

# HAS THE OBVIOUS BEEN OVERLOOKED?



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## The Unique Value of Lead-Carbon Technology

The demand for stronger, more reliable and longer lasting batteries does not have to be met with only lithium, nickel-metal hydride or other expensive chemistries. A more obvious choice is the new lead-carbon battery technology developed within the past 10 years by the lead-acid industry. While not yet well known to battery users, lead-carbon can outsell batteries made from other chemistries. Not only are lead-carbon batteries far less expensive, they are safer and more environmentally sustainable.

This report by the Advanced Lead-Acid Battery Consortium (ALABC) explains why lead-carbon is emerging as the battery chemistry of choice for both micro/mild hybrid vehicles and grid storage applications.



ALABC™

*The Advanced Lead-Acid  
Battery Consortium*

# THE LEAD-CARBON INNOVATION

While plug-in hybrid and all-electric vehicles with high voltage multi-kWh batteries have attracted significant public attention in recent years, it is the safety and high cost of lithium-ion battery systems that has prevented those vehicles from gaining broad market acceptance. Instead, in a development that has received little media coverage, consumers interested in purchasing hybrid vehicles are migrating toward “micro” and “mild” hybrids using batteries sized nearer to one kWh.



What is significant about this migration is that the batteries of choice for these micro-mild hybrids may well turn out to be those using lead-carbon technology rather than lithium-ion (Li-Ion) or nickel-metal hydride (NiMH) chemistries which have higher energy density but are more expensive.

This trend may not be obvious to many consumers and the mainstream media. For those inside or who deal directly with the battery industry, however, the trend toward advanced lead-carbon batteries makes perfect sense.

Lead-carbon has been developed by the lead-acid battery industry, a progressive and innovative industry which for more than 150 years has served consumers with a variety of battery products that are low-cost, fully safe, reliable in a wide temperature range, and have an undisputed advantage in environment stewardship.

Low-cost advanced lead-carbon battery products are being used in a variety of mobile and stationary applications that are offering significant savings in the consumption of fossil-based fuels and also significant reductions in emissions.

# Lead-Carbon: The batteries of choice for the best selling hybrid vehicles

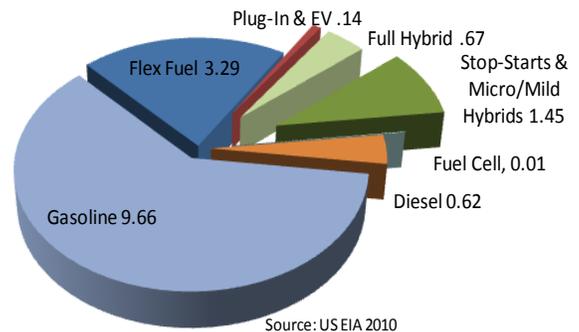
Recent data from the U.S. Energy Information Administration (EIA) reveals that sales of vehicles using "stop-start" and "micro-mild" hybrid technologies are expected to exceed sales of plug-in and all-electric vehicles using Li-Ion or NiMH batteries.

Lead-carbon batteries are the obvious batteries of choice for these stop-start, micro and mild hybrid vehicles for three reasons:

- **Low cost:** Lead-carbon batteries are produced and sold at costs below the \$150-200/kWh range, much lower than batteries made with other chemistries such as Li-Ion or NiMH in the \$650/kWh and above range.
- **Established large-scale infrastructure:** Lead-carbon batteries are produced by the lead-acid industry working within its existing infrastructure to develop this new range of advanced batteries that can meet higher performance standards required in hybrid vehicles and stationary applications such as the electric power grid. Raw materials for LC batteries (lead, sulfuric acid and plastics) are all produced within the domestic market, thereby contributing to national economic growth.
- **Sustainability:** Like all lead-acid batteries, lead-carbon products are entirely sustainable. No other battery chemistry can match the 98 per cent recyclability profile of lead-acid and lead-carbon. They are recycled in full compliance with strict federal, state and local environmental regulations. In fact, recycled lead is less expensive than lead processed from virgin ore. Increased demand for lead, therefore, has made lead-acid battery recycling a highly profitable industry.

While a plug-in hybrid or an all-electric vehicle can achieve impressive reductions in CO<sub>2</sub>, it is the *aggregated* sales of stop-start, micro and mild hybrids that actually result in greater mpg and CO<sub>2</sub> reduction than sales of only a few plug-in and electric vehicles.

