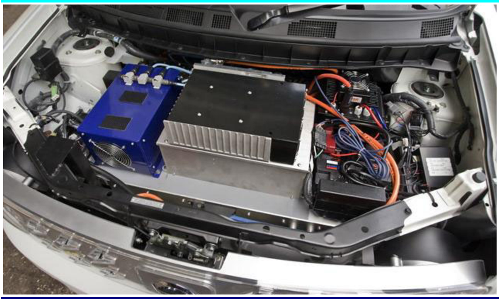
Figure 12

Tesla Roadster: PEV luxury at a cost

Source: Tesla Motors

Figure 13

PEV - Engine of the future?



Source: Nissan Motor

Fuel-cell vehicles - Still costly

Fuel-cell reaction does not release emissions

The most anticipated move towards a zero emission, gasoline-free vehicle is the introduction of fuel-cell technology. Even with hybrids and plug-ins, an external source of energy is still required to charge the vehicle. On the other hand, fuel cells directly generate electricity by chemical reaction as long as hydrogen and oxygen are available. The outputs are electricity, heat and water, which theoretically provide energy with no carbon emissions. As well, the fuel cell also eliminates the need for petroleum-based fuels, which are still required in hybrid engines.

Simple chemistry, but not cheap to achieve

Figure 14

Fuel cells: Theoretically emission-free

$$Anode \quad H_2 \rightarrow 2H^+ + 2e^-$$

$$Cathode \quad 2e^- + 2H^+ + \frac{1}{2}(O_2) \rightarrow H_2O$$

$$Cell \quad H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$

Source: CLSA Asia-Pacific Markets

Many issues still to be resolved for FCVs

Fuel-cell vehicles (FCVs) can be fuelled in a variety of methods. The most energy-efficient means would be pure hydrogen gas stored onboard in high-pressure tanks, but hydrogen-based fuels like methanol and ethanol could also be used if reformed into hydrogen. Hydrogen production and storage is a significant challenge in developing a FCV and is one of several hurdles before this technology can become widely adopted. Other issues include poor cold-weather operation, expensive platinum catalysts, hydrogen infrastructure costs and low well-to-wheel efficiencies - estimated to be only a-third of the energy efficiency of PEVs.

Hydrogen infrastructure could cost US$600bn

Cost is the largest deterrent to FCV adoption. An analysis by Arthur D Little commissioned by the US Department of Energy concluded that annually hydrogen FCV usage will cost at least US$5,000, which is US$1,000 per year higher than similar costs for HEVs, and US$1,500 higher than gasoline ICEs vehicles. Furthermore, the costs of building out a hydrogen infrastructure are estimated to be between US$100-600bn. Coupled with energy efficiency and other technical challenges, industry analysts do not expect commercial FCV production for at least another 10-20 years. Comparatively battery-based PHEVs and PEVs require very little infrastructure costs as they are grid connected, ie, charged at home. Although there is the potential for charging stations outside the home, this will not be a necessity prior to their widespread use.

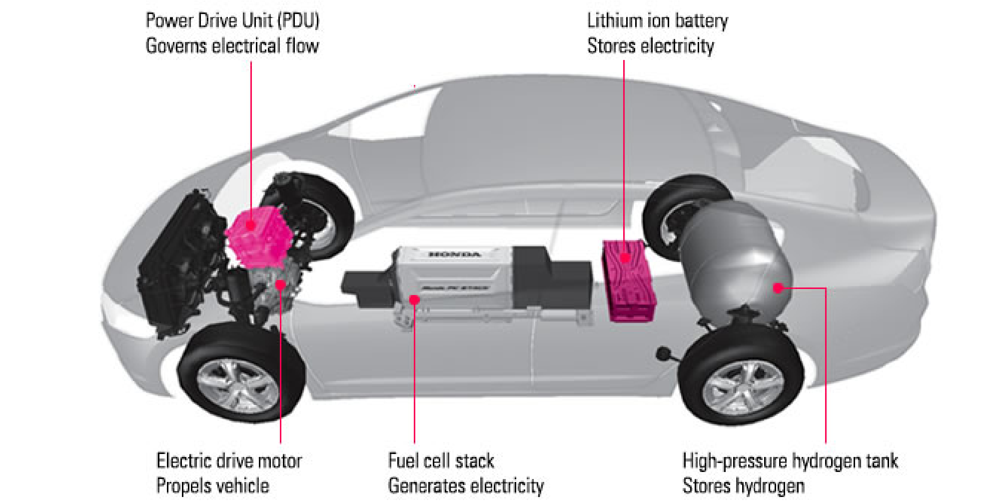
Honda FCV ready for lease this summer

These obstacles have not stopped automakers from developing fuel-cell concept vehicles for today. For example, Honda plans to publicly lease its FCX Clarity concept in limited numbers some time in summer 2008. The offer is a three-year US$600/month lease, though the actual cost of the vehicle, including the hydrogen maintenance, is likely to be significantly higher.

Honda plans to use Li-ion in fuel-cell vehicles

Figure 15

Honda FCX clarity: A working fuel-cell drivetrain

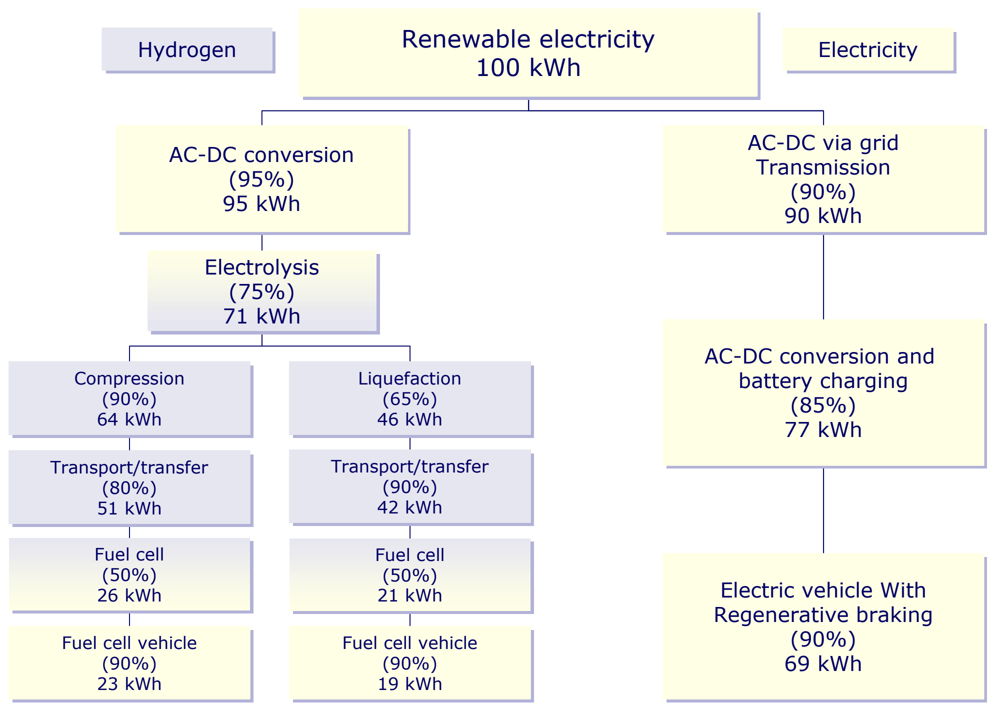


Source: Honda Motor

Hydrogen efficiency a significant barrier to actual adoption

Figure 16

Poor fuel-cell energy efficiency



Source: Proceedings of the IEEE Vol. 94. No. 10, October 2006

Batteries are the primary propulsion in EVs, only auxiliary in ICE

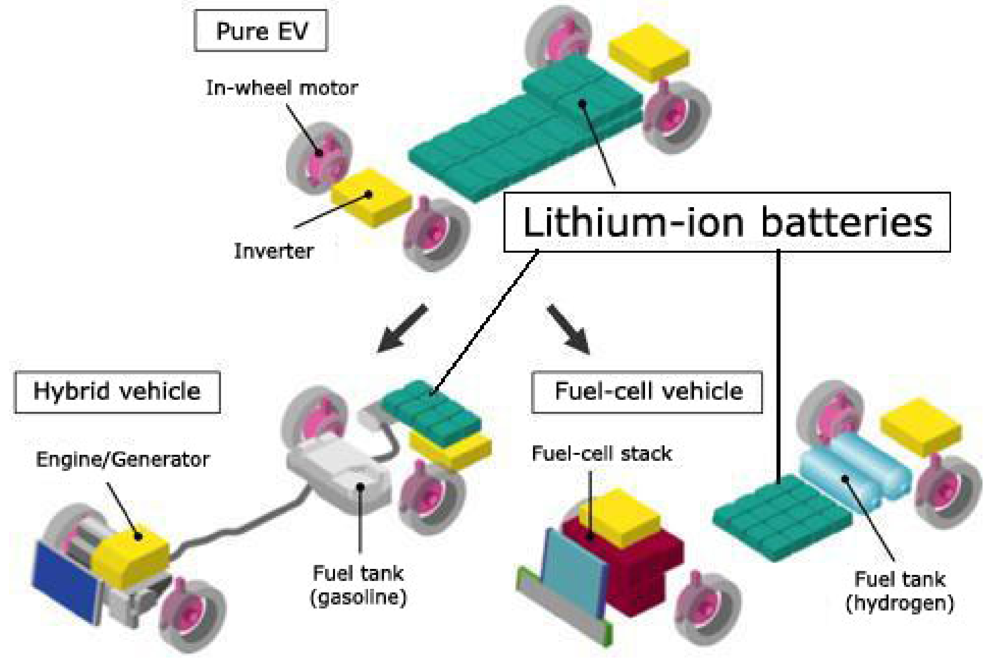
A shared problem

In all of these upcoming technologies there is a common bottleneck before practical adoption - the battery. At the core of hybrid technology, the battery stores the charge required to power the electric motor, but will become even more essential for any functional plug-in or pure-electric vehicle. At the same time the electrification of car interiors, from audio systems to satellite navigation devices, is already placing a higher battery strain in current automobiles. Even fuel cells will require batteries in order to store energy required to supply power during transient and overload stages. The critical difference is that while batteries in ICE vehicles are mainly for auxiliary uses, the stored electricity needed for propulsion in EVs is the primary source of energy, hence requiring much higher capacity, power and longevity.

Batteries in all future alternative powertrains

Figure 17

Energy storage: The EV common bond



Source: Mitsubishi Motors

Most automakers looking to Li-ion as the solution

The current generation of electric vehicles utilises nickel metal-hydride (NiMH) batteries, a well-understood technology mired in the trade-off between chemical stability and build durability versus energy density and heat output. Given these limitations, EV-focused automakers are looking towards lithium-ion (Li-ion) batteries to succeed NiMH in the immediate future. Li-ion batteries still need further improvements to safety, longevity, and most importantly, cost before wider adoption is possible.

Close, but no cigar

Current vehicle batteries not ready for PHEV or PEV

Electric vehicles require batteries that are light, robust and cost-efficient enough to function as the primary mode of propulsion. Presently there are two well-developed battery chemistries used for car batteries: lead-acid and nickel metal-hydride. Commonly-found lead-acid batteries are cheap but heavy, while the nickel metal-hydride batteries used in current generation hybrids are lighter but much more expensive. Both battery chemistries have strengths in different applications, but neither provides a promising solution to power the future generation of plug-in and pure battery electric vehicles.

Automobile batteries

Growing demand for high-capacity batteries

From engine ignition to powering satellite navigation systems, batteries already form an essential part of the modern driving experience. The global market for automotive batteries is estimated to be nearly US$16bn and growing. Electric-energy demand in vehicles has increased dramatically in recent times and faces an even higher hurdle with the introduction of PHEVs and PEVs. There are several battery chemistries available from the mature and cost-effective lead-acid batteries to the heavily-researched Li-ion batteries. Each has significant benefits and drawbacks when considered for practical application in EVs.

Built on cells

Batteries built from cells up into packs

At the core of vehicle batteries are the individual battery cells. Each cell is capable of chemically storing and releasing an electric current. Vehicle batteries are comprised of cells connected in series to form modules. Battery modules are then connected in series and/or parallel as packs in order to provide the required voltage and energy capacity to power the vehicle. For example, the typical car battery contains six cell/modules generating 2.1V in parallel to provide a standard 12V battery.

