Axion Power International Inc.

Advances in Battery Development for Vehicles (Advanced Lead Acid and Li-ion), Near Term Electrification of Transportation System, Feasibility of Near Term Retrofitting of Inefficient Vehicles to EV's

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1 Overview of Different Vehicle Technologies

In recent years many new vehicle technologies have emerged mainly in response to rising fuel prices and environmental concerns. These new technologies include:

- HEV – Hybrid Electric Vehicles
- BEV – Battery Electric Vehicles
- FCV – Fuel Cell Vehicles
- DID – Direct-Inject Diesel/Advanced Diesel
- FFV – Flex Fuel Vehicle
- PHEV – Plug in Hybrid Electric Vehicle
- TGDI – Turbo Gasoline Direct-injection
- ICE – Internal Combustion Engine / Traditional Gasoline

A new survey taken by the global market research firm Synovate [1], found that when consumers were educated on the different available vehicle technologies, a large percentage, who would normally be expected to buy a traditional ICE vehicle decided on one of the other available technologies. Before and after education, the percentage of customers who said they would buy an ICE vehicle dropped from 76% to 45%, and for FFV the number decreased from 55% to 42%. In contrast, the decision to purchased PHEV vehicles increased dramatically from 33% to 64%, HEV from 57% to 64%, and BEV from 33% to 35%. The consumers that chose to remain with the ICE technology cited battery cost and life concerns as their main reasons for not considering BEVs and PEVs.

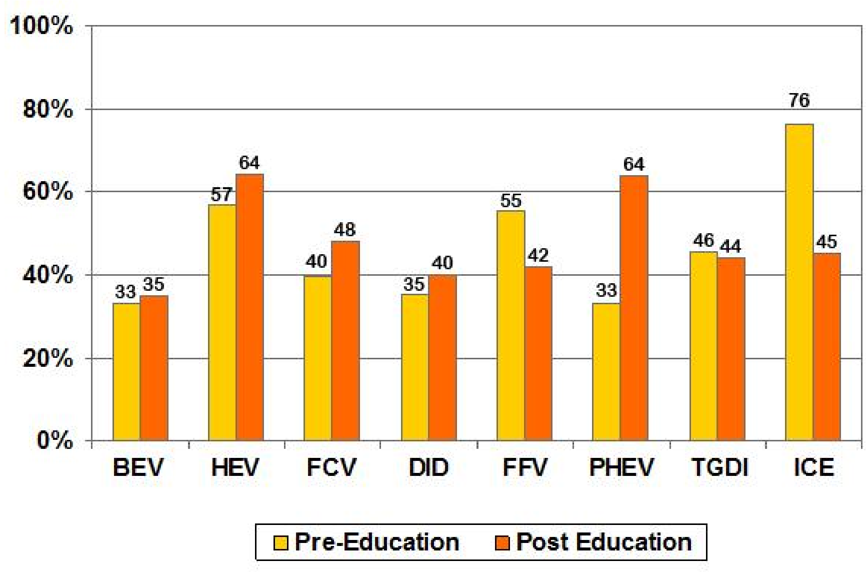


Figure 1: Customer Preference for Different Vehicle Technologies Before and After Education. (Source: Synovate Microresearch, 2008 [1])

Additional important facts from the survey of consumers who were looking to purchase a new vehicle include [1]:

1. 66% of consumers will chose vehicles that reduces their monthly fuel expense.
2. 75% of consumers said they would consider paying $1,500 more for a vehicle that achieves 30% better fuel economy.
3. 25% of consumers are willing to pay $2,000 or more extra for a vehicle that is significantly better for the environment.
4. 25% of consumers surveyed expressed a willingness to pay $2000 or more above the cost of an HEV to purchase a PHEV (roughly $4500 more than a normal combustion engine vehicle)

