Electric Vehicles and Peak Oil Demand

*By Samuel A. Van Vactor**

Introduction

Since the oil crises of the 1970s, oil demand has largely retreated to the transportation sector, where the fuel's low handling and storage costs and a mature delivery infrastructure give it a significant advantage. Competing alternatives, such as compressed natural gas or hydrogen, have made little headway in developing delivery systems. The tables are about to turn, however, because in the last two decades a superior battery has been developed to power laptop computers, cell phones, and hand-held tools. Larger-scale lithium-ion batteries can be adapted to vehicles, so that existing household power outlets can be used to deliver the energy, avoiding the infrastructure constraints holding back other options.

The auto industry is gearing up to deliver radically new types of vehicles based on the success of hybrid models of the last few years. These new vehicles, electric cars and plug-in hybrids, will use battery-stored electricity. The running costs of electric vehicles are significantly less than those relying exclusively on petroleum products, and the plug-in hybrid provides the consumer a valuable fuel-switching option. The costs of such vehicles and their batteries, however, are higher. Nonetheless, the crossover point for plug-in hybrid cars in North America is as low as $55 per barrel and the cost will almost certainly decline as the technology matures. In addition, because the environmental and national security costs of relying on oil are high, national polices are likely to be aimed at furthering the introduction of alternative fuel vehicles. As a consequence, the demand for oil is likely to go into a slow, but irreversible, decline.

Hybrid Cars and the Path to Reduced Oil Demand

Electric vehicles (EVs) are not a new idea and have been in some form of continuous production for over a century. They have, however, been limited mainly to golf courses, city driving, and similar short-term low-speed applications. So far, the vehicles have limited maneuverability, limited range, and a long recharge time. The constraint has been battery technology – for electric vehicles to be competitive with gasoline engines a new generation of batteries must be commercialized that are lightweight, long-lasting, safe, and cheap. It is only in the last few years that various technological advances have converged to make this a realistic possibility.

The motivating force behind electric vehicles has been the effort to reduce emissions and clean the air, rather than replace high-cost oil. To no surprise California has led much of this effort. In 1990 the state launched a zero emission vehicle (ZEV) initiative. The initiative required that 2% of all new car sales in 1998 and 10% in 2003 should be meet the zero emission standard, as defined by the California Air Resources Board. The mandate has been modified by the Board, but a number of automobile manufactures introduced EVs in 1990s (Sawyer 2006). The most successful electric car, the EV1, was built by General Motors (GM). *Time* magazine listed the EV1 as one of the fifty worst cars of all time, but noted: "The EV1 was a marvel of engineering, absolutely the best electric vehicle anyone had ever seen," (*Time*, 2007). The problem was the battery. When it was introduced it had a pack of conventional lead-acid batteries, but ended production with a nickel-metal hydrate battery (NiMH). GM would only lease the car and withdrew it in 2003, concluding that it was too costly to build. However, the NiMH battery (which the California program helped to foster) went on to become a crucial building block of hybrid cars.

Hybrid electric vehicles (HEVs) have been extremely successful, largely because their introduction coincided with rapidly rising gasoline prices. They can, in theory, run off batteries (for very short distances), but they were designed to lower emissions by getting better mileage. Annual sales have grown rapidly from 10,000 sold in 2000 to 355,000 in 2007 (R.L. Polk 2008). Despite low taxes and relatively low gasoline prices, three-quarters of the hybrid market has been in the United States. Most significantly, HEVs have opened an economic path to fuel substitution, which for the first time promises a realistic option to lower U.S. dependence on imported oil. The 2007 expert report to the CARB concluded that: "It is the Panel's opinion that HEVs, due to their success, are providing major support to future mass market ZEVs by continuing to stimulate advances in electric drive systems, electric accessories, and battery technologies," (Kalhammer 2007, p. 10).

Even if coal dust engines, hydrogen-based fuel cells, and other innovative options for cars and trucks can be developed at reasonable cost, they will be stillborn without a supporting delivery infrastructure. One of the primary attractions of gasoline as a fuel is its widespread availability with precisely manufactured characteristics that match an engine's requirements. The replacement of such an infrastructure is a classic "chicken and egg" problem.

Hybrid cars have opened the path to fuel substitution because the electric drive systems, which power their wheels can switch to any source of electricity, including batteries which could be recharged with household current. Unlike cars that depend exclusively on plug-in recharging, however, these cars can also use gasoline and draw energy from the existing infrastructure – they are not limited to a short range from their garage or by the length of time necessary to recharge.

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To date, hybrid cars use the NiMH battery, which is mass-produced in Japan. In the next few years, however, the NiMH battery will be replaced by lithium-ion (Li-ion) batteries. The Li-ion battery is capable of providing the length of charge, battery life, and depth of power to make electric vehicles' performance comparable to (or even better than) conventional gasoline and diesel-driven vehicles (Kalhammer 2007). This has been amply demonstrated by the new Tesla EV, which began commercial production in 2008. The company's first year of production, 600 vehicles, is sold out even at its asking price of $98,000 (Business Week 3/20/08). The Tesla uses 6,800 mass produced Li-ion batteries in each car. They are like those used in laptop computers, but the company has added cooling and other measures to ensure safety (Berdichevesky 2006).