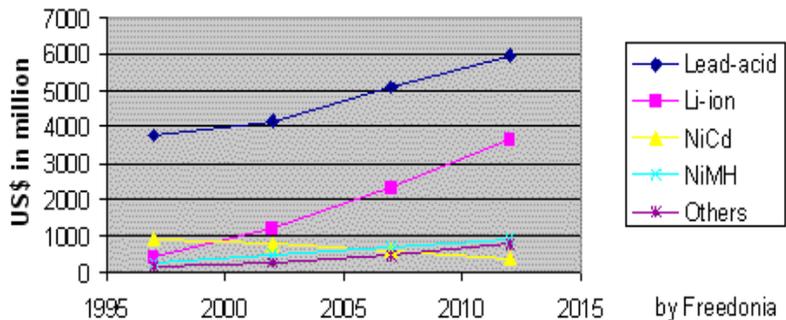
Projected US Light Vehicle Sales – 2020  
Millions



	STOP-START	MICRO HYBRID	MILD HYBRID	FULL HYBRID	PLUG-IN HYBRID	ELECTRIC VEHICLE
Idle elimination	✓	✓	✓	✓	✓	✓
Regenerative braking		✓	✓	✓	✓	✓
Acceleration boost			✓	✓	✓	✓
Electric-only drive				✓	✓	✓
Electric motor power			10-20k Wh	30 kWh	50 kWh	90 kWh
Preferred battery	LC*	LC*	LC*/NiMH	NiMH	Li+	Li+
Annual gasoline savings	20 gallons	40 gallons	100 gallons	160 gallons	320 gallons	400 gallons
Annual CO <sub>2</sub> abatement	212 kg	424 kg	1,059 kg	1,694 kg	2,072 kg	2,480 kg
Implementation cost	\$500	\$1,000	\$1,500-\$2,000	\$4,000	\$15,000	\$18,000
Cost recovery (years)	1	3	4-5	8	10	

It is a fact that the “gravimetric energy density” of lithium cells can exceed that of lead-carbon by a factor of 3 to 10, but this advantage is normally offset by the added weight of electronic controls, cooling and other packaging required to assure safe operation of lithium battery systems. It is the high *total* cost of producing and utilizing lithium battery packs that have impeded them from overtaking lead-acid sales in the rechargeable (or “secondary”) battery markets for both mobile and stationary applications. As a result, the lead-acid industry’s work on lead-carbon products will help the industry maintain its lead in energy storage sales for years to come.

Demand for secondary batteries



A recent paper issued by the U.S. Department of Energy states:

*"...the current cost of (lithium) EV batteries is about \$650/kWh, which is much greater than an estimated target of \$125/KWh of usable energy for widespread implementation."<sup>1</sup>*

The economic advantages of lead-carbon have been recognized by industry and governments throughout the world. For example, when Congress enacted the \$800 billion American Recovery and Reinvestment Act in 2009, \$1.3 billion was allocated to energy storage manufacturing facilities. While most of the media attention was focused on funds awarded to lithium manufacturing projects, two major lead-carbon manufacturers also received funds:

- Exide Technologies and Axion Power International received \$34.3 million for production of lead-acid batteries using lead-carbon electrodes.
- East Penn Manufacturing received \$32.5 million for the production of the UltraBattery, a lead-acid battery with a carbon super capacitor.

The result of this funding is that lead-carbon batteries used in demonstration vehicles, power cubes and storage systems demonstrate excellent performance and much longer cycle life than any other battery type.

## LC Super Hybrid

Recently, the ALABC has worked in a European-based consortium to develop the new "LC Super Hybrid" – an alternative approach to mild hybrids – that achieves significant reductions in CO<sub>2</sub> emissions, but uses lead-carbon batteries at a cost far lower than that of a "conventional" hybrid using more expensive battery systems. In addition to the lower CO<sub>2</sub> emissions, the LC Super Hybrid achieves an average 50 mpg.

The ALABC's partners in the development of the LC Super Hybrid are:

- Valeo, which provided the electric supercharger
- Controlled Power Technologies (CPT), which provided the stop-start system
- Mubea the providers of an advanced belt-tensioning system
- Exide Technologies, which provided the advanced lead-carbon batteries
- Provector, providers of the battery management system
- AVL Schrick who were responsible for the vehicle integration.