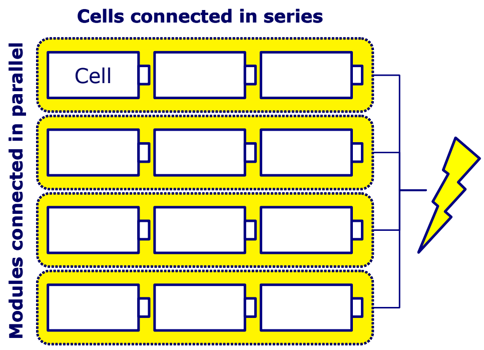
Figure 18

Standard car batteries

Source: GS Yuasa

Figure 19

Battery-pack configuration



Source: CLSA Asia-Pacific Markets

Four cell parts: cathode, anode, electrolyte and separator

There are four fundamental components in a battery cell: the cathode, anode, electrolyte and separator. The chemical composition of the cathode and anode determines the energy potential of the cell and hence the battery type, eg, the lead-sulphate cathode is what forms the basis of a "lead-acid" battery. The substances used in electrolytes and separators also affect cell efficiency, heat levels, self-discharge and other battery characteristics.

Figure 20

Basic battery components

Cathode (positive electrode)	Typically a solid-state oxide or sulfide compound capable of being reduced during cell discharge. Consumes electrons on discharge.
Anode (negative electrode)	A solid-state metal or alloy that will be oxidised during cell discharge. This electrode generates the electrons for the circuit when discharged.
Electrolyte	Medium used to permit ionic conduction between the electrodes. Usually liquid, but can be gel, paste or solid state, eg, Li-Polymer.
Separator	Electrically insulating layer of material separating the electrodes to prevent short circuits. Must be permeable to the ions of the electrolyte.

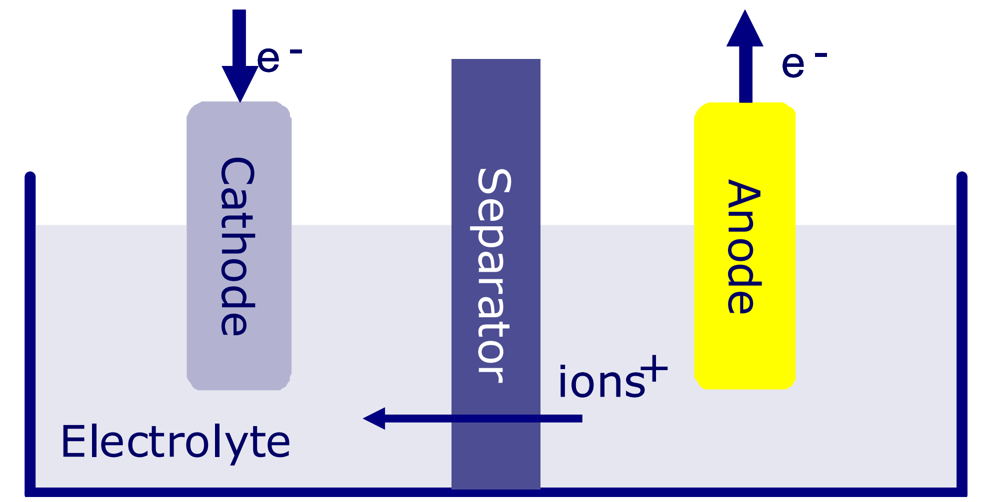
Source: CLSA Asia-Pacific Markets

Circuit required before discharge, but self-discharge still possible

Chemical reactions at each electrode cause electrons to flow from the anode to the cathode once an external circuit is created. This allows for the electrical energy to be used on demand only when the circuit is present. However, in many batteries, discharge will occur without a completed circuit, known as self-discharge. This is a major problem for some battery chemistries.

Figure 21

Basic cell discharge cycle



Source: CLSA Asia-Pacific Markets

Hybrid vehicles charge batteries as you drive

Batteries can be primary or secondary batteries, the former depleting its electrical usage upon full discharge, the latter capable of recharging for continued use. Vehicle batteries are all secondary by necessity and charged by an on-board alternator once the vehicle is in motion. More advanced technology such as regenerative braking is used in current HEVs as another means of charging the battery.

PHEV and PEV put greater stress on battery cycles, requires tougher tech

The method and frequency of charging is critical as current HEVs are charged continually in what is known as "charge-sustaining" operation - when the battery is never fully charged nor discharged. This puts much less demand on the battery, allowing for a longer lifespan. PHEVs and PEVs will need to operate on a "charge-depletion" mode, requiring continual deep discharges placing a heavy strain on the battery. Many present battery chemistries are unable to manage a large number of deep discharges.

Evaluating batteries

Lead-acid battery is good enough for current uses

Depending on the chemical composition of the cell components, batteries can take on widely varying characteristics. In an ICE vehicle, batteries are mainly used for "starting-lighting-ignition" purposes, ie, for auxiliary use. For these purposes the lead-acid battery has been sufficient. With the introduction of limited electric drive in HEVs, the NiMH battery provides a better combination of weight and power. However, as EVs move towards heavier dependence on electric motors in PHEVs and PEVs, the strain and demand on the battery will be proportionally greater. Not only will the battery require a larger capacity, but will also need to minimise weight, heat and cost, at the same time maintaining a high level of safety. In terms of measuring performance, there are a few key factors to consider:

Heavy battery strain requires improvements in certain characteristics

- Capacity: The amount of charge able to be generated by the battery, typically measured in ampere-hours or kilowatt hours. As batteries are often connected in series, the total capacity is determined by the capacity of the smallest cell.
- Voltage: A measure of the force of the electric current. A specific property of the chemistry of the battery. Lithium possesses a naturally high electronegativity and a correspondingly higher voltage.
- Specific power: Measures the power delivered against mass showing the "torque" available from the battery. Particularly important in power-assist HEV applications.

Specific energy probably Li-ion's greatest strength

- Specific energy/energy density: Measures the energy discharged versus mass and volume. Li-ion is considered superior to other chemistries because of its higher specific energy and energy density.
- Cycle life: Number of charge/discharge cycles possible before the capacity falls below a certain percentage (often 80%) of its initial capacity. Usually measured at a given depth of discharge.

Lithium-ion the winner in energy density, but the current loser in costs

Figure 22

Comparison of battery characteristic

Battery type	Specific energy (Wh/kg)	Specific power (W/kg)	Energy efficiency (%)	Cycle life	Estimated cost (US$/kWh)
Lead-acid	30-50	150-400	80	500-1000	100-150
Nickel-cadmium	30-80	100-150	75	1,000-2,000	250-350
Nickel metal-hydride	60-120	200-300	70	1,000-2,000	250-350
Lithium-polymer	150-200	350	na	1,000	>400
Lithium-ion	80-200	200-300	>95	1,000-1,500	>450

Source: Electric and Hybrid Vehicles: Design Fundamentals, CRC Press

Lead-acid batteries: cheap and plentiful

Failure to start - Lead-acid batteries

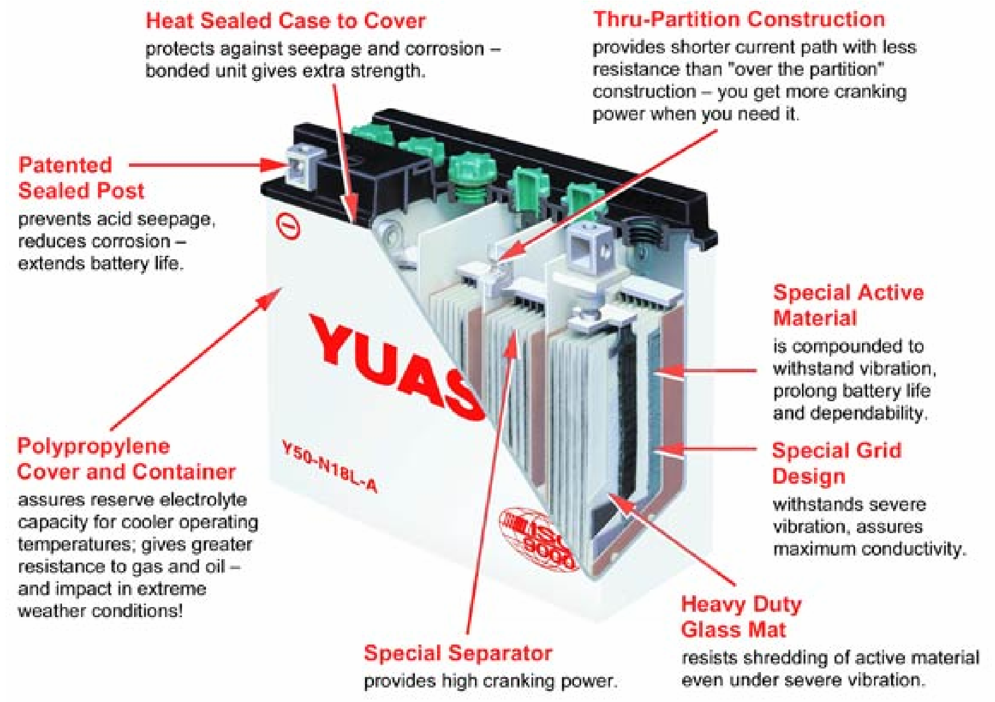
The lead-acid battery is a very mature and cost-efficient technology but is unsuitable for electric vehicles. For use in ICE automobiles, the lead-acid battery has proved to be the best combination of reliability, safety and cost. A valve-regulated lead-acid battery (VRLA) is commonly installed due to safety concerns from the buildup of combustible oxygen and hydrogen gases. From a cost perspective, lead-acid batteries are a very well-understood technology and can be provided at a relatively low cost of US$100-150/kWh.

Many drawbacks in using lead-acid batteries in EVs

However, the amount and frequency of energy usage in EVs is significantly different, revealing how lead-acid batteries are inferior to other alternative chemistries. There are many reasons for this, including poor cold-temperature performance, short calendar and cycle life, and slow charging times. But the main problem with lead-acid batteries in EVs is their low specific energy and energy density.

Figure 23

VRLA component breakdown



Source: Yuasa Batteries

Simply put: Lead-acid is too big and heavy

Notably, the first generation GM EV1s used 26 12V lead-acid batteries in order to have enough battery capacity for 90-120km worth of travel per charge. This accounted for 35% of the total vehicle weight - a stark comparison to the Toyota Prius in which battery weight accounts for only 3.4% of the total car albeit without full electric range.

Figure 24

Lead-acid battery

Pros	Cons
Low-cost materials and ease of manufacture	Poor specific energy and energy density limits usage to ICE for auxiliary power usage
High specific power, capable of high discharge rates	Toxicity of lead content and sulphuric acid is an environmental risk
Mature technology that is relatively safe and well understood	Short lifespan with limited discharge cycles - not suitable for extended use applications
Ready availability of raw materials (lead, sulphur)	Safety risks during transit due to flooded lead-acid cell spillage
Low self-discharge relative to other secondary batteries	Excessive charge may lead to thermal runaway
	Not suitable for extended storage in discharged state

Source: CLSA Asia-Pacific Markets

No secret that NiMH is in all hybrids today

Good enough for now - Nickel metal-hydride

VRLA batteries may be used in most of the vehicles on the road today, however NiMH batteries are powering all commercially available HEVs. Compared to lead-acid, NiMH chemistry benefits from higher specific energy and power, as well as having a longer cycle life. This makes NiMH-based batteries better suited for the purpose of vehicle propulsion.

Better specific energy for NiMH vs lead-acid

NiMH is based on oxidising metal-hydrides that absorb and release hydrogen many times without deterioration. This chemistry is stable and has a higher specific energy than lead-acid, allowing for more efficient usage of space. Also, NiMH batteries have a much longer life cycle than lead-acid batteries, and are safe and abuse tolerant. However, NiMH batteries are expensive at over US$250/kWh in portable use and US$700/kWh for high capacity cells. Also NiMH is highly sensitive to metals prices for nickel, cobalt and rare-earth metals. This metals exposure limits the ability for significant cost reductions.

Figure 25

Nickel metal-hydride battery

Pros	Cons
High energy density relative to lead-acid and many other battery chemistries	Compared to Li-ion, lower specific energy and energy density, partly due to use of nickel
Well-understood technology already in mass production for vehicles	Costly use of nickel, cobalt and rare-earth metals in cell cathodes
No transportation risks with no regulatory restrictions	High self-discharge - approximately 30% of SOC per month for most cells
Can be recycled and disposed of without significant environmental damage	Exothermic during charge and requires slightly longer charge times than other batteries
Superior memory versus nickel-cadmium, but still poorer to other alternatives	Not suitable for repeated deep cycling and will suffer capacity degradation
	Sensitivity to temperature during storage - performance loss if stored at high temperatures.
	High maintenance - must be fully discharged on a regular basis to maintain capacity levels and minimise memory effects.

Source: CLSA Asia-Pacific Markets

Applications and limitations

Serial drive system solely dependent on battery

NiMH batteries have been successfully utilised in the current generation of HEVs, but lack the energy density to be used in more advanced EVs. Today's hybrid drivetrains are mostly parallel (electric motor and gasoline engines in unison) or series-parallel (variable) drivetrain designs. In order to maximise fuel efficiency and minimise emissions, full electric drive is required. This can be achieved with a series hybrid system with an electric motor providing the sole driving force, whereupon a gasoline engine is used solely to charge the battery upon depletion. However this system is heavily reliant on electric energy and will require a robust and high-capacity battery.