Subaru is introducing the R1e electric car in Japan in 2008, with the New York Power Authority testing the cars in the summer in the U.S. The car is powered by a Li-ion battery and, according to the company, can be "quick charged" to 80% capacity in fifteen minutes in special electric hookups. Similarly, both Nissan and Mitsubishi have introduced electric cars in recent auto shows, the Denki Cube and i-MiEV respectively. The cars are small and designed for the Japanese market, but all depend on the Li -ion battery technology.

The full-scale commercialization of Li-ion batteries for cars is the next crucial step in the evolution, but that will require a large market. Because battery-powered electric vehicles are small and limited in range they are unlikely to have sufficient sales. On the other hand, pairing of electrical and hybrid technologies can ramp up battery demand as well as provide motorists with a choice of fuels. This new type of car is referred to as a plug-in hybrid (PHEV). The idea is to use household current to charge an advanced battery system which can then be used for short trips without gasoline. For longer trips, the gasoline engine kicks in and charges the battery. Thus the consumer has the option of using electric current or conventional fuels. According to GM, 70% of all car journeys are less than 40 miles, which means that electricity from the grid would power the car the majority of the time.

The car that has received the most recent attention in the U.S. is GM's concept car, the Volt. GM aims to produce the Volt for $30,000+ and market it in 2010. It will have a range of 40 miles based on a Li-ion battery under development (GM Volt webpage). Crucial to the car's price will be the cost of the battery, which has been described by GM's Bob Lutz as "more than several thousand dollars, but less than $10,000" (New York Times, 3/19/08). Lutz has also commented that alternative auto sales will be one-third of the market by 2015. According to Lutz, the primary reason is that the industry must meet an average standard of 35 miles per gallon (mpg) by 2020 for all vehicles and this will require a major shift in vehicle design (Bloomberg, 3/18/08). The "DNA" of the automobile is undergoing a major change. The advances made by the high-tech industry mean that vehicles can be streamlined with electric motors, electric drive systems, and optimizing electronic controls replacing older mechanical designs (Burns, 2008). Although this transition is initially costly, in the end it is likely to result in less expensive vehicles, since less material will be required in manufacturing, there are fewer moving parts, and the designs are fundamentally simpler.

The Economics of Consumer Choice

Consumers take market signals as their guide when buying long-lived equipment that depends on a particular energy source. When oil prices were low in the 1990s, consumers showed a strong preference for big cars. In the U.S., the market was constrained by regulations that required an average of 27.5 mpg for car sales, but there was a loophole. Trucks and sport utility vehicles (SUVs) were exempted from the stringent requirement and their sales took off. However, as gasoline prices rose, demand shifted into smaller cars and hybrids. Once a new vehicle is purchased the consumer is locked in; opportunities for fuel substitution are limited.

It was fuel substitution in the boiler fuel market that played a major role in bringing oil prices down in the 1980s. A similar role is likely to be played by plug-in hybrids and electric cars in the coming decades. The running costs of electric vehicles are now much less than for gasoline or diesel vehicles. The cost of battery-stored electricity for the Tesla is about $0.025 per mile, or the equivalent of about $0.68 per gallon of gasoline for most cars and light trucks presently produced in the U.S. Of course, the battery pack is not included in these figures, and in the case of the Tesla, this added cost more than offsets the gasoline savings. If plug-in hybrids and electric cars are going to appeal to a mass audience, fully amortized costs must be considered.

Car buyers do not explicitly consider the battery costs in their calculation; they will look at the total cost of the vehicle and its leasing or purchasing terms. In the case of electric cars, which will not require an engine, it is the incremental cost that matters – batteries less engine and other savings costs. It is also incremental costs that matter when choosing a plug-in hybrid, but these are harder to pin down. In the case of the Volt, it is planned to have a small engine with the primary function to generate electricity. So there are likely some cost savings on the engine, but it is unclear how much. On the other hand, it is known that the battery will be costly. It is also necessary to take into account the impact of mass production. Once designs have stabilized, manufacturing costs can be brought down through economies of scale.

Mitsubishi's "I" minicar has been designed as either a small efficient gasoline-driven or a battery-electric vehicle. Both will be marketed in Japan, and if the market exists, the electric car will be marketed in the U.S. The electric version of the minicar will cost up to $7,000 more (Durbin, 2008). The "I" averages 43 mpg; if driven 15,000 miles per year, the cost of gasoline at $3.50 per gallon would be $1,221. The same mileage would require about 4,286 kWh of electricity per year at a cost of about $471; thus the annual savings would be $750. Assuming a battery life of 10 years and a discount rate of 6%, the present value of the savings is $5,851, somewhat less than the higher cost of the battery-electric version of the car. The breakeven gasoline price is $3.92 per gallon and for the U.S. market, and this implies crude oil prices well in excess of $100 per barrel.