All these innovations came together to give the regular commercial Volkswagen Passat TSI with a 1.4 liter engine the driving dynamics of a larger (1.8 – 2.0 liter) engine while at the same time reducing CO<sub>2</sub> emissions by 26% - lower than that of the control 1.4 L engine. The result is that the LC Super Hybrid performs as well as a full hybrid, but at a substantially lower cost.

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<sup>1</sup> U.S. Department of Energy, "Energy Innovation Hub – Batteries and Energy Storage," Funding Opportunity Number: DE-FOA-0000559, February 1, 2012

High-voltage hybrids, which reduce CO<sub>2</sub> emissions by 15-20 per cent, add \$4,000-7,000 to manufacturing costs. Plug-in hybrids, which reduce CO<sub>2</sub> emissions by more than 20 per cent, cost significantly more at \$8,000-13,000 due to the high cost of lithium-ion batteries. This is why the lithium industry has lobbied for significant government subsidies to help make them more attractive to consumers.

In contrast, the ALABC estimates that the production-ready “super micro-mild” hybrid technology, when applied to a 1.4L turbo charged engine, will only cost approximately an additional \$900-2000 per car, but will offer more than 20 per cent reduction in CO<sub>2</sub> emissions compared to a gasoline turbo charged 1.8-litre engine. It offers a 26 per cent reduction in CO<sub>2</sub> compared to a 2.0 L non-turbo engine. This avoids, therefore, the need for large government subsidies.



## Performance Comparisons

System ► Metric ▼	Micro Hybrid	Micro/Mild LC Super Hybrid	Mild Hybrid	Full Hybrid	Plug-in Hybrid
Voltage	12V	<b>12- 48V</b>	<b>24-130V</b>	200-270V	300-400V
Regen. Power	0.5-3.0 kW	<b>3-8 kW</b>	<b>~10 kW</b>	~20 kW	20 kW +
e-Drive Range	0	<b>0</b>	<b>0</b>	~ 2 km	~ 30 km
OEM on-cost *estimate	\$200 - \$900*	<b>\$1,000 - \$2,000</b>	<b>\$2,100 - \$4,000*</b>	\$4,000 - \$6,600*	\$8,000 - \$13,000*
CO <sub>2</sub> Benefit %	4 - 7 %	<b>15-25%</b>	<b>8 - 15%</b>	15 - 30%	30 % +
OEM Cost/ Benefit	\$45 – 130 per 1% CO <sub>2</sub> less	<b>\$65 – 80 per 1% CO<sub>2</sub> less</b>	<b>\$265 – 330 per 1% CO<sub>2</sub> less</b>	\$265 – 330 per 1% CO <sub>2</sub> less	\$400 – 660 per 1% CO <sub>2</sub> less

## Lead-Carbon: Helping the electric power industry operate more efficiently at lower cost



**Rendering of a prototype lead-acid battery grid storage project by Ecoult**

Not only are lead-carbon batteries helping the motor vehicle industry achieve greater fuel efficiencies; they also are helping the electric power industry.

Within the past 25 years, the electric power industry has undergone a fundamental change in the way energy storage has been used. For many years, the technology of choice has been “pumped storage,” a proven means by which water is held in a reservoir and then released through turbines when power demand is at a “peak.” Utilities also have relied on “peaking” units fired by natural gas. Both work well, but require several minutes to begin supplying power. For many years, waiting several minutes for peaking power to come on line was considered “good enough.” Not anymore.

Financial institutions, medical facilities, homeland security and other institutions that cannot afford lapses in power flows have begun using a new variety of energy storage facilities to maintain reliability. Grid operators also face increased demands to moderate frequency fluctuations in power delivery. With many countries also establishing new standards to integrate renewable energy facilities into their electric power grids, new forms of energy storage are being tested and implemented. New energy storage options, therefore, are needed to provide power within milliseconds, not just a few minutes as before.

As a result, the energy storage industry, which was rather modestly valued at \$1.5 billion in 2010, is expected to grow into \$40 billion industry by 2020.

Lead-carbon batteries are playing an important role, not just in commercial settings, but also in government and utility research programs. The US Department Energy has included two major lead-acid demonstrations (a \$5 million ancillary services project in Pennsylvania and a \$6 million power smoothing project in New Mexico) among ongoing energy storage projects.



**Lead-acid battery rack in grid storage unit**

The Pennsylvania-Jersey-Maryland Interchange (PJM) recently synchronized a new power cube storage unit developed by Axion Power International of Pennsylvania that supplies power to the grid within a fraction of a second that PJM signals a requirement.