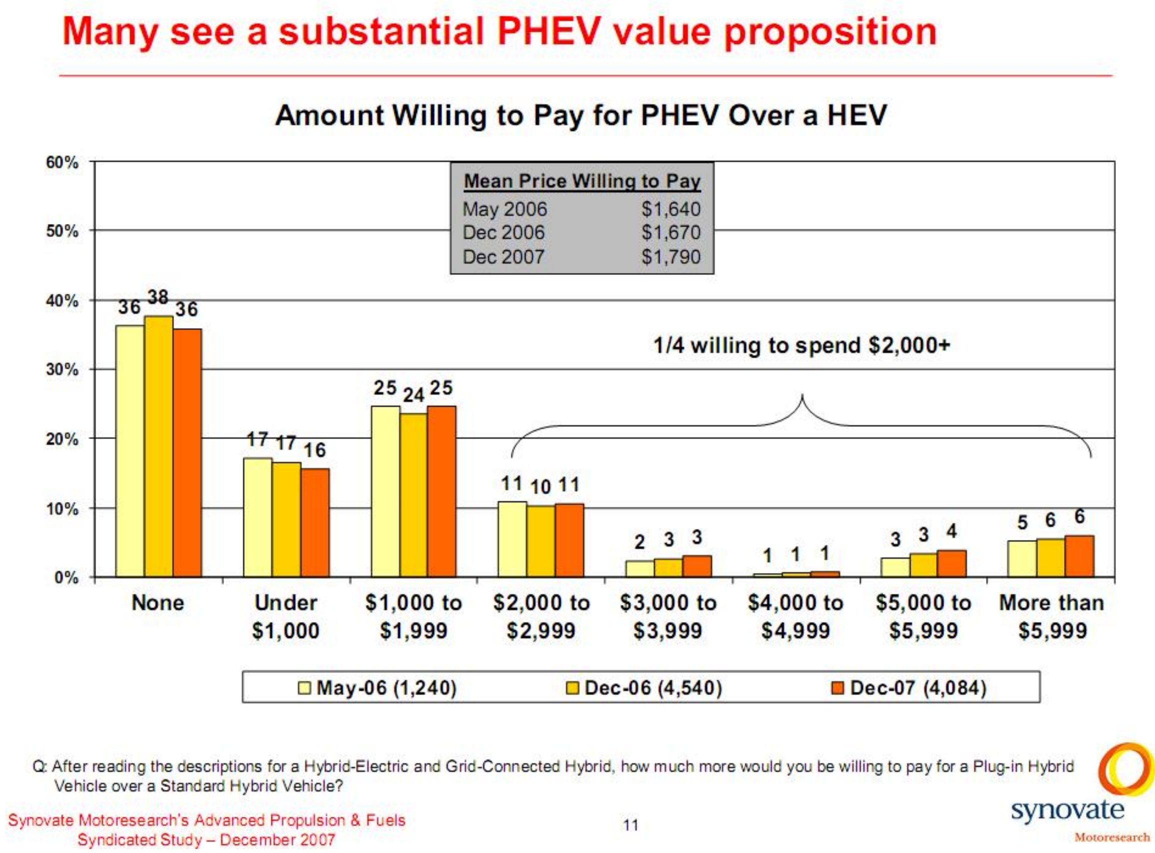


Figure 2: Analysis of cost sensitivity to PHEV technology.
(Source: Synovate Motorresearch from the 2008 Proceedings of the AABC Conference)

The main conclusions from this study is that consumers are willing to pay more for technologies that achieve better fuel economy and are better for the environment. However, the amount they are willing to pay is only $1500-2000 for conventional ICE and HEV technologies and up to $4500 (25% of consumers) for a vehicle that would spend a larger portion of time in an electric only mode of operation.

2 Hybrid Vehicle Influence on US Fuel Consumption

Current HEV vehicles achieve between 30-50 mpg [2]. Although this is an improvement over the current average fleet fuel economy in the US of 22 mpg (Source: 2009 Fuel Economy Guide [3]) for cars and light trucks, this will not significantly affect US dependence on oil. The three main reasons for this are dilution of this technology in a large fleet of conventional ICE vehicles, marginal improvement of fuel, and low customer adoption rates and low manufacturer production rates. Total world wide production rates for hybrid electric vehicles is growing however only about 500,000 hybrid vehicles were produced world wide in 2007 [4].

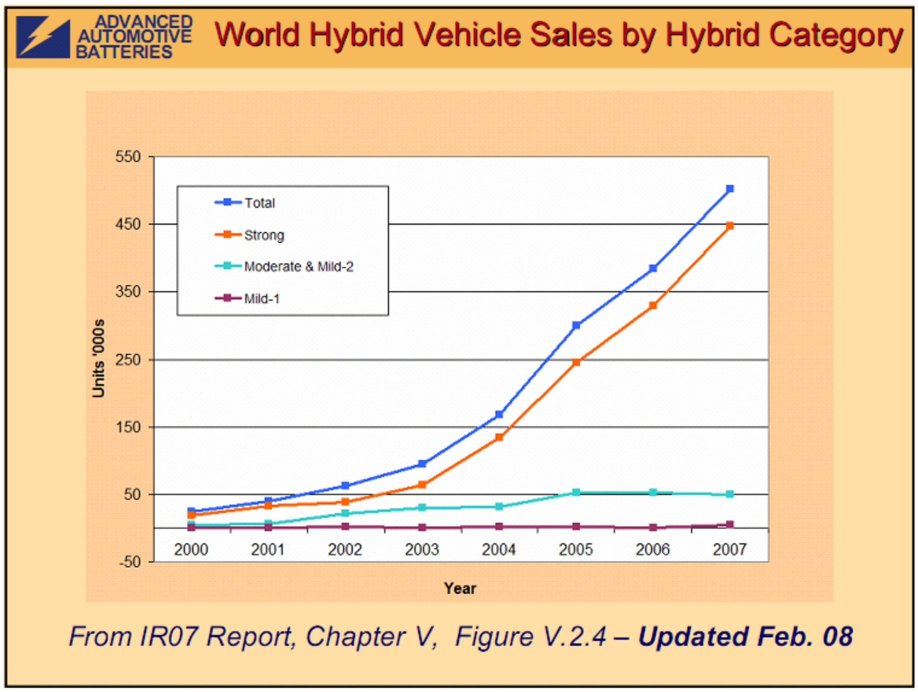


Figure 3: World Hybrid Vehicle Sales by Category (Source: Menahem Anderman, AABC Conference 2008 [4])