NiMH is also too heavy and expensive to power PEV

Though superior to lead-acid, NiMH does not practically have a high enough specific energy to power a vehicle for a reasonable distance on electric power alone. A currently available NiMH HEV battery weighs about 55kg and provides 1.3kWh of capacity. It is estimated that for 40 miles (64km) of pure electric drive it will require 16kWh of capacity. The equivalent battery weight would be about 675kg. Not only would this be more than half the weight of the car, but also a NiMH battery of this size would cost roughly US$17,000. Given these limitations, NiMH batteries are only suitable for hybrid applications with minimal reliance on pure electric drive.

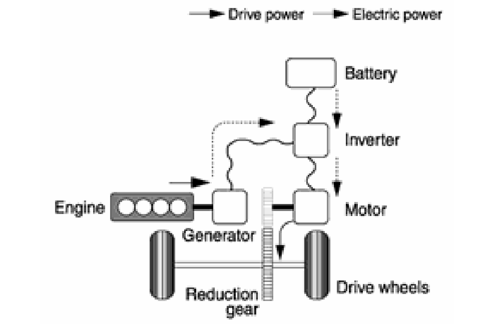
Figure 26

Prismatic NiMH battery module

Source: Panasonic EV Energy

Figure 27

Series hybrid system



Source: Toyota Motor

What a car wants, what a car needs

The ideal EV battery does not exist yet

The ideal battery for PHEVs and PEVs would have a high specific power, high specific energy/density, high charge acceptance in recharging, long cycle life, low temperature tolerance, minimal exothermic tendencies, all at a low cost. But this battery does not exist yet, and further development is required. A more realistic goal is to build batteries with specific targets in mind.

A historical look

NiMH one-third the weight and twice the capacity versus lead-acid in actual EVs

It is possible to examine the practical usage of different battery technologies. Comparing the Toyota Rav4 EV, only produced for fleet usage, to the GM EV1. The NiMH battery pack is nearly a-third of the weight of the VRLA pack, at the same time providing nearly twice the capacity. This comparison reveals the fundamental problems in using VRLA for EVs and the necessity of developing a battery with a high specific energy and energy density.

Figure 28

Actual EV battery comparison

	1997 GM EV1	1998 Toyota Rav4 EV
Manufacturer	Delphi	Panasonic
Battery type	Valve-regulated lead-acid	Nickel metal-hydride
Number of modules	26	24
Weight of module	18.8kg	18.75kg
Weight of packs	1,175kg	461kg
Pack location	T-Pack Integral	Underbody
Nominal module voltage	12V	12V
Nominal system voltage	312V	288V
Nominal capacity	53 Ah (1C)	95Ah (C/3)

Source: CLSA Asia-Pacific Markets, Electric Transportation Applications

Government targets

Government targets still far from being realised

The US Advanced Battery Consortium has provided the following targets for PHEV and PEV battery development that are still far from actualisation. While these targets provide rough guidelines for EV expectations, there are no current batteries that provide these properties at a cost level suitable for production. Lead-acid batteries provide the cheapest option, but are less desirable in terms of weight, energy, power and lifespan. This has led to the use of NiMH batteries, which provide better specific energy and power, but are more than double the cost at approximately US$250-US$350/kWh. While the requirements vary depending on the vehicle design, neither of these current technologies will be able to meet the government targets.

US targeting 40 miles PHEV electric driving

Figure 29

USABC PHEV end-of-life battery requirements

Characteristics	High power/energy ratio battery	High energy/ power ratio battery
Reference equivalent electric range (miles)	10	40
Calendar life, 40°C (year)	15	15
Maximum system weight (kg)	60	120
Maximum system volume (litre)	40	80
Maximum self-discharge (Wh/day)	50	50
Unassisted operating & charging temperature range (°C)	-30 to +52	-30 to +52
Survival temperature range (°C)	-46 to +66	-46 to +66
Maximum system production price @ 100k units/Y (US$)	1,700	3,400

Need 30x current NiMH batteries to reach PEV target

Figure 30

USABC goals for advanced batteries in EVs

Parameter (Units)	Long-term minimum	Long-term target
Power density(W/L)	460	600
Specific power – Discharge, 80% DOD/30 sec(W/kg)	300	400
Specific power - Regen, 20% DOD/10 sec (W/kg)	150	200
Energy density - C/3 discharge rate(Wh/L)	230	300
Specific energy - C/3 discharge rate(Wh/kg)	150	200
Specific power/specific energy ratio	2:01	2:01
Total pack size (kWh)	40	40
Life (years)	10	10
Cycle life - 80% DOD (cycles)	1,000	1,000
Power & capacity degradation (% of rated spec)	20	20
Selling price - 25,000 units @ 40kWh (US$/kWh)	<150	100
Operating environment (ºC)	-40 to +50 20% Performance Loss (10% desired)	-40 to +85
Normal recharge time	6 hours (4 hours desired)	3 to 6 hours
High rate charge	20-70% SOC in <30 minutes @ 150W/kg (<20min @ 270W/kg desired)	40-80% SOC in15 minutes
Continuous discharge in one hour - No failure (% of rated energy capacity)	75	75

Source: US Advanced Battery Consortium

Lithium-ion - The answer

The question: What will power the cars of the future?

Lithium-ion batteries are the most immediately realisable solution to power the next generation of EVs. The characteristics of lithium are chemically superior and allow Li-ion to outperform other batteries. In terms of costs and availability, Li-ion exposure to expensive metals can be minimised while lithium-salt deposits are relatively abundant. There is still room for further cost savings as researchers globally are developing several new cathode formulations. With higher global demand, we expect exponential growth within the next five to 10 years, signalling a promising future for Li-ion vehicle batteries.

Lithium-ion characteristics

Lithium chemistry and potential cost reductions make Li-ion a winner

The element lithium is the lightest metal and has the ability to hold a strong electric current. These factors allow lithium-based batteries to have a high specific energy and power density which are attractive for use in EVs where size and weight must be rationed but a standard driving experience needs to be provided. Also, the lithium chemistry can be less costly with much lower self discharge rates than NiMH as well as less harmful to the environment when disposed of. While NiMH is relatively well understood, Li-ion is still undergoing extensive research to develop more efficient cells from a lifecycle, safety and cost perspective. It is expected that once these obstacles have been overcome, Li-ion will become the standard battery in electric vehicles.

Ideal chemistry

Danger! High voltage!

Most major global automakers are rapidly developing Li-ion batteries because the chemical characteristics of lithium are considered ideal for use in batteries. Lithium has a high electrochemical reduction potential that theoretically provides the basis for a 3 volt battery cell when combined with the appropriate cathode. Also lithium has the lowest atomic mass of any metal which allows for a lighter and smaller cell, contributing to the high specific energy and energy density of Li-ion batteries.

Lithium highly reactive and requires absorption into other materials

However, lithium is highly reactive to water and other solvent electrolytes making it unsuitable in batteries until researchers discovered that lithium can be absorbed ("intercalated") into other materials in order to be used in solution. This discovery allowed for carbon based anodes coupled with a lithium metallic oxide cathode to form a complete battery cell.

Figure 31

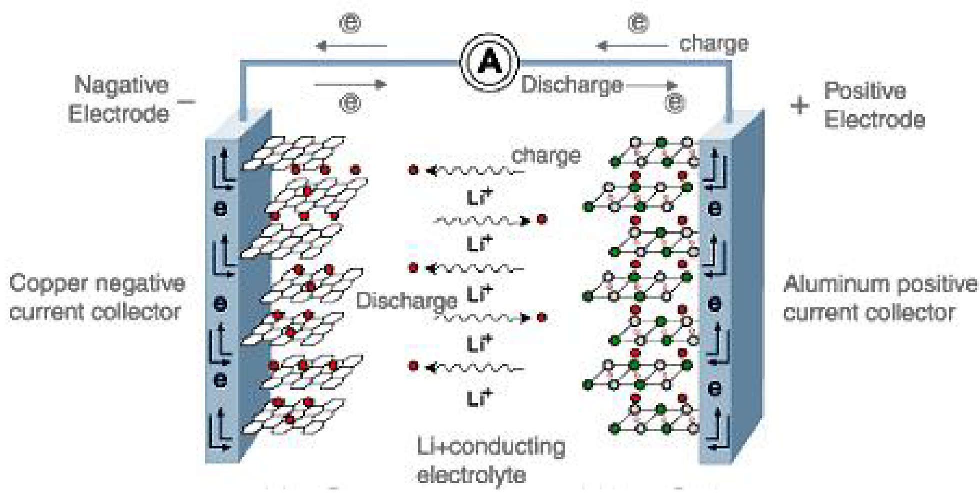
Estimated battery chemistry characteristics

	Lead-acid (sealed)	Nickel-cadmium	Nickel-metal-hydride	Lithium-ion (cobalt)	Lithium-ion (manganese)	Lithium-ion (phosphate)
Specific energy (Wh/kg)	30-50	30-80	60-120	150-190	100-135	90-120
Cycle life (to 80% DoD)	500-1,000	1,000-2,000	1,000-2,000	1,000	1,000	1,500
Quick charge time (hour)	8-16	1	2-4	1.5-3	1	1
Overcharge tolerance	high	Moderate	low	low	low	low
Self discharge/month (%)	5	20	30	10	10	10
Nominal cell voltage	2	1.25	1.25	3.6	3.6	3.3
Operating temperature (°C)	-30 to 70	-40 to 60	-20 to 60	-20 to 60	-20 to 60	-20 to 60
Safety	Thermally stable	Thermally stable, fuse recommended	Thermally stable, fuse recommended	Protection circuit mandatory; stable to 150C	Protection circuit recommended; stable to 250C	Protection circuit recommended; stable to 250C
Commercial use since	1970	1950	1990	1991	1996	2006
Toxicity	Toxic lead and acids, harmful to environment	Highly toxic, harmful to environment	Relatively low toxicity, should be recycled	Low toxicity, can be disposed in small quantities	Low toxicity, can be disposed in small quantities	Low toxicity, can be disposed in small quantities

Source: Cadex Electronics

Figure 32

Lithium-ion discharge cycle



Source: Samsung SDI

Cathode cell component the biggest driver of costs

Of the cell components anodes are usually graphite or coke and generally inexpensive to produce. On the other hand, cathode formulations vary widely, each providing different energy characteristics. The most commonly used cathode is lithium cobalt oxide ($LiCoO_2$) given its superior characteristics. But due to the high cost of cobalt, researchers globally are developing new formulations. Two promising chemistries for EV battery use are lithium manganese spinel ($LiMnO_2$) and lithium iron phosphate ($LiFePO_4$). The other two cell components are the electrolyte used, typically a fluoride-lithium salt in an organic solvent, and the separator, a micrometer-thin porous membrane made of polypropylene or polyethylene. From a total cost perspective, neither of these components adds significantly to the cost of production compared to the cathode.

Lithium cobalt oxide has the best chemistry but prohibitively expensive

Of the cathodes available, lithium cobalt oxide is most commonly used in portable consumer batteries due to its high energy density, chemical stability and electrochemical reversibility. During cell discharge, the carbon-based anode is oxidised to release electrons and lithium ions which move through the lithium conducting electrolyte to the positive electrode. The ions are then incorporated into the cobalt-oxide cathode allowing for a reversible transaction once the cell is recharged. The reaction is as follows:

Figure 33

$LiCoO_2$ cell reaction (charge/discharge)

$$\text{Anode} \qquad Li_xC_6 \Leftrightarrow 6C + xLi^+ + xe^-$$

$$\text{Cathode} \qquad xLi^+ + xe^- + Li_{(1-x)}CoO_2 \Leftrightarrow LiCoO_2$$

Source: CLSA Asia-Pacific Markets

Advantages and drawbacks

Smaller, better, lighter, stronger

The greatest advantages of Li-ion batteries are the properties of the element lithium. The electronegative potential of lithium allows for higher levels of voltage in Li-ion cells. This ranges from 2.75-4.2V depending on the cathode used. Comparatively, typical NiMH cells have a nominal voltage of 1.2V. Also, another key advantage of lithium is the low molecular weight of the element itself. This allows lithium to enter reversible electrochemical reactions with minimal degradation to electrodes. The integrity of the electrodes is critical to producing longer cycle life in batteries. These two factors have an exponential effect on the specific energy of Li-ion allowing for smaller, lighter cells that can be used in a wide range of applications.

Temperature and current safety must be monitored

There are equivalent drawbacks to the high reactivity of lithium. Temperature and current must be carefully monitored to maintain the safety and lifespan of the cell, two characteristics especially critical in vehicle batteries. The negative potential of a Li-ion battery needs to be carefully checked to prevent uncontrolled discharge. This is done by choosing appropriate electrolyte solvents and additives and keeping cell temperatures at roughly 45-50°C.