The performance results of lead-carbon batteries are revealed in the following chart:

**Present Worth Cost of 10-year Operation in Year 1 (\$kW)**

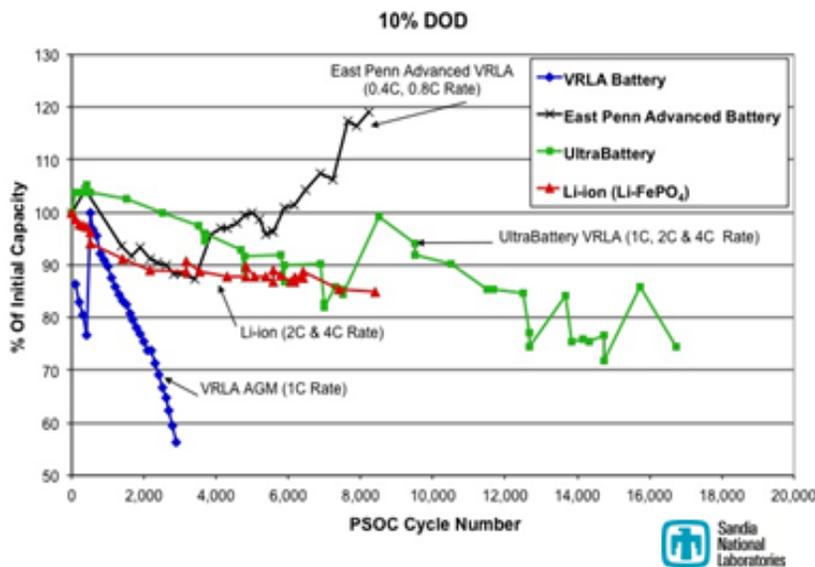
<b>Technology/Use</b>	<b>Advanced Lead-acid battery</b>	<b>Sodium Sulfur (7.2 hr)</b>	<b>Lead-acid &amp; Carbon-enhanced Electrodes</b>	<b>Li-Ion</b>	<b>Compressed Air (8 hrs)</b>	<b>Pumped Hydro (8 hrs)</b>	<b>High-speed Flywheel (15 min)</b>
Long-duration, frequent discharge	2839.26	2527.97	2017.87	2899.41	1470.10	2399.90	
Long-duration, infrequent discharge	1620.37	2438.97	1559.57	2442.79			
Short-duration, frequent discharge	1299.70		669.85	1409.99			965.73
Short-duration, infrequent discharge	704.18		825.57	960.48			922.67

Source: Energy Storage Systems Cost Update, Sandia National Laboratories (SAND2011-2730) April 2011

# How has lead-carbon achieved this dramatic cost advantage?

In the case of vehicles, the lead-acid industry has aggressively responded to the fact that vehicles have become more complex and, as a result, more demanding of energy from battery systems. Lead-carbon batteries are now being manufactured so they can absorb very high power (high current) charge pulses of brake energy and provide high current discharge pulses for frequent engine cranking as well as more energy for vehicle equipment like air conditioning, lights, audio etc. Lead-carbon battery performance remains stable for more than 100,000 miles, thereby eliminating the need for frequent battery replacement.

## Summary Utility PSOC Cycle-Life Lead-Acid and Li-ion



All this is possible because the ALABC has led efforts to achieve one of the biggest breakthroughs in the history of battery design which is now becoming known.

This is the use of carbon additives to the negative plates which dramatically reduces their sulfation at partial state of charge and pulse mode operation, something that had been shortening dramatically the cycle life of regular lead-acid batteries. The chart to the left shows how the use of carbon additives in the UltraBattery (shown in green color) developed by the ALABC dramatically improves battery performance.

For many years, the major problem of lead-acid batteries was their very short life in demanding storage systems. These batteries had to be replaced several times in the expected life-time operation (15 years in many cases). Now, with battery endurance dramatically improved (by 4-5 times), the need for replacement of these low-cost lead-carbon batteries is virtually eliminated.

The appearance of this new power source – the lead-carbon battery – is a breakthrough that already has caught the attention not only of battery manufacturers, but also of automakers and manufacturers of applications used in stationary grid storage. It also has drawn attention from the U.S. Department of Energy (DOE), which has co-sponsored with the ALABC further research in the carbon additive.