There are currently over 250,000,000 registered highway vehicles in the United States and the average vehicle life is 9.0 years and increasing, according to a report released by R. L. Polk & Co. [5] and increasing. 35% of these vehicles are 11 years or older [6]. In order to determine the effect of hybrid vehicles on gasoline consumption, we can assume that approximately $1/9^{th}$ (11.1%) of the vehicles on the road are replaced each year based on the average vehicle life span and assuming that the total number of vehicles is somewhat constant. If we further assume that 10% of these vehicles will achieve double the average fuel economy of a standard passenger vehicle, then the decrease in gasoline consumption as a result of the introduction of more efficient HEV and other technologies is ½ x 11.1% x 10% or 0.5%. It is difficult to see how this would have a significant effect on gasoline consumption in the near term. This also assumes that offset of conventional ICE vehicles was not offset by an increase in the total number of vehicles which could easily over shadow the gains made by the introduction of these more efficient vehicles.

3 Assessment of Vehicle Retrofitting Programs to Achieve Accelerated Gasoline Demand Reduction

Further reductions in gasoline consumption can be achieved by the introduction of vehicles that can operate for prolonged periods in electric only mode. These vehicles include PHEVs, BEVs, and retrofitting existing passenger vehicles to operate as BEVs (RBEVs). The following sections have been designed to address the minimum requirements of RBEVs and an analysis PHEVs and BEVs is beyond the scope of this report. This report is not designed to promote any single technology and all technologies should be pursued vigorously in order for the cumulative efforts to accelerate the decrease in gasoline consumption.

3.1 Minimum RBEV Range Requirements

Considering the daily driving distances for US driver shown in Figure 4, 75% of US drivers drive fewer than 50 km (31 miles) per day and 90% less than 100 km (62 miles). For a RBEV, a 50-60 mile range would be sufficient for 90% of Americans daily driving needs. Such a vehicle would be considered limited compared to today's ICE vehicles however this may prove adequate for many 2-car families.

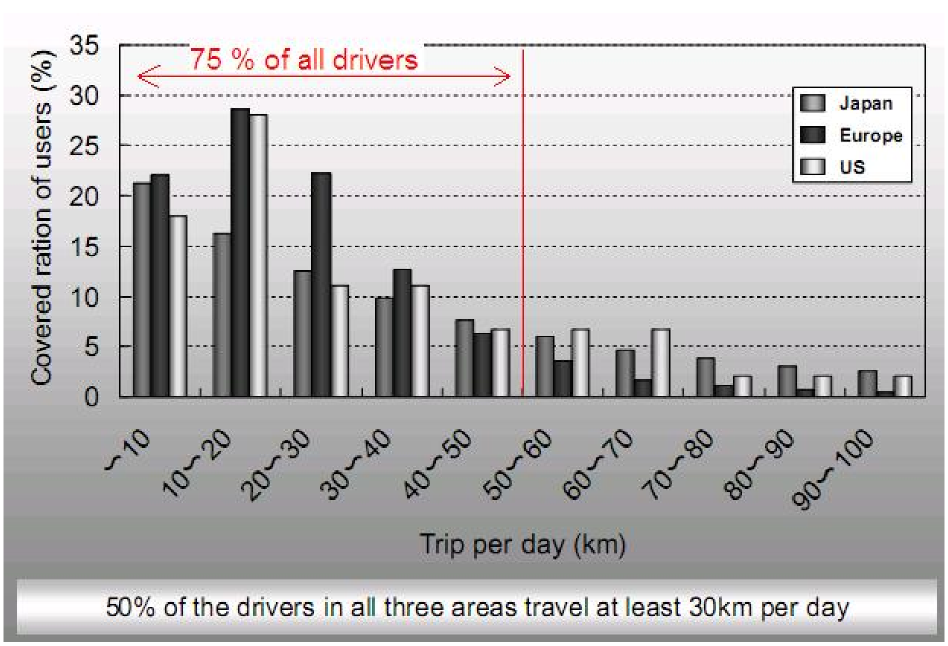


Figure 4: Average Daily Driving Distance. (Source: Hironori Harada, Toyota Motor Company [5])

3.2 Battery Requirements for a RBEV with a 50-60 Mile Range

3.2.1 Battery Capacity

The size of the battery needed for a RBEV with a 50-60 mile driving range is dependent on many factors such as vehicle size, weight, driving conditions, etc. Data from the GM EV-1 vehicle that was produced from 1997-2000 and originally designed and displayed in the LA auto show in 1990 was used to determine vehicle range vs. battery capacity. The EV-1 Generation 1 used lead acid batteries and the EV-1 Generation 2 used NiMh batteries. Data from each generation of vehicle is shown in Table I.

Table I: General Motors EV-1 Generation 1 and Generation 2 battery specifications.

	EV-1 Generation 1	EV-1 Generation 2
Battery Type	Lead Acid VRLA	NiMh
Battery Capacity (kWh)	18.7 kWh (60 Ah)	26.4 kWh (77 Ah)
Battery Voltage (V)	312	343
Battery Weight (kg)	595	521
Vehicle Range (miles)	55 to 95*	75 to 130*
Battery Cost ($/kWh)	$150/kWh	$900/kWh **

* - Driving distances vary depending on driving style, terrain, specific route traveled, temperature and other factors.