Low overcharge tolerance leads to overheating risk

Also, unlike NiMH and other secondary battery types, Li-ion cells are prone to chemical decomposition upon overcharge. This leads to lithium metal disposition on the anode creating a safety risk. Not only does this damage the cell, but also results in the release of flammable gases leading to overheating and explosion. Much of the lithium-ion development costs are incurred in finding solutions to eliminate these safety concerns.

Figure 34

Lithium-ion battery

Pros	Cons
Highest specific energy and energy density compared to other common battery types	Still more expensive to manufacture than lead-acid, NiMH and other current batteries
Inherently high voltage allows for superior capacity and specific power	Significant safety concerns and public scrutiny - must use external monitoring to maintain cell current and temperature levels
Potential of long cycle life and smaller cells	Still under development - new metals and chemicals are still being researched
Can be less exposed to metals prices than NiMH	Poor overcharge tolerance requiring careful monitoring
Significant room for cost reduction with development of future cathodes	May age when not in use, ie, capacity will degenerate over time
No memory effect and very low self discharge	Poor low-temperature performance, a significant issue when used in all-climate vehicles
Relative abundance of lithium	Large quantities may be subject to transport restrictions

Source: CLSA Asia-Pacific Markets

Material costs and availability

Attractiveness of Li-ion is in potential for further cost improvements

While safety and lifespan are still key issues, the primary bottleneck to Li-ion usage in vehicles is material costs. By breaking down the cell components it is possible to see that much of the current cost can be reduced by minimising cobalt usage in the cathode. Availability of lithium will not be a limiting factor, while other raw materials will depend on the cathode chemistry that prevails.

Cell costs

Cathode costs are multiplicative in larger batteries

In terms of total cell cost, the cathode is the most expensive component at 30-50% of total cell cost. Li-ion cell cathodes can take on several different chemistries, but for portable usage lithium cobalt oxide is favoured for its high specific energy and general stability. Material cost impacts are less evident for small-scale applications, whereas for vehicle usage much more cathode material is required so total costs are magnified.

Trade-offs required when looking at alternatives

Many battery researchers are looking towards manganese and iron phosphate based cathode alternatives as potentially cheaper substitutions to cobalt. However, difficulty remains in balancing cost with capacity, as cobalt-based Li-ion cathodes have shown to have the highest specific energy of all known cathodes. For example, a lithium manganese-oxide cathode Li-ion battery would need about 50% more mass and volume in order to deliver the same capacity as cobalt-oxide. For vehicle applications, requiring minimal weight and size, this added difference has a significant performance impact.

Cathode material - the biggest cell cost

Figure 35

Li-ion materials costs for 100Ah and 10 Ah cells

	Price (US$/kg)	High-energy cell (100 Ah)			High-power cell (10 Ah)		
		Quantity (g)	Cost/cell (US$)	(%)	Quantity (g)	Cost/cell (US$)	(%)
Cathode	**55**	**1,408.60**	**77.47**	**48.8**	**64.8**	**3.56**	**28.1**
Separator	180	60.5	10.89	6.9	16.4	2.95	23.3
Electrolyte	60	618	37.08	23.4	44	2.64	20.9
Graphite	30	563.6	16.91	10.7	12.7	0.38	3.0
Can and vent		291	3.2	2.0	70	0.77	6.1
Binder	45	162.6	7.32	4.6	8.8	0.4	3.2
Copper	15	151.9	2.28	1.4	41.6	0.62	4.9
Aluminium	20	63	1.26	0.8	19.4	0.39	3.1
Carbon	20	46.4	0.93	0.6	2.2	0.04	0.3
Other	20	67.1	1.34	0.8	44.8	0.9	7.1
Total		**3,432.70**	**158.68**		**324.7**	**12.66**	

Source: Argonne National Laboratory

Recently much attention has also been placed on lithium iron phosphate cathodes currently used in power tools and Segway devices. While it appears that this chemistry exhibits the durability required for PHEV usage, it is still uncertain whether a vehicle battery can be cost efficiently produced with all the necessary usage parameters.

Lithium availability

Potentially over 11.0m MT of global lithium reserves

Lithium is the 33rd most abundant element on Earth, and is only found as a mineral compound due to the highly reactive nature of its elemental state. This is typically as lithium carbonate (Li_2CO_3) found in brine deposits. The US Geological Survey estimates global lithium supply of 4.1m tonnes in reserves and 11.0m tonnes in reserve base. Current production levels are at around 25,000 tonnes of lithium per annum, or approximately 85,000 tonnes of lithium carbonate. At the current rate, the reserve amount should last for roughly 170 years, though demand is expected to rise steadily at 5-7% for the next five years. It is uncertain what the actual total global lithium availability is with estimates ranging from 13.4m to 28.4m tonnes.

South America the global lithium leader and China the leader in Asia

Lithium deposits are scattered in several large deposits spread out globally. The largest producers are in Chile and Argentina, where 3m and 2m tonnes of lithium equivalent reserves are reported. While South America has the largest potential to supply lithium deposits to the world, China also boasts several salt lakes and is rapidly expanding lithium production to become the largest producer in Asia. Chinese lithium carbonate production capacity is estimated to be 33,000 tonnes, but this is expected to increase to 45,000 tonnes from 2008 to 2010.

Figure 36

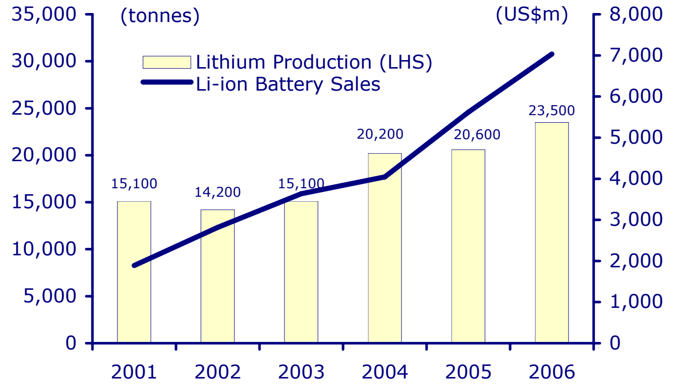
Global lithium production and reserves

	Mine production 2006	Mine production 2007	Reserves	Reserve base
United States	na	na	38,000	410,000
Argentina	2,900	3,000	(2,000,000 est)	(2,000,000 est)
Australia	5,500	5,500	160,000	260,000
Bolivia	-	-	-	5,400,000
Brazil	242	240	190,000	910,000
Canada	707	710	180,000	360,000
Chile	8,200	9,400	3,000,000	3,000,000
China	2,820	3,000	540,000	1,100,000
Portugal	320	320	na	na
Russia	2,200	2,200	na	na
Zimbabwe	600	600	23,000	27,000
World total	**24,489**	**24,970**	**4,131,000**	**11,467,000**

Source: USGS, Meridian International Research

Figure 37

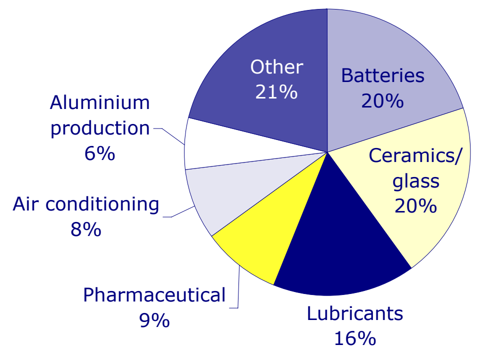
Global lithium production



Source: CLSA Asia-Pacific Markets, USGS

Figure 38

Lithium end-usage



Source: USGS

Enough lithium for 40bn Toyota Prius HEVs

Enough to go around and then some

The current lithium demand levels do not yet take into account expected growth in Li-ion vehicle batteries, expected to become significant around 2010. Despite reports of a potential lithium shortage, our estimates find this conclusion unlikely:

Roughly 0.08-0.14kg of lithium equivalent content will be required for every kWh of capacity for use in Li-ion vehicle batteries.

- Using the conservative USGS reserves estimate of 4.1m tonnes there is ample supply of lithium for future usage in vehicles with enough for 39.7bn current hybrids, 3.2bn plug-in hybrids, and 1.3bn PEVs.
- For reference, the present total global vehicle population is approximately 800m-900m, of which less than 0.2% are hybrids.
- It would take over 65 years at an aggressive 10% Cagr for all current vehicles to be replaced by hybrids.
- Even in the theoretical case that replacement is all PHEVs, over 70% of the current reported reserves would still remain.

Figure 39

Known lithium reserve vehicle equivalents

	HEV (Toyota Prius)	PHEV (GM Volt)	PEV (USABC Target)
Battery capacity (kWh)	1.3	16	40
Lithium equivalent content (kg)	0.104	1.28	3.2
Vehicle potential (m units)	39,721	3,227	1,291

Source: CLSA Asia-Pacific Markets

98% recovery of lithium potentially possible

Furthermore, lithium-ion batteries are recyclable. Since 1992 Sony has partnered with Sumitomo Metals to recover cobalt content from used Li-ion batteries. Also, US specialist Toxco has been successful in recovering up to 98% of the lithium carbonate from lithium wastes. Once Li-ion vehicle batteries are in common usage, there should be sufficient economic incentive for large-scale recycling projects. Therefore it is unlikely that there will be a shortage of lithium due to the introduction of PHEVs or PEVs anytime in the midterm future.

Cathode materials - The high price part

Cobalt cathode cells has seriously high costs

The largest proportion of material costs in a Li-ion cell is the metallic oxide cathode, estimated to be nearly 50% of the total cost of a high energy cell. Lithium cobalt oxide cathodes are used in most current cells available today, but will not be economical for use in large-scale applications due to the high cost of cobalt. In terms of raw materials, the average 2007 prices of cobalt used in cathodes was about US$65/kg. This is nearly twice as expensive as nickel at US$37/kg, providing a rough economic explanation for why NiMH batteries have met the cost threshold to be included in the present generation of HEVs. Much of the undergoing research on Li-ion batteries is to develop a robust yet low cost alternative to the lithium cobalt oxide cathode.

Figure 40

Li-ion cathode materials

Cathode chemistry	Capacity (mAh/g)	Nominal voltage (V)	Specific energy (Wh/kg)	Energy density (Wh/L)	Cost (US$/kg)	Cost (US$/kWh)
$LiCoO_2$	145	4.00	602	3073	30-40	57-75
Li (NiCoAl) O_2	160	3.80	742	3784	28-30	50-55
Li (NiCoMn) O_2	120	3.85	588	2912	22-25	30-55
$LiMnO_2$	100	4.05	480	2065	8-10	20-25
$LiFePO_4$	150	3.34	549	1976	16-20	25-35

Source: Argonne National Laboratory

Mixed metallic oxides - Minimising cobalt

Mixed metallic oxides still effected by cobalt prices

One option has been creating mixed metallic oxides with lower cobalt content such as $Li(Ni_{0.85}Co_{0.1}Al_{0.05})O_2$ and $Li(Ni_{1/3}Co_{1/3}Mn_{1/3})O_2$ commonly known as NCA and NCM respectively. Both of these lithiated mixed oxides exhibit similar characteristics to lithium cobalt oxide cells at a lower cost. However these cathodes are still exposed to cobalt costs, and are not yet able to reach price levels suitable for production EVs.

Manganese spinel - Eliminating cobalt

Manganese a potential low cost cobalt substitute

Another focus of cost reduction research has been to develop completely cobalt-free cathodes. Manganese exhibits similar properties to cobalt, and $LiMnO_2$ (lithium manganese spinel) is being examined as a lower cost alternative. The price of manganese by content is only US$0.80/kg, much cheaper than cobalt or nickel. Also, the spinel crystal structure is more stable than cobalt oxide and has few excess lithium ions in fully charged state.

However, the energy capacity and density of $LiMnO_2$ batteries are roughly a third less than lithium cobalt oxide, a significant factor when considering use in vehicles. Also, manganese cathodes are highly electronegative and prone to degradation through electrochemical dissolution.

Iron phosphate - An even-cheaper alternative?

Iron phosphate lithium batteries already used in power tools

Another potential cobalt-free alternative is lithiated iron phosphate, $LiFePO_4$. Though originally these cathodes suffered from poor conductivity, recent advances using doping has resolved this issue. Iron phosphate cathodes are already in commercial production of power tool batteries and are undergoing tests for use in vehicles. Similar to manganese spinel, lithium iron phosphate based batteries do not yet provide the same high energy capacity and density as lithium cobalt oxide.

Cheap iron could be the next best thing to cobalt

On the other hand, iron phosphate is chemically more stable than both cobalt oxide and manganese spinel and is able to withstand higher temperatures before any adverse effects. From a cost angle, iron is cheap and abundant compared to other alternatives with 2007 average prices of iron ore at approximately US$0.06/kg. Many automakers are planning to use some variation of iron phosphate given its low cost and robust chemistry. High capacity versions of iron phosphate based batteries are undergoing extensive tests for application in PHEVs.