# Lead-Carbon Sustainability

Lead-acid and lead-carbon batteries have another huge advantage. The industry that produces them is the worldwide leader in product recycling. Lead-acid and lead-carbon batteries are recycled at a rate of up to 98 per cent, exceeding other consumer products like motor vehicles, tires, aluminum, and glass. As a result, more than 85 per cent of lead used in North America and Europe comes from recycling facilities, a performance record the recycling industry is implementing throughout the rest of the world.

Recycling does far more than protect human health and the environment from toxic compounds used in battery production.

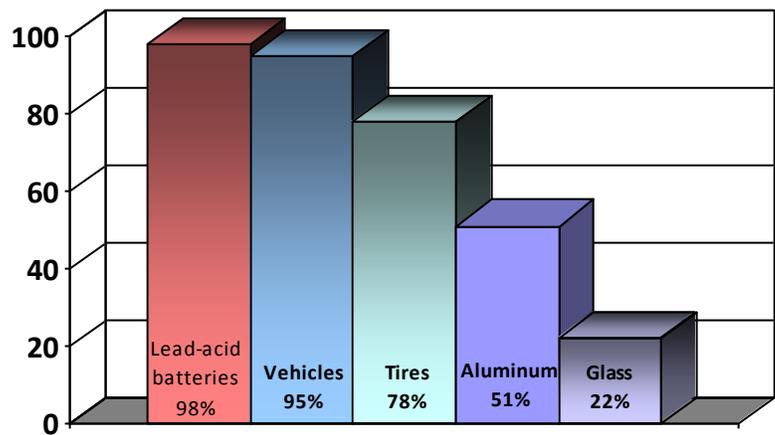
By making products from recycled materials instead of virgin materials, land is conserved and the need for mining new lead ore is reduced.

Reducing the need for lead from virgin ore deposits reduces dependence on imported materials, minimizes the cost of investment in mining equipment and also eliminates a source of excess mining waste.

Because ore extracted from ground deposits must be refined before use in production, significantly more energy must be used in the refinement. Recycling can reduce energy demand by as much as 30 per cent.

Therefore, the question of whether the obvious economic and environmental advantages of lead-carbon and lead-acid battery technology have been overlooked can be readily answered. The birth of a new battery type – the lead-carbon battery – is becoming known by more and more battery experts and users. The advantages of it have been recognized by governments, industries and academic researchers throughout the world. Consumers have benefitted from lead-acid battery products for more than 150 years and will continue to do so with the new generation of this reliable power source – the lead-carbon battery – to improve the performance of mobile and stationary applications.

**Product Recycling Rates in U.S.**



Source: Battery Council International, Vehicle Recycling Assoc.

# The Advanced Lead-Acid Battery Consortium

*A program of the International Lead Zinc Research Organization*

20 years – 70 members – 92 projects - 125 articles in the Journal of Power Sources

Acumuladores Moura	H.J. Enthoven & Sons
Addenda Corporation	Hammond Group
Amer-Sil	Hollingsworth & Vose Company
ArcActive Limited	H-Power
Atraverda	Hubei Camel Storage Battery Academy
Axion Power	INCI AKU SAN. ve TIC
BAE Batterien	Jiangsu Shuangdeng Group Co
Banner Batterien	Johnson Controls
Battery Technology Group	Luminous Power Technologies
Bernard Dumas	MeadWestvaco Corporation
Berzelius Metall	Met-Mex Penoles
BHP Billiton	MIDAC
BMG	Moll Batterien
Borregaard LignoTech	Mutlu Aku Ve Malz
C&D Technologies	Nelson Mandela Metropolitan University
Cabot Corporation	Northstar Battery
CEA - INES	Nyrstar
Concorde Battery Corporation	Recylex
CPqD (Center for R&D & Telecommunications)	Reem Batteries & Power Appliances Co.
CSIRO Energy Technology	Richardson Molding
Dixon Batteries	Rombat SA
Doe Run Company	RSR Corporation
East Penn Manufacturing Company	Shandong Sacred Sun Power Sources Co.
Eastman Chemical Company	Shin-Kobe Electric Machinery Co.
ECO-BAT	Societe de Traitement Chimiques (STCM)
Ecotality N. America	Southern California Edison
Effpower	Superior Graphite
EnerG2	Teck Metals
EnerSys	TIMCAL
Exide Technologies	Tovarna Akumulatorskih Baterij (TAB)
FIAMM	Trojan Battery Company
Firefly International Energy Company	Willard Batteries
First National Battery	Xstrata Zinc & Xstrata BRM
Fry's Metals	YottaQ
Furukawa Battery Company	Zhejiang Narada Power Source Co.