** - Based on the current OEM cost of a 1.2 kWh battery for the Honda Civic.

Based on this data, a 20 kWh battery is sufficient to provide for a driving range of 50-60 miles based on the data for the EV-1 Generation 1.

3.2.2 Battery Cost, Safety, and Manufacturability in the US

Assuming that a 20.0 kWh battery would be sufficient to allow 90% of Americans to commute back and forth from work in an electric-only mode, the cost of different battery technologies can be estimated:

Table II: Project Cost of Different Battery Technologies Needed to Achieve a 50-60 mile range.

Battery Type	Cost for 20.0 kWh	Safety	Manufacturing Base in US
Lithium Ion (1200 $/kWh)	$24,000	Needs Improvement	Needs Improvement
Nickel Metal Hydride (900 $/kwh)	$18,000	Acceptable	Poor
Lead Acid (150 $/kWh)	$3,000	Excellent	Excellent

The cost data presented in Table II also agrees with many of the presentations that were presented at the recent AABC conference in Tampa Florida [4]. Advanced battery cost ranged from 750-2000 $/kWh based on the technology, maturity, and economy of scale.

Although Lithium ion batteries offer the best energy density resulting in the longest vehicle range, this technology also suffer from safety problems that may require further materials R&D to resolve. Honda [3] and Toyota [6] both discussed safety concerns at the recent AABC conference. Panasonic EV Energy (the joint venture between Toyota and Panasonic) announced on May 27, 2008 that they would spend $290 million on a plant to producte 100,000 NiMh batteries per year. This decision to focus on NiMh batteries instead of lithium ion is a further indication of concerns by the dominant producers of HEVs that safety is still a major concern for lithium ion batteries. Again, this technology has many merits and should continue to be pursued vigorously as a long term solution for BEVS, PHEVs, and HEVs. However, safety concerns and battery cost favor lead acid batteries and advanced lead acid batteries for near term use in RBEVs.

Manufacturability should also be a major long-term concern for the United States. In order to guard against interruptions in the supply of critical commodities, it would seem prudent to focus on US made products. As shown in Figure 5, the majority of Lithium ion batteries are currently produced in Japan, China, and Korea. There are currently no large volume manufacturers of Lithium Ion Batteries in the United States [7] although Electro Energy and EnerDel both have manufacturing facilities in the US.

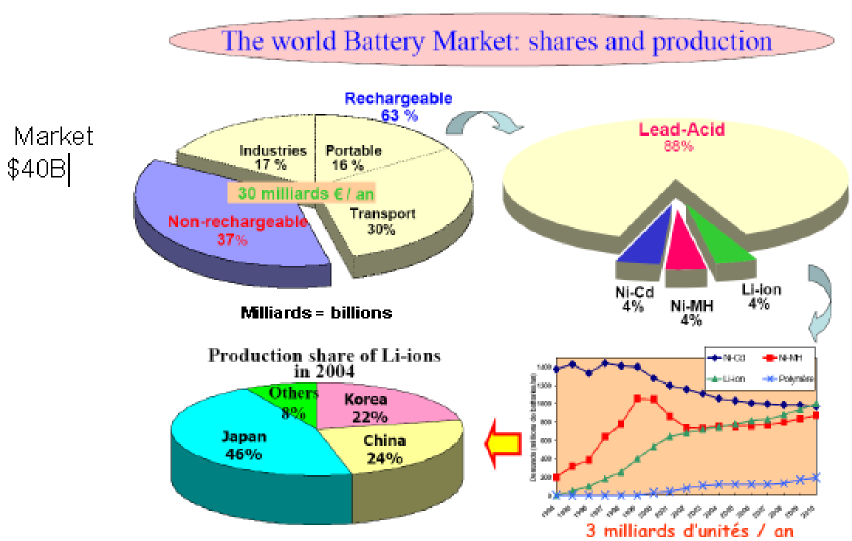


Figure 5: Landscape of Current Commercial Battery Technologies (Source: Jean-Marie Tarascon[8])

In contrast, the United States currently produces an estimated 120 million lead acid batteries per year and employs over 100,000 people in this sector (Source: Battery Council International). 99% of lead acid batteries produced in the United States are recycled back into new lead acid batteries. The recover rate for lead, plastic, and acid is currently 95-99%. In terms of sustainability, you could therefore say that lead acid batteries represent the model by which all other materials should be judged.

3.3 Case Study: Converting Existing ICE Vehicles to RBEV

A project was conducted in combination with Nord Kendal to evaluate the feasibility of converting a normal ICE vehicle to a BEV. The vehicle that was selected was a Chevrolet S-10 pickup truck. Pickup trucks and SUVs are good choices for vehicle conversion because of the availability of the necessary space for batteries, motors, controllers, and other ancillary equipment. They also typically exhibit poor fuel economy because of their larger size, poor aerodynamics, and heavier weight.

This vehicle was converted with the aid of a retrofit kit that was purchased from Wilderness-EV of Utah. A cost breakdown of what was required for the project is shown in Table III. All of these costs are at the retail pricing level and do not reflect a true manufacturing cost for a larger scale production of RBEVs.