Figure 41

"Ferrous" automobile battery

Source: BYD Auto

Figure 42

$LiFePO_4$ used in Segway batteries

Source: Segway

Other cell costs

Economies of scale should lower electrolyte and separator costs

The other two significant cell component costs are the separator and the electrolyte which make up 30-40% of total estimated costs. High purity levels are required for electrolyte solutions as well as exact dimensional accuracy for separators. The high prices for both components are due to the intensive production process required rather than the underlying raw-materials costs.

However, this is promising for Li-ion development as there is potential additional cost savings through economies of scale. In particular separator manufacturing costs can benefit significantly from increasing battery demand. Japanese chemical companies have already targeted this niche as an area for expanded production. The other components, namely the anode (carbon-based), copper and aluminium foil conductors, binders, etc., all make up a considerably smaller portion of the total cell cost. Although we expect improvement in performance, there is unlikely to be any significant reduction of cell costs from these components.

Global lithium-ion demand

Li-ion growth due to portable applications

Li-ion technology has existed for decades, yet it has not been until relatively recently that Li-ion batteries have been in widespread use. Since Sony released the first commercial Li-ion battery in 1991, there has been steady growth in this market particularly in the past several years. Worldwide demand for Li-ion batteries has expanded more than fourfold since 2001, mostly attributable to the growth in portable electronics such as notebook computers, mobile phones and digital cameras.

Driving growth

Battery safety even more important in EVs

We expect the introduction of PHEVs and PEVs to increase this demand even further but many issues remain. The current materials used for portable Li-ion battery applications would be too expensive for high capacity batteries. Also, battery safety has been subject to public scrutiny following widely reported incidents of battery explosions in notebook computers. The challenge to develop a robust vehicle battery is even more critical as there are inherent risks to passenger lives.

Global R&D effort in developing large capacity Li-ion batteries

Governments and corporations globally are racing to improve cell components in Li-ion technology for the lucrative automotive sector. The US government has earmarked US$4.5bn in FY2009 on R&D for Li-ion batteries and related renewable energy technologies. Nissan also has plans to invest up to US$1bn in battery-powered electric vehicles with pilot projects planned in Denmark and Israel. Sanyo Electric, the leading Li-ion manufacturer, is planning to invest ¥125bn in Li-ion development and production in the next three years. With this massive global effort, it will only be a matter of time before an electric vehicle battery is produced that can provide high capacity and safe energy storage at a low cost.

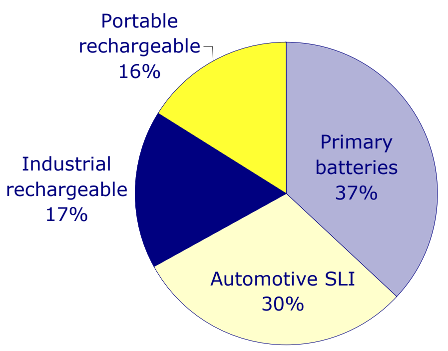
Automobile battery market - Asian growth story

Battery volume growth likely to come from Asia

The worldwide market for batteries is estimated to be over US$50bn, of which 30% is for automotive use (starting-lighting-ignition), a segment primarily comprised of common lead-acid batteries. Global industry volumes of lead-acid batteries in 2007 are estimated to be 337m units with the majority from North America and Europe, accounting for roughly 60% of total volumes. However, we expect less growth in these mature markets, but volumes in Asia to rise to over 35% of the market within the next decade. This demand will primarily be from rising automobile usage in rapidly growing economies such as China and India.

Figure 43

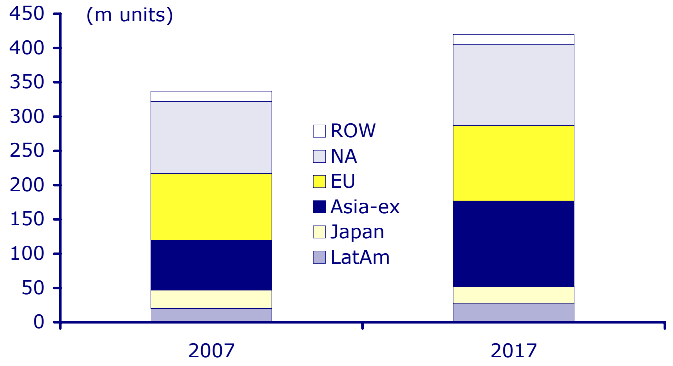
Global battery market by usage



Source: ETC Battery

Figure 44

Lead-acid battery volume by region



Source: Johnson Controls

Market leaders may be challenged by the introduction of Li-ion

Nickel metal-hydride market - Japanese first movers

The HEV battery market is estimated to be over US$800 million and dominated by only three companies. Currently the largest maker of NiMH EV batteries is Panasonic EV Energy, a 60/40 joint venture between Toyota and Panasonic, producing over 400,000 units annually and targeting one million units by 2011. The other maker of significant size is Sanyo Electric, which produces for Honda and Ford. Cobasys, a joint venture between Chevron and Ovonics, supplies the batteries for current GM hybrid vehicles such as Saturn Aura Green Line and Chevrolet Malibu Hybrid. Cobasys is a joint venture between Chevron and Ovonics, which invented NiMH battery technology. However, with the introduction of Li-ion batteries the sector may revert to a growth stage where several small innovative manufacturers will try to gain market share at the expense of the large incumbents staying defensive.

Panasonic/Toyota tie-up dominates due to Prius

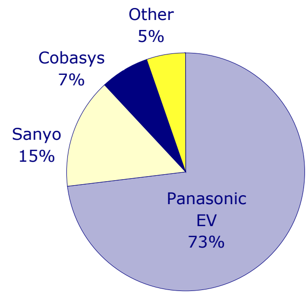
Figure 45

Panasonic EV Energy - NiMH module

Source: Panasonic EV Energy

Figure 46

Hybrid battery market share



Source: CLSA Asia-Pacific Markets

Li-ion batteries already over US$7bn global market

Lithium-ion battery market - Asia in the lead

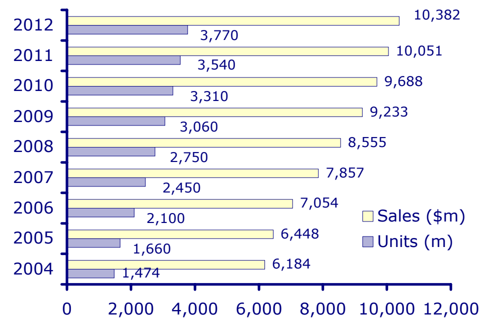
The majority of Li-ion batteries are included under the portable rechargeable segment, which accounts for 16% of the total battery market. This share has been steadily rising with global sales of Li-ion cells reaching US$7bn in 2005 due primarily to mobile handsets sales. This growth is expected to continue as other uses of Li-ion batteries, such as for industrial use and EVs, become more common.

Asian manufacturers dominate the Li-ion scene

Li-ion batteries are nearly exclusively produced in Asia. Japanese companies have led the way in Li-ion battery development and the three major cell manufacturers (Sanyo, Matsushita, Sony) account for 47% of total global sales. Korean and Chinese manufacturers make up most of the rest of the market, led by Samsung SDI, LG Chemical and BYD.

Figure 47

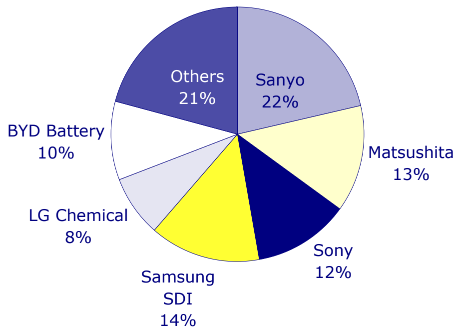
Global Li-ion battery forecast



Source: CLSA Asia-Pacific Markets, Yano Research

Figure 48

Consumer Li-ion cell market share



Source: CLSA Asia-Pacific Markets

The dominance of Li-ion manufacturers in Asia has followed the rising strength of Asia-based electronics assemblers. This can be most clearly seen in China which has rapidly become the largest manufacturing base for Li-ion batteries worldwide accounting for 41% of total production. It is likely that automobile assemblers, with strong incumbents in the US and Europe will eventually be sourcing batteries from Asian players.

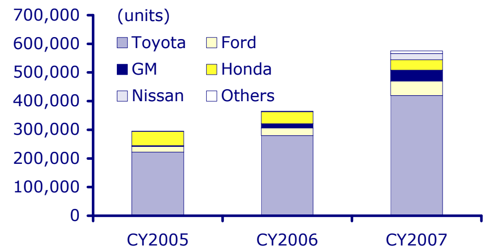
Li-ion batteries in automobiles

HEV battery market to double to US$1.4bn by 2010

Industry estimates by consulting firm Advanced Automotive Batteries predict the current HEV battery market to double to US$1.4bn by 2010 and US$2.3bn by 2015. NiMH batteries will still be installed in most upcoming HEVs and will continue to be the prevailing battery technology for the next three years, but will likely lose market share to Li-ion after that point.

Figure 49

Hybrid market share



Source: CLSA Asia-Pacific Markets

Figure 50

AESC production module

Source: AESC

Plug-in introduction to provide catalyst for Li-ion vehicle battery sales

Li-ion batteries will start to make an impact from 2010 when automakers are hoping that economically practical cells will be ready for several HEV and PHEV models expected to launch such as the Chevrolet Volt, Toyota Plug-in Prius and Nissan's planned PEV. Li-ion batteries are estimated to capture 5% of the market by 2010 and 36% by 2015.

Toyota must have Li-ion ready for PHEV release

As the current leader in hybrid vehicle batteries with 73% market share, Toyota owned Panasonic EV Energy has plans to expand current NiMH capacity and is targeting initial Li-ion production by 2010. This coincides with the planned release of their upcoming PHEV.

Nissan and Mitsubishi both use JV partners for Li-ion development

Nissan and Mitsubishi are also starting production of Li-ion batteries. Nissan has partnered with NEC to form a 51/49 owned Automotive Energy Supply Corporation (AESC) specifically producing Li-ion cells for vehicle use. Also Mitsubishi has established Lithium Energy Japan with VRLA battery maker GS Yuasa to develop and manufacture Li-ion technology for their cars.

The dark horse of the Japanese companies is Honda, which still has plans to use NiMH in future hybrid vehicles. Honda appears to be the most cautious towards the promise of Li-ion and has focused more on clean diesel, advanced gasoline engine, and fuel cell technologies.

Honda is sticking to NiMH for now

> Lithium-ion batteries are still not usable from our perspective. In terms of reliability and durability, I must say there still remain some concerns, I don't think they are necessarily best suited for mass-produced vehicles.
>
> Honda President, Takeo Fukui (Automotive News)

Playing the theme

Many companies involved but few will fully benefit from Li-ion future growth

It should come as no surprise that Asia will have a leading role to play in the introduction of lithium-ion automotive batteries. For years Japanese companies like Sony, Sanyo and Panasonic have been the leading developers of portable Li-ion cells and set the international standards for production. However, leading Korean and Chinese companies like LG Chemical, Samsung SDI, and BYD have seen tremendous growth in the last five years. For vehicle batteries, few publicly traded companies will generate significant revenues from Li-ion related sales alone. The best bets along the value chain range from speciality chemical companies to automobile assemblers.

From finish to start

Taking a top-down approach to value chain

Electric vehicle batteries are sold on an OEM basis and directly dependent on vehicle sales. In order to identify the key players in Asia we have taken a top-down look at the coming lithium-ion value chain for vehicles starting with automakers and trickling down to mining, materials and chemical firms. We have identified three broad sectors that will be likely beneficiaries.

- Automobile assemblers: Automakers have varying degrees of focus on plans to release lithium-ion based EVs. Companies hedged in all technologies will be the most successful. A few differentiation focused firms may be successful if PEVs become the dominant green technology.
- Electronics manufacturers: A handful of leading firms have built up expertise in advanced battery production for consumer use. For next generation electric vehicles, tie-ups with major automakers will push the development and commercialisation of Li-ion batteries. Only Asian incumbents will have the production scale to bring down battery prices.
- Materials and chemical: Metals and mining companies are important suppliers of raw materials for batteries, but often a marginal business highly exposed to price fluctuations. In cell parts, separators require precision processing which gives a competitive advantage to the speciality chemical firms that provide the highest quality and strength.

Automobile assemblers - Who wins?

Mix-and-match engines a strong possibility

Our thesis presumes the rise of electric vehicles driving lithium-ion demand. Yet, despite much positive momentum towards EVs, there is always the possibility that clean diesel engines, bio-fuels, or some other alternative fuel-efficient technology will take the lion's share of future green growth. While EVs are most efficient in short distance stop-and-go city driving, diesels have better capacity for high speed, long distance trips. In the future it is possible that consumers will be presented with a mix of different engines to pick from based on personal driving patterns. However, even with these technologies, pressure will remain to reduce emissions even further.