The *Report of the ARB Independent Expert Panel 2007* provides an objective analysis of likely Li-ion battery costs as production ramps up. The report concluded that batteries for virtually all prototype plug-in hybrids and electric vehicles had a positive net present value when compared to cars that depend on buying retail gasoline, including taxes. Their analysis was based on a robust definition of the battery characteristics (ten year life at 80% capacity or more,) but assumed high gasoline prices. The Report included an extended analysis of manufacturing costs, with much of the data provided by the industry. Briefly, they concluded that battery costs would range from $1,650 for hybrids to $13,680 for full-featured electric cars suitable for the American market. The costs varied based on battery capacity, from 2 kWh to 40 kWh, and rate of production from 20,000 to 100,000 units per year (Kalhammer 2007, p. 47).

Table 1: Running Cost Comparison

	2008 Conventional	Plug-in Hybrid
Gasoline prices	$3.50	$3.50
Miles on gasoline	15,000	4,500
MPG	25	35
Annual gasoline cost	$2,100	$450
Electricity prices	$0.11 kWh	$0.11 kWh
Miles on electricity	0	10,500
kWh for battery power		3,000
Annual electricity cost	0	$330
Total annual running cost	$2,100	$780
Annual savings		$1,320
Ten year savings, PV @ 6%		$10,298

The average for new conventional cars and SUVs sold in the U.S. is now about 25 mpg. Assuming gasoline prices of $3.50, running costs are calculated in Table 1. According to the Expert Panel Report a battery with a capacity of 14 kWh will average about $5,218. This should provide up to 40 miles per trip on the battery and cover about 70% of the driving, or 10,500 miles per year. The running costs for a plug-in hybrid would realize an annual savings of $1,320, with a ten year present value of about $10,298, significantly greater than the battery cost, but other aspects of hybrid technology may cost more (or in the long run, possibly less). To put this in further perspective, if GM can market the Volt for $30,000 and gasoline prices average around $3.50 per gallon, the car will have a distinct competitive advantage. Based on the assumptions in Table 1, the breakeven price for gasoline is $2.12 per gallon if the battery cost represents the cost difference in the technologies. In the present U.S. market, state and local taxes average $0.42 and refining and retail margins are about $0.39 per gallon. Thus the net crude-oil component is about $1.31 per gallon, or $55 per barrel.

The Expert Panel Report calculates that Hybrid batteries are expected to cost an average of $2,338 as compared to $5,218 for a battery with a capacity of 14 kWh. The new U.S. vehicle target is 35 mpg and this is also about the average mpg of a typical hybrid car. In the U.S., with its demand for larger vehicles, the industry believes the target can best be achieved by producing a significant number of hybrid cars. Bob Lutz of GM has commented that "Around 2015 we're going to sell a ton of hybrids whether people want them or not," (Bloomberg 3/18/08). Based on the Report's battery figures, it costs $2,880 extra to equip a hybrid with a battery sufficiently large to allow the majority trips to be made on household electricity. At $3.50 per gallon for gasoline, this would represent a savings of $720 per year, with a net present value of $5,617 over ten years. The breakeven gasoline price in this analysis is $2.33 per gallon, or about $63 per barrel for crude oil.

Considering Externalities

The preceding calculations do not include environmental impacts or national security implications of depending on foreign oil. When these factors are considered it enhances the benefits of switching from gasoline and diesel vehicles to plug-in hybrids and electric cars. One approach to analyzing the issue is to compare the costs of Canadian oil sands to that of plug-in hybrids. To a large extent these activities represent the marginal cost of new supply as compared to the marginal value to consumers, the point of price determination in a competitive market. Previous analysis concluded that at oil prices above $55 per barrel, in North America it becomes economic to shift from gasoline and diesel powered cars and trucks to some form of electric-driven vehicles. The marginal cost of Canadian oil sands is close to the crossover point, about $60 per barrel. However, the environmental consequences of the two choices are quite different.

In-situ production of oil sands is expected to require up to 2.6 million Btu of natural gas per barrel. The same amount of gas can generate and deliver about 341 kWh, assuming a modern combined combustion turbine and a transmission loss of 7%. That is enough power to provide from 1,194 to 1,364 miles in battery driven car. In contrast, this quantity of natural gas can produce 42 gallons of diesel from oil sands; good for 1,050 miles at 25 mpg and 1,470 miles at 35 mpg. The primary difference is that the diesel or gasoline powered car will have will have additional polluting emissions that electric vehicles will not have.

Future Battery Costs

It has been less than two decades since the development of the Li-ion battery and in that time its efficiency and reliability has vastly improved. Cost calculations made earlier are based on existing technology and production techniques. There are, however, a number of remarkable R&D advances in battery design that promise substantially more efficient designs and, by implication, lower costs.

The Tesla battery-powered car uses off-the-shelf batteries with conventional "energy density." GM plans to use a more advanced battery based on nanophosphate technology, which will improve the energy density by a factor of two. In December 2007, Stanford announced that its researchers had developed a technology based on silicon lithium nanowires, which would improve energy density by a factor of ten (Stanford 2007). It is expected to take five years to commercialize Stanford's technology. If such a technology is successful, it would, for example, allow the Tesla to decrease the number of batteries from 9,800 to 980 or extend the car's range. The increase in energy density also means that battery weight and size will decline, further improving the efficiency of battery-powered cars.

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