Table III: Chevrolet S10 Pickup Truck Retrofit Costs.

Equipment	Cost
Lead Acid Batteries (10):	$2000
Conversion Kit:	$4500
Other Materials	$500
Labor	$3000
TOTAL	$10,000

Pictures of the vehicle are shown below:

The vehicle retrofit provided for 10 lead acid batteries. The ICE engine was completely removed. Three batteries were placed under the hood and a row of 7 batteries were placed in the front of the truck bed. The motor controller and the DC motor were connected directly to the transmission. Future work will focus on removing the transmission and using the DC motor to drive the drive shaft directly.

Table IV: Converted S10 Pickup BEV Specifications

Specifications	Units	Value
Number of lead acid batteries:	#	10
Total Battery Capacity	kWh	20
Vehicle Range on Full Charge	miles	50
Increase in Curb Weight	lbs	750

Vehicle conversion kits are also available for a number of other vehicles including trucks, passenger vans, delivery vehicles, and cars.

3.4 Further Considerations for RBEV Vehicles

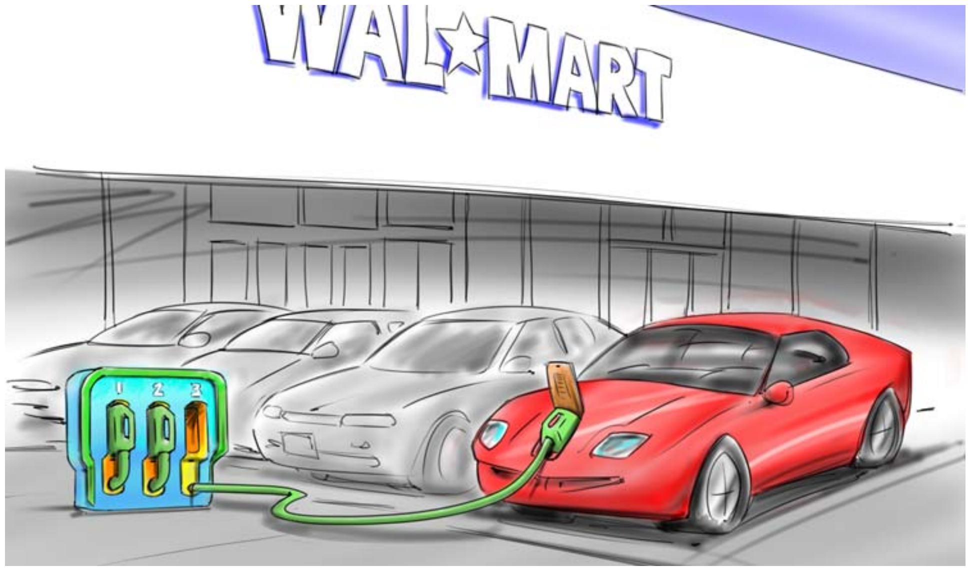
The retrofitting of conventional ICE vehicles to RBEVs is currently being lead by small business and individuals scattered across the US. This creates significant safety concerns, pricing concerns, and reliability concerns when compared to the standard production of conventional vehicles. Many of these concerns can be addressed by better engineering and the formation of a centralized testing center similar to what is currently in place for passenger buses (i.e. The Altoona Bus Research and Testing Center). Currently the Federal Transit Authority has created minimum safety and systems requirements for passenger buses and it is believed that a similar organization should be created to address similar concerns with RBEVs.

4 Axion's Vision for Tomorrow

The development of additional technologies such as electricity infrastructures for power generation, distribution, and vehicle charge will be critical for the wide spread adoption of PHEVs, BEVs, and RBEVs. Axion has been working to develop several new ideas that pertain to distributed charging capabilities and on-the-road charging.

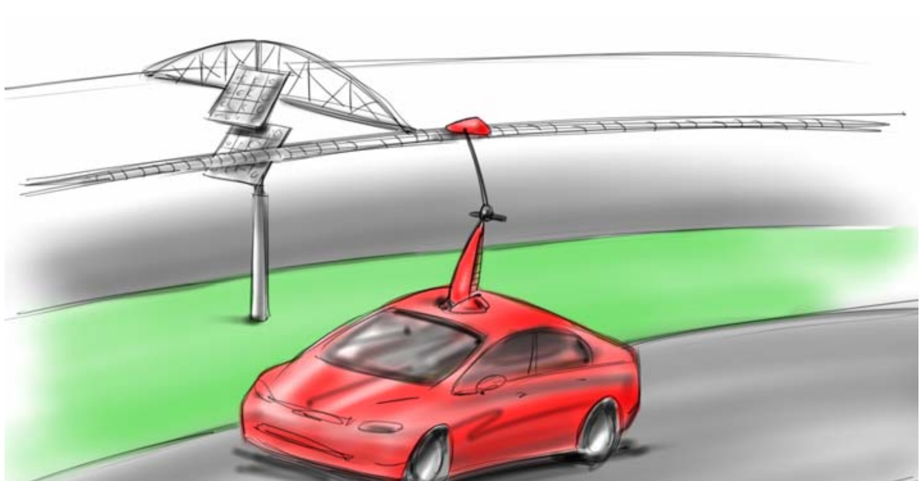
4.1 Distributed Charging

The need to be able to charge vehicles at work, when shopping, or whenever the vehicle is stopped, is an important consideration for increasing vehicle range. The illustration below shows how these vehicles could be charged while the driver is shopping.