> Emissions - ultimately, it's got to be zero.
>
> Nissan CEO, Carlos Ghosn (40th Tokyo Motor Show)

Only the largest makers have the resources to bet on several technologies

In terms of automakers we prefer those with a broader exposure to several technologies, effectively hedging their bets on future growth. Given the high level of capital investment and research required, only the largest car companies will have the means to fully develop several engine technologies, leading us to top Japanese makers such as Toyota Motor and Nissan Motor.

Figure 51

Upcoming advanced engines by automakers

	Clean diesel	Li-ion hybrid	Plug-in hybrid	Pure EV	Fuel cell	Note
Toyota	Plan for Tundra Sequoia clean diesel (no date)	Plans for use in future line-up (no release date)	Plug-in Prius fleet testing in 2009, targeting release by 2010	Test vehicles but no target for production	Limited testing of fuel cell hybrid vehicles, no target set	Views hybrids as a key strategic advantage. Wants to maintain the innovative, green mantle by moving aggressively into plug-in
Honda	Plans to release Acura clean diesel by 2009 for NA markets	New HEV in 2009, four scheduled in lineup, NiMH or Li-ion unconfirmed			Public testing of FCX Clarity concept in mid 2008	Lags in hybrid sales despite early adoption. Promising growth in clean diesel. No plans for PHEV. Focused on developing fuel cell.
Nissan	Plans to release Maxima clean diesel by 2010	Original and Infiniti hybrids scheduled for 2010 release		Plans for retail EV by 2010 in specific global markets	Test vehicles, no target for production	No current plans for PHEV, but has shown the most initiative in developing an aggressive PEV strategy of the Japan Big 3.
Mitsubishi	2009 European production planned of Concept cX		Targeting domestic sales by end 2009 of i-MiEV PHEV	Fleet testing of i-MiEV PEV in late 2008	Test vehicles, no target for production	Plans for clean diesel in Europe. Focusing on early release of small car PHEV and PEV.
Hyundai	Stated for 2009 or 2010 release	Domestic Elantra LPG hybrid scheduled for 2009 release	Original PHEV40 targeting release by 2011		Limited testing in 2012, full release target 2015 or beyond	Management has stated that hybrid technology to be a priority in future vehicle line-up
BYD Auto			F6DM PHEV60 targeting late 2008 release	e6 crossover PEV to be sold by 2010, also planned for export		May be first to market with PHEV and PEV. No proven track record in global automobile market.

Source: Wards Auto, Edmunds, Automotive News, Company websites

Toyota Motor (7203 JP - BUY)

Toyota looking to PHEV to keep Prius momentum

The best diversified automaker in advanced engine technology and with an estimated 73% hybrid market share Toyota is the safest bet to invest in EV growth. Prius sales, up 52% in 2007, have provided as much to the bottom line as it has to building up Toyota's green credentials. Management have prioritised the commercialisation of plug-in hybrids by 2010 to maintain their lead in this rapidly growing market.

Panasonic EV subsidiary will be used to produce Li-ion batteries by 2010

Toyota is directly involved in Li-ion battery development. The company has increased their stake to 60% of Panasonic EV Energy, a joint venture with Matsushita Electric Industrial (6752 JP) that currently produces NiMH batteries for Toyota and a few other car makers. Toyota expects annual capacity to reach 1 million units at Panasonic EV by 2010. They also plan to open a Li-ion dedicated plant with initial capacity of over 10,000 units for the anticipated launch of PHEV vehicles in 2010.

Figure 52

Prius major market sales

	2002	2003	2004	2005	2006	2007
Global Prius sales (¥m)	27,648	42,536	104,663	172,002	178,227	271,499
% of Toyota total	0.45	0.65	1.44	2.20	2.11	3.08

Figure 53

Financials

Year to 31 Mar (¥m)	05A	06A	07A	08A	09CL
Revenue	18,551,526	21,036,909	23,948,091	26,289,240	25,411,084
Operating profit	1,672,187	1,878,342	2,238,683	2,270,375	1,660,769
Recurring profit	1,754,637	2,087,360	2,382,516	2,437,222	1,744,486
Net profit	1,171,260	1,372,180	1,644,032	1,717,879	1,325,093

Source: CLSA Asia-Pacific Markets

Nissan Motor (7201 JP - U-PF)

Nissan doubling down on PEV vs other green techs

Though lagging in hybrid sales, Nissan has shown the most initiative in developing a PEV strategy of the Japanese Big 3. The company has made the development of zero emissions vehicles one of the three pillars of their most recently released five year plan. Nissan will eschew PHEVs to focus on PEVs primarily for city driving. Vehicle costs are to be minimised by partnering directly with national (Israel, Denmark) and local governments (Kanagawa) to provide subsidies for EVs. The company hopes to begin limited PEV sales in US and Japan by 2010 and a roll out on a global scale by 2012.

Figure 54

Denki Cube concept

Figure 55

Nissan/NEC JV branding

Source: Nissan Motor

Increasing stake in JV will allow consolidation of Li-ion related profits

Nissan has taken the majority stake in a JV with NEC (6701 JP) and NEC Tokin (6759 JP) to manufacture manganese-based Li-ion batteries. This entity, Automotive Energy Supply Corp. (AESC), is planning to invest ¥12.0bn in the next three years at the Nissan facility in Kanagawa. AESC is initially planning to produce enough cells for 13,000 EVs in 2009, but capacity is expected to increase, targeting an annual production of 65,000 packs.

Figure 56

Financials

Year to 31 Mar (¥m)	05A	06A	07A	08A	09CL
Revenue	8,576,277	9,428,292	10,468,583	10,824,238	10,197,062
Operating profit	861,160	871,841	776,939	790,830	541,952
Recurring profit	855,700	845,872	761,051	766,400	561,388
Net profit	512,281	518,050	460,796	482,261	350,004

Source: CLSA Asia-Pacific Markets

Hyundai Motor (005380 KS - U-PF)

Hyundai set to go electric using Li-ion batteries from LG Chemical

In Korea, Hyundai Motor also has plans to release a Li-ion based PHEV by 2011, but with a limited track record in this market, it is a less compelling EV play than most established Japanese makers. Nonetheless, management is firm on providing an expanded selection of hybrids in the future vehicle line-up. The current Hyundai hybrids utilise NiMH batteries from Panasonic EV Energy, but the next generation HEVs and PHEVs will be supplied by LG Chemical, one of the largest consumer Li-ion battery manufacturers.

Figure 57

Financials

Year ending 31 Dec (bn won)	05A	06A	07A	08CL	09CL
Revenue	27,384	27,335	30,489	32,196	33,240
Operating Ebit	1,384	1,234	1,815	2,235	2,280
Profit before tax	2,739	1,886	2,222	2,564	2,816
Net profit	2,315	1,526	1,682	1,933	2,128

Source: CLSA Asia-Pacific Markets

BYD Auto (1211 HK - U-PF)

BYD: looking to be first to market PHEVs and PEVs

Surprisingly the auto company most geared into lithium-ion growth is not from Japan, Korea or the US but in China. BYD is already one of the leading consumer Li-ion battery makers globally, but also operates BYD Auto, their automotive subsidiary which accounts for 23% of their business. The company plans to release a PHEV using iron phosphate Li-ion batteries in late 2008. BYD's key strength is still in Li-ion technology for consumer use and they have no track record in advanced automotive products. It is doubtful that this vehicle will have any significant commercial impact though BYD does have plans for export. However, in terms of direct exposure to this Li-ion technology, BYD could be at the forefront of the lithium wave.

Strength is in Li-ion for consumer use, prowess in automobiles still unknown

Figure 58

Segment breakdown

FY12/07 (Rmbm)	Batteries	Handset parts	Automobile	Others
Revenue	7,149	9,187	4,872	3
% total revenue	33.7	43.3	23.0	0.0
Operating profit	756	1,072	257	(1)
Operating margin (%)	10.6	11.7	5.3	-28.3

Source: Company results

Figure 59

Financials

Year ending 31 Dec (Rmbm)	05A	06A	07A	08CL	09CL
Revenue	6,498	12,939	20,532	33,169	43,045
Operating Ebit	748	1,565	2,228	2,908	3,622
Profit before tax	593	1,181	1,743	2,674	3,267
Net profit	503	1,117	1,612	2,129	2,625

Source: CLSA Asia-Pacific Markets

Figure 60

PHEV engine from BYD Auto

Source: BYD Auto

Electronics manufacturers - Coupling up

Common for automakers and battery companies to team-up for EV batteries

The strategy of partnering with an experienced electronics maker is nothing new in the development of EVs. In the late 1990s Sony partnered with Nissan to produce the Li-ion based Nissan Altra EV. The current leader is Panasonic, which has a long history of providing NiMH batteries to car makers, even supplying the batteries for the second generation GM EV1. Now owned by Toyota, Panasonic EV Energy, is the runaway leader in current NiMH HEV

GS Yuasa good proxy into pure auto battery growth

batteries due to the success of the Toyota Prius. Several partnerships have been established between major battery makers and auto companies in the rush to be first to market with this technology. We highlight the companies well-positioned for further growth when lithium-ion vehicle batteries come to the fore.

Figure 61

Vehicle battery partnerships

Automaker	JV (%)	Electronics Mfg	JV (%)	Year est	Relationship
Toyota Motor	60	Panasonic (MEI)	40	1996	JV - Panasonic EV Energy
Nissan Motor	51	NEC/NEC Tokin	49	2007	JV - AESC (Li-ion)
Mitsubishi Motors	49	GS Yuasa	51	2007	JV - Lithium Energy Japan
Mitsubishi Motors	87	TDK	5	2000	Subsidiary - Litcel
Honda Motor	-	Sanyo/MEI	-	2002	Joint development (NiMH)
Volkswagen AG	-	Sanyo	-	2008	Joint development (Li-ion)
Hyundai Motor	-	LG Chemical	-	2007	Supply agreements (Li-ion)
BYD Auto	-	BYD (parent)	-	2003	Subsidiary of parent

Source: CLSA Asia-Pacific Markets

GS Yuasa (6674 JP - N-R)

Formed from the April 2004 merger of Yuasa Corporation and Japan Storage Battery, GS Yuasa is now the second largest VRLA manufacturer globally and the leading producer in Asia. The company established a JV with Mitsubishi Motors in Dec. 2007 specifically to develop and manufacture vehicle Li-ion batteries. The JV, Lithium Energy Japan, is 51% owned by GS Yuasa and expected to produce 200,000 units in FY2009. The company provides an opportunity to invest specifically in future vehicle battery growth in Asia.

Figure 62

Financials

Year to 31 Mar (¥m)	05A	06A	07A	08A	09F
Revenue	239,696	243,428	260,732	312,012	340,000
Operating profit	1,191	5,652	6,789	12,384	13,000
Recurring profit	23	5,099	5,517	9,946	12,000
Net profit	(14,732)	598	4,130	2,670	6,000

Source: Toyo Keizai, Company results

Figure 63

Revenue breakdown

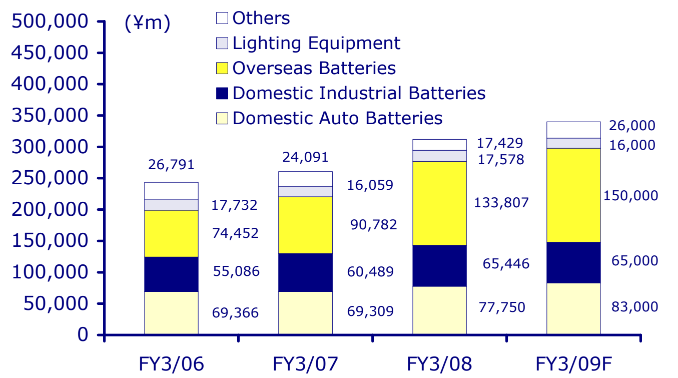
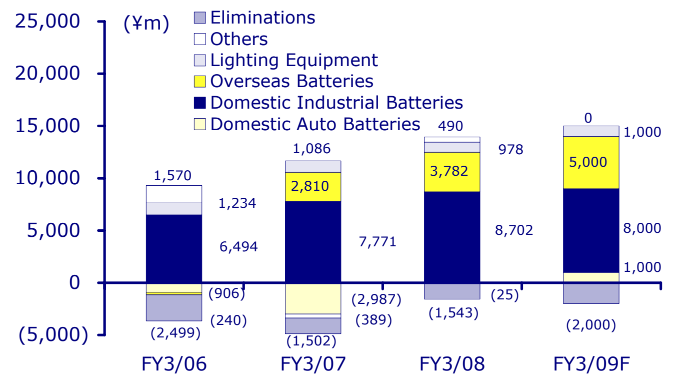


Figure 64

OP breakdown



Source: CLSA Asia-Pacific Markets

Sanyo Electric (6764 JP - N-R)

Sanyo: the current global leader in Li-ion batteries

Of the established Japanese electronics firms, the most geared into lithium growth is Sanyo Electric. The company has faced several years of restructuring and has recently sold of their mobile phone division to Kyocera. The company has recently returned to profitability focusing on core businesses like batteries and has been re-branding under the green banner, "Think Gaia". However, the company has a very large convertible preference-share overhang.