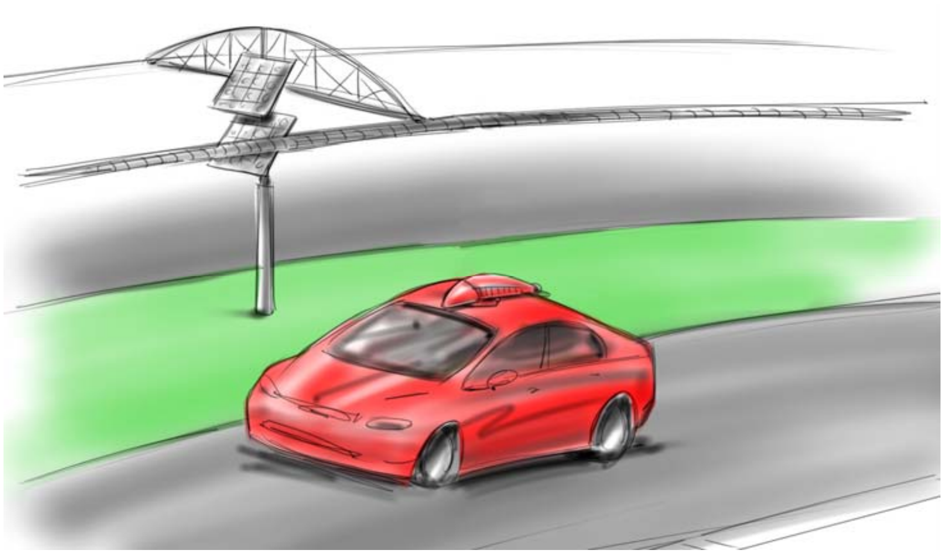


Additionally, all electric vehicles will have significant range limitations due to charge time. Charge times as long as 2-3 hours and ranges of less than 200 miles will make long distance travel very difficult and subsequently will stall the adoption of electric vehicles. This limitation could be significantly improved by utilizing the concept of on-the-road-charging (OTRC). OTRC would allow the vehicles to charge and drive for prolonged periods. A vehicle with a 50-60 mile range may be all that is necessary in order to provide a driver with the needed range to drive through a city to an Interstate, to charge while driving the bulk miles of his/her journey, and then be fully charged when the vehicle leaves the interstate to travel the remaining miles to his/her destination. Such a capability would also allow for better use of heating/cooling which is a considerable challenge, especially heating in cold temperatures, for electric vehicles. The following two illustrations are designed to provide an idea on how this could work.

Vehicle connected to the charging system:



Vehicle disconnected from the charging system:



5 Axion's Advanced Lead Acid Battery Technologies

Even though the first generation of EV-1 vehicle was capable of meeting the cost and range requirements for 75% of Americans, Axion has made further improvements to lead acid batteries that make them more suitable for use with HEV, PHEV, and BEV vehicle technologies. These three technologies include: PbC Technology; Carbon Additive Technology; and Embossed Grid Technology.

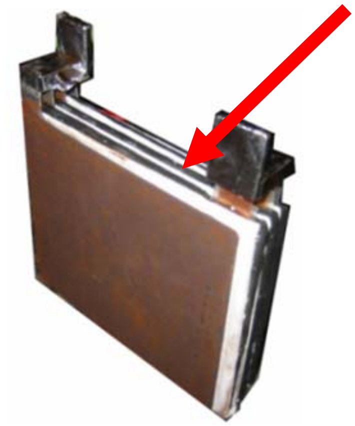
5.1 PbC Technology

Axion's core technology is the development of a hybrid battery/supercapacitor called the PbC Technology. This technology uses a standard lead acid battery positive electrode, a new proprietary carbon negative electrode to replace the standard lead negative electrode in a lead acid battery, and the same manufacturing process as a conventional lead acid battery. In addition, the new PbC Battery uses the same case, cover, separator, acid, and other materials that are standard in conventional lead acid battery construction. This is important in order to keep the cost of this new battery technology close to the same level as conventional lead acid batteries.

As shown below, the cells that feature the PbC negative carbon electrode are similar to the standard cell configurations.

Standard (Lead-Lead)

PbC (Lead-Carbon)



Activated Carbon Electrodes

This allows for easy assembly into the standard lead acid battery case and cover as shown below:

The key advantages of this technology include:

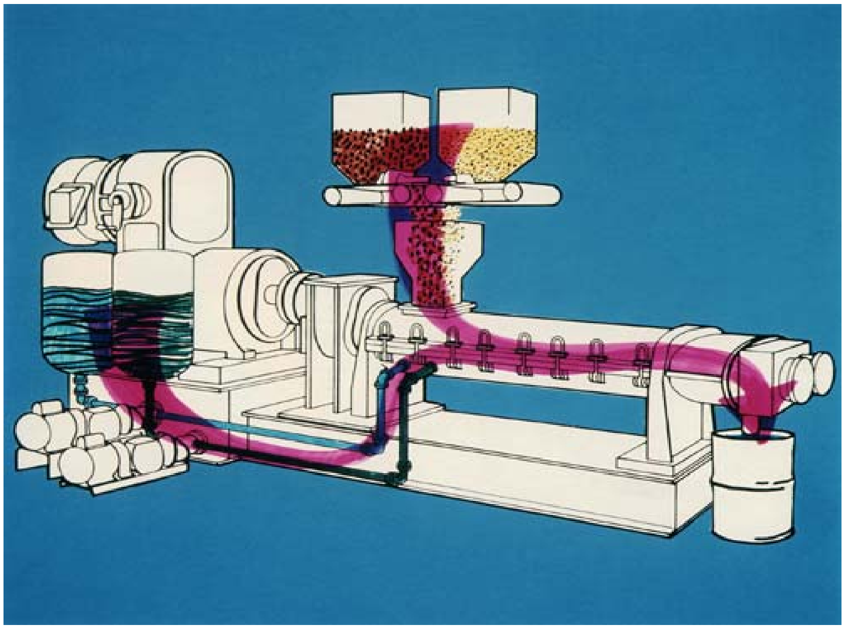
- Longer cycle life
- Faster recharge rates
- No sulfation of the negative electrode
- Lighter weight
- Higher power capability

All of these advantages are very important for use with hybrid vehicle operation. The elimination of the problem with sulfation of the negative electrode is also critical in allowing for regenerative braking in any type of electric vehicle without greatly decrease battery life. This is the main problem prevent the use of a standard lead acid battery in HEV, BEV, PHEV, and RBEV applications.

5.2 Carbon Additive Technology

Axion has also developed a carbon additive solution for the standard negative electrode of a lead acid battery. This technology allows for much better resistance to sulfation of the negative electrode when compared to a conventional lead acid battery and may prove sufficient for several vehicle applications. Currently this technology is being developed by Axion mainly for use in hybrid train, hybrid truck, and hybrid bus applications where the cost of the batteries is the dominating factor.

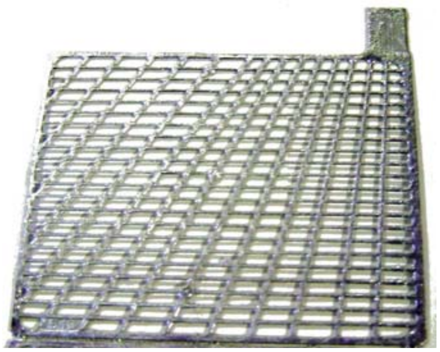
Axion has developed a novel new continuous paste mixing process which allows for higher carbon loadings in paste when compared to conventional lead acid battery mixing technologies.

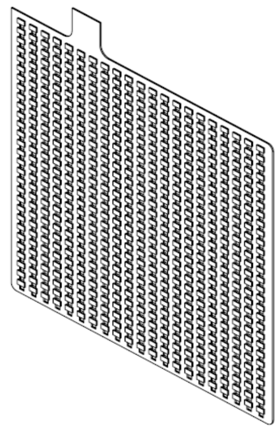


5.3 Embossed Grid Technology

Axion's third new lead acid battery technology was developed to improve the power, cycle life, and endurance of the positive electrode. This grid technology features a continuous sheet of lead that is embossed with a pattern to allow for the support of the active material. This technology is currently in a pre-production commercialization phase and will be used in all of the Axion vehicle demonstration batteries.

Standard (Lead-Lead) Continuous Grid





6 Axion's Additional HEV, PHEV, and BEV Projects

Axion is also working to demonstrate the use of Axion's three advanced lead acid battery technologies in HEVs, PHEVs, and BEVs.

6.1 HEV Project

The HEV project consists of retrofitted two Hybrid Civic vehicles with advanced lead acid batteries based on Axion PbC Technology.

This project will be completed in conjunction with Provector who has already retrofitted Honda Civic vehicles with advanced lead acid batteries in the UK. Once these vehicles are completed, they will be put through a series of drive cycle tests to 100,000 miles to demonstrate the success of the Axion new battery technology. Axion will also work to develop an aftermarket replacement battery kit for the Hybrid Civic that will be manufactured in Pennsylvania as a result of this project that will features Axion's advanced lead acid batteries.

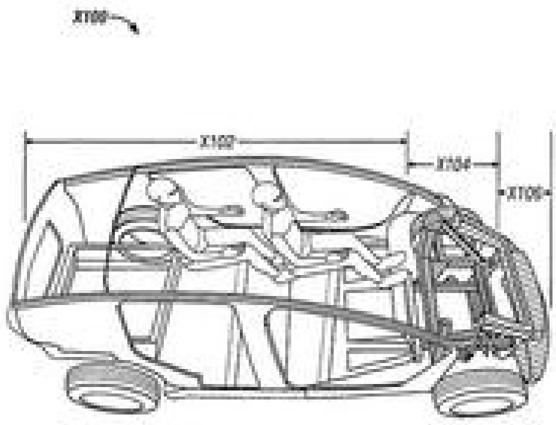
6.2 PHEV Project

The PHEV project would consist of modifying two Toyota Prius' with an extended range advanced lead acid batteries with a capacity of around 20.0 kWh. This substantially increases the existing capacity by about 15 times (from 1.3 kWh).

This project will be completed in conjunction with Electric Transportation Applications (Phoenix, AZ) who has already retrofitted Toyota Prius vehicles as PHEV vehicles. Once these vehicles are completed, they will be put through a series of drive cycle tests to 100,000 miles to demonstrate the success of the Axion new battery technology. Axion will also work to develop an aftermarket PHEV conversion kit for the Toyota Prius that will be manufactured in Pennsylvania as a result of this project and feature Axion's advanced lead acid batteries.

6.3 BEV Project

The BEV project would consist of modifying a pure electric vehicle that was developed by Advanced Composites (Harrisburg, PA) with Axion's advanced lead acid batteries. This vehicle has already been constructed and is currently using conventional lead acid batteries. The main goal of this project is to demonstrate the versatility of Axion's advanced lead acid battery technology by, for the first time, allowing this BEV vehicle to make use of regenerative braking. Previous versions of the vehicle could not make use of regenerative braking because the high power charge/discharge resulted in sulfation of the negative electrodes and premature failure of the batteries. Using Axion's PbC and/or Axion's Carbon Additive technology, we expect to eliminate the sulfation problem and greatly enhance the performance and viability of this vehicle. Since the vehicle has already been constructed and fitted with lead acid batteries, a limited amount of time and expenses are projected for this project.



This project will be completed in conjunction with Advanced Composites. Once the vehicle is outfitted with Axion's new battery technology, it will be put through a series of test to determine range and applicability for commuter, delivery, and other vehicle applications.

7 Energy and Environmental Benefits of PHEV and BEV Projects

7.1 Energy Benefits - Fuel conservation

Compared to other electric vehicle technologies, the PHEV, BEV, and RBEV projects could result in a dramatic decrease in gasoline/diesel fuel consumption. 90% of American's daily commuting mileage could be converted to electric only operation. This would result in a reduction of 500 gallons (approximated $2,000 per year at $4.00/gallon of fuel) per vehicle per year assuming a 22 mpg average fuel economy and 11,000 miles / year average miles driven per year. This corresponds to a reduction of 250 million gallons of fuel per year for every 500,000 vehicles that could be produced as PHEV, BEV, or RBEV. For the average consumer, charging the battery would cost roughly $3.00 (assuming $0.12/kWh and a 25% over charge). In order to cover the same distance of 75 miles in electric only mode, a standard car would consume 3.4 gallons of fuel which costs $13.60 at $4.00 / gallon. This is a reduction of 78% and an annual reduction of $1560 per consumer. In broader terms, for every 1% conversion from ICE vehicles to BEVs, PHEVs, or RBEVs there is a corresponding reduction of 1.25 billion gallons of gasoline consumption per year.

7.2 Environmental Benefits

Axion's current HEV, PHEV, BEV, and RBEV projects will be equipped with data acquisition systems that would collect and record real data from the actual "real-time" use of these vehicles to determine further environmental benefits of these technologies**.**

HEVs would likely reduce the gasoline consumption, unburned hydrocarbons, oxides of nitrogen, and air CO_2 emmisions by 50%:

Table V: Environmental Benefits of HEV technology

Estimated Emission Reductions per 500,000 vehicles	Tons per year
Gasoline Fuel Reduction	125 million gallons
Unburned hydrocarbons (HC) and oxides of nitrogen (NOx) (assumption: 44 kg per vehicle per year: source CARB)	12,000 tons
Air pollutant reduced per year (specify) **CO2** (assumption 19.6 lbs/gallon of gasoline: source US DOT)	1.25 million tons

PHEV, BEV, and RBEVscould eliminate the gasoline consumption, unburned hydrocarbons, oxides of nitrogen, and air CO_2 emmisions:

Table VI: Environmental Benefits of PHEV and BEV technologies.

Estimated Emission Reductions per 500,000 vehicles	Tons per year
Gasoline Fuel Reduction	250 million gallons
Unburned hydrocarbons (HC) and oxides of nitrogen (NOx) (assumption: 44 kg per vehicle per year: source CARB)	24,000 tons
Air pollutant reduced per year (specify) **CO2** (assumption 19.6 lbs/gallon of gasoline: source US DOT)	2.5 million tons

8 Going Forward

Axion is not working alone in the areas we have spoken of in this report. Rather we are working with two of the three largest battery manufacturers in North America. Since we first established an MOU relationship in 2004, our vision remains the same going forward in that Axion will continue to develop technology products that can and will be manufactured on the assembly lines of much larger lead acid battery companies. In addition to our work, the entire lead acid battery industry continues to develop products of their own. Both cases would be helped by a dollar infusion for research and demonstration projects. While hundreds of millions of dollars have gone into other types of battery technologies, very, very little has gone into the enhancement of lead acid batteries.

Certainly tax credits for consumers and corporations that invest in converting their vehicles from ICE to any of the electric alternatives (HEV, PHEV, BEV, or RBEV) would be a further inducement to moving the conversion process forward quickly. If we do not all act together - business, consumer and government - America will be forever mired in oil dependency.

9 References

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