Sanyo earned 24% of revenue and 73% of operating profits from battery sales in FY 3/08. The company is the global leader in Li-ion manufacturing and sales, but also provides the NiMH batteries for current Honda and Ford HEVs. The company is investing heavily in Li-ion and is planning to spend ¥125bn on development and production in the next three years. Sanyo has recently partnered with Volkswagen AG to develop Li-ion vehicle batteries and targets to start sales by 2012.

Figure 65

Financials

Year to 31 Mar (¥m)	05A[1]	06A[1]	07A	08A	09F
Revenue	2,586,586	2,484,305	1,882,612	2,017,824	2,020,000
Operating profit	42,316	(17,154)	42,605	76,141	50,000
Ordinary profit	(64,991)	(165,696)	(16,084)	57,228	15,000
Net profit	(171,544)	(205,661)	(45,362)	28,700	35,000

[1] Results for FY3/05, FY3/06 not amended. Source: Toyo Keizai, Company results

LG Chemical (051910 KS - U-PF)

LG Chemical not a pure Li-ion play, but one of the largest battery makers

In Korea, LG Chemical could also benefit from EV growth. LG Chem is already one of the largest Li-ion battery manufacturers in the world. 20% of operating profit in FY 12/07 was from their information and electronic materials division. OP more than doubled year-on-year with growth driven by profitable Li-ion battery sales. The company has the technology and production capability to develop electric vehicle batteries and has agreed to supply Li-ion for future Hyundai EVs. LG Chem also owns Compact Power Inc., a subsidiary based out of the US which is a leading contender to provide batteries for the Chevrolet Volt PHEV. The company boasts proprietary manganese spinel based technology allowing for lower production costs.

Handset and notebook are key battery drivers, but EV seen on the horizon

Figure 66

Segment OP, FY12/06

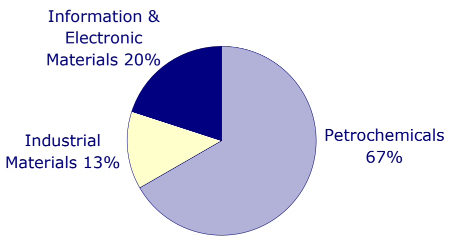
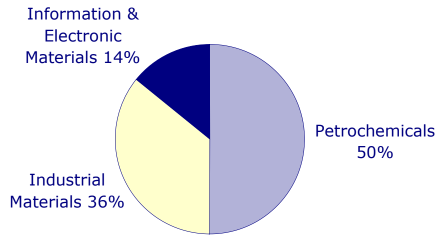


Figure 67

Segment OP, FY12/07



Source: CLSA Asia-Pacific Markets

Figure 68

Financials

Year ending 31 Dec (bn won)	05A	06A	07A	08CL	09CL
Revenue	7,425	9,302	10,488	13,123	13,602
Operating Ebit	422	334	748	1,025	904
Profit before tax	468	395	804	1,007	914
Net profit	400	319	649	812	737

Source: CLSA Asia-Pacific Markets

Materials and chemical - Limited exposure

Mining companies do not specifically produce battery materials

By nature of the industry, there are few if any mining, materials or chemical companies highly leveraged into Li-ion battery growth. Battery materials are typically a peripheral business given the varied uses of nickel, cobalt and other core metals. Most suppliers provide base materials with marginal value-add, however there are still a few investments worth considering. We review several companies that have been expanding further into this market or potentially have a competitive edge in this emerging technology.

Lithium: Citic Pacific (0267 HK - BUY)

Citic Pacific subsidiary looking to expand China lithium mining operations

The only abundant source of lithium in Asia is found in China. Mostly these deposits are located in the salt lakes of Tibet and Qinghai province. Citic Guoan, part of the Citic Pacific conglomerate is actively involved in the exploration and trial production of lithium carbonate from the Taijinaier Salt Lake in Qinghai Province, with lithium reserves of approximately 3.4m tonnes. Citic Guoan is also mining spodumene, a hard mineral form of lithium, at their Maerkang site which is estimated to have 483,000 tons of reserve as measured by lithium oxide content. Another subsidiary, Citic Guoan MGL, is China's largest producer of lithium battery cathode materials and benefits from the primary lithium production of the parent company's mining operations. Unfortunately the impact of this growth is marginal as Citic Guoan still only represents just over 1% of Citic Pacific NAV.

Potential growth but only marginal impact on the consolidated level

Figure 69

Financials

Year ending 31 Dec (HK$m)	05A	06A	07A	08CL	09CL
Revenue	26,564	47,049	45,023	52,087	55,542
Operating Ebit	2,838	3,433	3,214	4,899	5,508
Profit before tax	4,642	9,359	12,337	6,491	6,767
Net profit	3,989	8,272	10,843	4,644	4,809

Source: CLSA Asia-Pacific Markets

Components: NEC Tokin (6759 JP - N-R)

Potential benefit for NEC Tokin if AESC is a success

NEC Tokin has been appointed the supplier of lithium manganese spinel cathodes for the AESC JV between NEC and Nissan. While the company only has a 7% stake in AESC, it has developed the laminated cell technology which should assist in cost reductions in production. NEC Tokin plans to invest ¥11bn in the next three years to mass produce electrodes in Kanagawa.

Figure 70

Financials

Year to 31 Mar (¥m)	05A	06A	07A	08A	09F
Revenue	119,365	121,274	135,864	120,011	126,000
Operating profit	4,722	4,757	4,772	575	3,200
Recurring profit	4,439	4,899	5,323	(1,778)	2,000
Net profit	801	921	(1,873)	(12,785)	500

Source: Toyo Keizai, Company results

Components: Mitsubishi Chemical (4188 JP - N-R)

One of the few companies that produce all cell components for Li-ion

Mitsubishi Chemical Corp, a subsidiary of the holding company, is currently one of the few companies that provides all cell components and is a leader in electrolyte production. The company is spending ¥2bn in order to start mass-producing cathode materials at its 600MT capacity Okayama plant in 2009. The company also plans to expand their separator business in the next few years. However, as a large chemical conglomerate, the earnings specifically from Li-ion related sales will have a marginal impact on the total bottom line.

Figure 71

Segment breakdown

FY03/08 (¥m)	Petrochemical	Functional chemicals	Functional materials	Healthcare	Other	Total
Revenues	1,431,858	522,246	402,004	395,793	177,909	2,929,810
% Total	48.9	17.8	13.7	13.5	6.1	
Operating profit	9,214	36,125	19,246	57,232	13,144	134,961
% Total	6.8	26.8	14.3	42.4	9.7	

Source: Company results (totals before eliminations)

Figure 72

Financials

Year to 31 Mar (¥m)	06A	07A	08A	09F
Revenue	2,408,945	2,622,820	2,929,810	3,340,000
Operating profit	133,619	128,589	125,046	158,000
Recurring profit	143,575	141,296	128,885	166,000
Net profit	85,569	100,338	164,064	70,000

Source: Toyo Keizai, Company results

Cathode: Toda Kogyo (4100 JP - N-R)

Toda Kogyo could lower exposure to cobalt costs with new tech license

A small cap specialist manufacturer of powdered iron oxide used in magnetic cards and toners, Toda Kogyo is aiming to become a leading cathode producer for Li-ion batteries. The company's expertise in metallic oxides allowed them to expand into the materials market for rechargeable batteries. Last year, 37% of revenues were from batteries and related electronic materials sales - primarily the sale of cobalt based lithium-ion cathodes.

Toda Kogyo operates a North American subsidiary in Canada producing cathode materials with a reported annual production capacity of 4,000 MT. The company has also acquired a plant in the Detroit area in order to serve US automobile manufacturers. The company has recently licensed technology to produce high capacity lithium mixed manganese metal-oxide cathodes from the US Argonne National Laboratory. This will provide significant cost savings for the company as recently profitability has been squeezed by rising cobalt prices.

Figure 73

Financials

Year to 31 Mar (¥m)	05A	06A	07A	08A	09F
Revenue	22,565	24,498	33,276	43,956	49,000
Operating profit	381	415	1,170	929	1,500
Recurring profit	346	593	1,332	715	1,500
Net profit	(1,525)	213	1,119	(191)	850

Source: Toyo Keizai, Company results

Anode: Nippon Carbon (5302 JP - N-R)

Li-ion batteries a natural extension of synthetic graphite cathode business

The company is already a leading producer of artificial graphite electrodes used in steel production. While this core business accounts for 53% of sales, they are planning to expand into materials lithium-ion anodes initially for portable usage and eventually moving on to automobile batteries. The company reports that they have built facilities to become the world's largest producer of graphite powder specifically for lithium-ion anode use.

Figure 74

Financials

Year to 31 Dec (¥m)	05A	06A	07A	08F	09F
Revenue	25,990	30,607	35,167	37,500	39,000
Operating profit	3,184	5,084	7,552	6,600	7,600
Recurring profit	3,122	4,957	7,383	6,300	7,480
Net profit	1,337	2,684	3,571	2,900	3,580

Source: Toyo Keizai, Company results

Anode: Mitsui Mining and Smelting (5706 JP - N-R)

Silicon-carbon anodes a potential competitive advantage for MM&S

Also in the anode supply market, Mitsui Mining and Smelting (5706.JP) has developed higher capacity silicon-based carbon anodes. They expect to generate JPY10bn in sales by 2010 on sales of this anode product. However this will only represent approximately 1.7% of total revenues to the company.

Figure 75

Financials

Year to 31 Mar (¥m)	05A	06A	07A	08A	09F
Revenue	438,143	503,370	591,518	595,463	591,000
Operating profit	44,515	45,052	38,865	27,993	28,200
Recurring profit	45,433	50,487	56,858	41,780	30,000
Net profit	20,780	23,374	31,370	7,830	12,000

Source: Toyo Keizai, Company results

Separator: Asahi Kasei (3407 JP - N-R)

Asahi Kasei looking to extend their lead in value-added separators

Asahi Kasei is estimated to hold 50% of the battery separator market and is expanding rapidly. The company's largest business is their chemicals group which makes up more than half of revenues and 48% of total operating profit. In this group, management has highlighted the "Hipore" flat-film separator for Li-ion batteries as a key driver of growth in the last fiscal year. This material boasts uniform pore sizes and high strength polyethylene, which does not emit harmful gases if incinerated, improving battery efficiency and safety.

To maintain and expand their share in the separator market, Asahi Kasei is building a ¥6bn plant in Miyazaki prefecture due to start operations in 2010 with an initial annual output capacity of 20 million square meters. They are also expanding capacity of its current separator plant in Shiga prefecture from 100 million square meters to 150 million square meters at a cost of ¥10bn.

Figure 76

Financials

Year to 31 Mar (¥m)	05A	06A	07A	08A	09F
Revenue	1,377,697	1,498,620	1,623,791	1,696,789	1,810,000
Operating profit	115,809	108,726	127,801	127,656	128,000
Recurring profit	112,876	104,166	126,507	120,456	125,000
Net profit	56,454	59,668	68,575	69,945	75,000

Source: Toyo Keizai, Company results

Petrochemical company TonenGeneral developing high tech separators

Separator: TonenGeneral Sekiyu (5012 JP - N-R)

The next largest player in Li-ion battery separators is Tonen Chemical, a wholly owned subsidiary of TonenGeneral Sekiyu, part of the ExxonMobil group. The company has identified high strength separators for HEV applications as a specialised niche with high potential for further growth. They use a proprietary 'wet manufacturing' process which results in high pore uniformity. This allows for a safe cell with enhanced permeability minimising cell resistance. TonenGeneral is looking to expand capacity and build a new manufacturing facility to produce separator film in Korea.

Figure 77

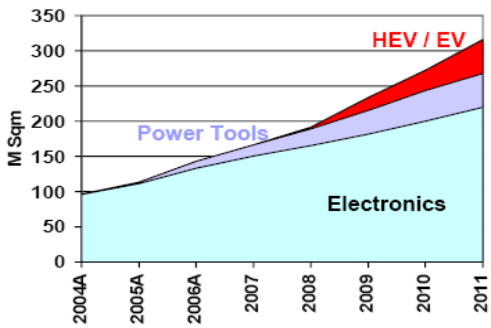
Financials

Year Ending 31 Dec (¥m)	05A	06A	07A	08F	09F
Revenue	2,856,182	3,078,772	3,049,842	3,500,000	3,230,000
Operating profit	19,978	58,694	7,063	51,000	47,300
Recurring profit	22,822	65,987	15,073	52,000	48,300
Net profit	13,015	39,820	7,014	32,000	29,700

Source: Toyo Keizai, Company results

Figure 78

Li-ion separator market forecast



Source: TonenGeneral Seikyu

Figure 79

Hipore battery separator

Source: Asahi Kasei

Appendix 1: Lithium-ion Japan universe

Japanese companies with lithium-ion exposure

Company	Code	Market cap (¥m)	Market	Sector	Li-ion exposure
Toyota Motor	7203 JP	17,308,948	TSE1	Automotives	Electric vehicle
Honda Motor	7267 JP	5,981,541	TSE1	Automotives	Electric vehicle
Matsushita Electric Industries	6752 JP	5,715,615	TSE1	Electronics	Battery cell
Sony Corp	6758 JP	4,921,818	TSE1	Electronics	Battery cell
Nissan Motor	7201 JP	3,991,792	TSE1	Automotives	Electric vehicle
Sumitomo Chemical	4005 JP	1,233,307	TSE1	Chemicals	Separator (plans)
NEC Corp	6701 JP	1,094,026	TSE1	Electronics	Battery cell
Dai Nippon Printing	7912 JP	1,065,431	TSE1	Other chemicals	Electrode, packaging
Mitsubishi Chemical	4188 JP	1,058,921	TSE1	Chemicals	Electrode, electrolyte
Mitsubishi Motors	7211 JP	980,208	TSE1	Automotives	Electric vehicle
Asahi Kasei	3407 JP	847,180	TSE1	Chemicals	Separator
Osaka Gas	9532 JP	779,176	TSE1	Power and gas	Electrode
NGK Insulators	5333 JP	606,258	TSE1	Glass, mineral	Battery cell
TonenGeneral Sekiyu Kk	5012 JP	550,487	TSE1	Oil and coal	Separator
Sanyo Electric	6764 JP	477,446	TSE1	Electronics	Battery cell
Mitsui Chemicals	4183 JP	468,084	TSE1	Chemicals	Electrolyte
Hitachi Chemical	4217 JP	467,746	TSE1	Chemicals	Electrode
Ube Industries	4208 JP	379,383	TSE1	Chemicals	Separator, electrolyte
Teijin	3401 JP	374,208	TSE1	Chemicals	Separator (plans)
Mitsui Mining & Smelting	5706 JP	200,538	TSE1	Metals	Electrode
Nippon Denko	5563 JP	147,650	TSE1	Metals	Electrode
GS Yuasa	6674 JP	144,457	TSE1	Electronics	Battery cell
Hitachi Maxell	6810 JP	135,065	TSE1	Electronics	Battery cell
NOF Corp	4403 JP	93,177	TSE1	Chemicals	Polymer solution
Nippon Carbon	5302 JP	61,766	TSE1	Glass, mineral	Electrode
Chuo Denki Kogyo	5566 JP	49,432	TSE2	Metals	Electrode
Shin-Kobe Electric Machinery	6934 JP	43,805	TSE1	Electronics	Battery cell
NEC Tokin	6759 JP	39,844	TSE1	Electronics	Electrode, battery cell
Kanto Denka Kogyo	4047 JP	31,132	TSE1	Chemicals	Electrolyte
Nippon Chemical Industrial	4092 JP	30,070	TSE1	Chemicals	Electrode, electrolyte
Stella Chemifa	4109 JP	27,368	TSE1	Chemicals	Electrolyte
Toda Kogyo	4100 JP	19,115	TSE1	Chemicals	Electrode
Sansha Electric Mfg	6882 JP	13,030	Osaka 1	Electronics	Electrode, electrolyte
Tanaka Chemical	4080 JP	12,459	JASDAQ	Chemicals	Electrode materials
Toyo Gosei	4970 JP	6,189	JASDAQ	Chemicals	Electrolyte

Source: CLSA Asia-Pacific Markets, Media-IR, Bloomberg

Appendix 2: Upcoming vehicles

Upcoming HEVs, PHEVs

Model	Maker	Battery	Expected launch	Hybrid type
Chevrolet Tahoe Hybrid	GM	NiMH	2008	Two mode
Cadillac Escalade Hybrid	GM	NiMH	2008	Two mode
Buick LaCROSSE	SAIC/GM	NiMH	2008	BAS
Tribute Hybrid	Ford	NiMH	2008	THS
Aspen Hybrid	Chrysler	NiMH	2008	Two mode
Dodge Durango Hybrid	Chrysler	NiMH	2008	Two mode
Crown Hybrid	Toyota	NiMH	2008	THS
Jiexun Hybrid	Chang'an	NiMH	2008	MILD
F6DM	BYD Auto	Li-ion	2008	Plug-in
Audi Q7 Hybrid	Audi	NiMH	2008	MILD
Saturn Vue Green Line Hybrid	GM	NiMH	2009	Two mode
Chevrolet Silverado Hybrid	GM	NiMH	2009	Two mode
Fusion Hybrid	Ford	NiMH	2009	THS
Premacy Hydrogen RE Hybrid	Mazda	NiMH	2009	MILD
S400 Blue Hybrid	Daimler Benz	Li-ion	2009	MILD
ML 450 Hybrid	Daimler Benz	NiMH	2009	Two mode
Prius (New Model)	Toyota	NiMH	2009	THS
New Hybrid Model	Toyota	Li-ion	2009	THS
Golf TDI Hybrid	VW	NiMH	2009	MILD
Chevrolet Volt	GM	Li-ion	2010	Plug-in Series
Saturn Vue Plug-in	GM	Li-ion	2010	Plug-in Two mode
Edge Hybrid	Ford	NiMH	2010	THS
Lincoln MKX Hybrid	Ford	NiMH	2010	THS
S300 Bluetec Hybrid	Daimler Benz	Li-ion	2010	MILD
S400 Bluetec Hybrid	Daimler Benz	Li-ion	2010	MILD
Lexus LF-Xh	Toyota	NiMH	2010	LHS
FT-HS	Toyota	NiMH	2010	LHS
Prius Plug-in	Toyota	Li-ion	2010	Plug-in
Infiniti Hybrid	Nissan	Li-ion	2010	MILD
Fit Hybrid	Honda	NiMH	2010	MILD
Elantra Hybrid	Hyundai	Li-ion	2010	MILD
X6 Active Hybrid	BMW	NiMH	2010	Two mode
308 Hdi Hybrid	Peugeot	NiMH	2010	MILD
C4 Hybrid	Citroen	NiMH	2010	MILD
KARMA	Fisker	Li-ion	2010	Plug-in Series
Touareg Hybrid	VW	NiMH	2010	MILD
Cayenne Hybrid	Porsche	NiMH	2010	MILD
Panamera Hybrid	Porsche	NiMH	2010	MILD

Source: HiEDGE Institute

Appendix 3: Glossary

Vehicle types

EV	Electric vehicles - refers to all automobiles using electric energy to power propulsion. Covers hybrids, plug-in hybrids, diesel hybrids, pure hybrid vehicles, and fuel-cell vehicles
ICE	Internal combustion engine - a standard automobile engine powered by the combustion of some external fuel
HEV	Hybrid electric vehicles - also referred to as "hybrids", a vehicle powered both by an internal combustion engine and an electric motor either in parallel, serial, or some other drivetrain system
PHEV	Plug-in hybrid electric vehicle - also referred to as "plug-ins", a hybrid vehicle that can also be charged externally, typically implies that the vehicle features the limited availability of pure electric drive
PEV	Pure-electric vehicle - a vehicle propelled only by an electric motor on stored electrical energy and requiring no external fuel

Battery parameters

Battery capacity	The amount of charge able to be generated by the battery, typically measured in "Ah". As batteries are often connected in series, the total capacity is determined by the capacity of the smallest cell
Voltage	A measure of the force of the electric current. A specific property of the chemistry of the battery
Discharge rate	The current at which the battery is discharged, typically measured in amperes. Simply the current released during a give time interval
State of charge (SoC)	The present capacity of the battery. The amount of capacity that remains after discharge from a fully charged state
State of discharge (SoD)	The measure of the charge that has been drawn from a battery. Or the opposite of state of charge
Depth of discharge (DoD)	The percentage of battery capacity to which a battery is discharged aka, the % SoD/Battery Capacity
Cycle life	Number of charge/discharge cycles possible before the capacity falls below a certain percentage (often 80%) of its initial capacity. Usually measured at a given DoD
Specific energy	Measures the energy discharged against mass. Measured in "Wh/kg"
Specific power	Measures the power delivered against mass. Measured in 'W/kg'
Energy density	Measures the energy discharged against volume. Measured in "Wh/L"
Power density	Measures the power delivered against volume. Measured in "W/L"
Rate of self-discharge	How fast the charge is depleted in an open circuit cell. Typically measured as a percentage of capacity per month

Notes

Notes

Research & sales offices

ASIA-PACIFIC MARKETS

www.clsa.com

China – Beijing
CLSA Beijing
Unit 10-12, Level 25
China World Trade Centre Tower 2
1 Jian Guo Men Wai Ave
Beijing 100004
Tel : (86) 10 5965 2188
Fax : (86) 10 6505 2209

China – Shanghai
CLSA Shanghai
3/F, Suites 305-310
One Corporate Avenue
No.222 Hubin Road
Luwan District, Shanghai 200021
Tel : (86) 21 2306 6000
Fax : (86) 21 6340 6640

China – Shenzhen
CLSA Shenzhen
Room 3111, Shun Hing Square
Di Wang Commercial Centre
5002 Shennan Road East
Shenzhen 518008
Tel : (86) 755 8246 1755
Fax : (86) 755 8246 1754

Dubai
Calyon Gulf
Dubai World Trade Centre
Level 32
PO Box 9256 Dubai
United Arab Emirates
Tel : (9714) 331 4211
Fax : (9714) 331 3201

Hong Kong
CLSA Hong Kong
18/F, One Pacific Place
88 Queensway
Hong Kong
Tel : (852) 2600 8888
Fax : (852) 2868 0189

India
CLSA India
8/F, Dalamal House
Nariman Point
Mumbai 400 021
Tel : (91) 22 6650 5050
Fax : (91) 22 2284 0271

Indonesia
CLSA Indonesia
WISMA GKBI Suite 901
Jl Jendral Sudirman No.28
Jakarta 10210
Tel : (62) 21 2554 8888
Fax : (62) 21 574 6920

Japan
Calyon Securities Japan
15/F, Shiodome Sumitomo Building
1-9-2, Higashi-Shimbashi
Minato-ku, Tokyo 105-0021
Tel : (81) 3 4580 5533 (General)
(81) 3 4580 8722 (Trading)
Fax : (81) 3 4580 5896

Korea
CLSA Korea
15/F, Sean Building
116, 1-Ka, Shinmun-Ro
Chongro-Ku
Seoul, 110-061
Tel : (82) 2 397 8400
Fax : (82) 2 771 8583

Malaysia
CLSA Malaysia
Suite 20-01 Level 20
Menara Dion
27 Jalan Sultan Ismail
50250 Kuala Lumpur
Tel : (60) 3 2056 7888
Fax : (60) 3 2056 7988

Philippines
CLSA Philippines
19/F, Tower Two
The Enterprise Center
6766 Ayala corner Paseo de Roxas
Makati City
Tel : (63) 2 860 4000
Fax : (63) 2 860 4051

Singapore
CLSA Singapore
9 Raffles Place, No.19-20/21
Republic Plaza II
Singapore 048619
Tel : (65) 6416 7888
Fax : (65) 6533 8922

Taiwan
CLSA Taiwan
27/F,
95, Tun Hwa South Road
Section 2
Taipei
Tel : (886) 2 2326 8188
Fax : (886) 2 2326 8166

CLSA is certified ISO14001:2004

CarbonNeutral® company

Thailand
CLSA Thailand
16/F, M. Thai Tower
All Seasons Place
87 Wireless Road, Lumpini
Pathumwan, Bangkok 10330
Tel : (66) 2 257 4600
Fax : (66) 2 253 0532

USA
Calyon Securities (USA)
Calyon Building
1301 Avenue of The Americas
New York, New York 10019
Tel : (1) 212 408 5888
Fax : (1) 212 261 2502

United Kingdom
CLSA (UK)
12/F Moor House,
120 London Wall,
London EC2Y 5ET
Tel : (44) 207 614 7000
Fax : (44) 207 614 7070

CLEAN & GREEN™

At CLSA we support sustainable development. We print on paper sourced from environmentally conservative factories that only use fibres from plantation forests. Please recycle.

Key to CLSA investment rankings: BUY = Expected to outperform the local market by >10%; **O-PF** = Expected to outperform the local market by 0-10%; **U-PF** = Expected to underperform the local market by 0-10%; **SELL** = Expected to underperform the local market by >10%. Performance is defined as 12-month total return (including dividends).

22/02/2008