Economics of Hybrid Electric Vehicles

*By Michael E. Canes**

Introduction

Well over 200,000 light duty hybrid electric vehicles (HEVs) have been sold worldwide within the past few years, thousands more per month are being offered, and additional models are on the way. The Toyota Prius, the Honda Insight and a hybrid version of the Honda Civic currently are being offered in the United States, Ford will introduce a hybrid version of its Escape Sport Utility Vehicle (SUV) in 2003, and Daimler-Chrysler a hybrid version of its Dodge Ram truck in 2004. In addition, General Motors and Toyota have announced plans to offer hybrid SUVs within the next few years. Other hybrid models are being sold in Europe and Japan.

Hybrid electric technology has captured policy maker attention because it is a means to conserve on fuel and to reduce emissions. The recently completed Partnership for a New Generation of Vehicles program sponsored by the Clinton Administration focused mostly on this technology to achieve its goals.

Hybrid technology also is being applied to buses and trucks, for the most part in experimental programs designed to learn more about operating and emission characteristics as well as economics. In addition, the military services are looking closely at hybrid technology as a means to curb logistics needs.

In this paper I will examine the economics of hybrid electric vehicles in civilian and military use. The analysis will examine the private return to a hybrid owner as well as the social return, which includes the value of reduced emissions. I also will assess the value to the military, where logistics concerns predominate.

The paper proceeds as follows. First, I will briefly describe HEV technology. Then, I will use net present value analysis to assess the economics of hybrid technology applied to civilian automobiles and trucks. This analysis will also look at the value of emission reductions for these vehicles. Next, I will assess the value of hybrids to the military. As will be seen, the economics of HEVs for the Armed Services are different from those of civilian vehicles. Finally, I will offer some conclusions.

Hybrid Electric Technology

In the context of motor vehicles, the term "hybrid" refers to two separate sources of power; for example, an internal combustion (IC) engine and an electric motor. There are many forms of hybrids, some of them exotic such as flywheels, fuel cells, or ultracapacitors in combination with an IC engine, but the hybrids here discussed involve an IC engine with an electric motor.

The two basic forms of hybrid electric vehicle are series and parallel. In a series hybrid, an IC engine drives a generator, which powers an electric motor. The generator also charges a set of batteries, which can supply power directly to the motor. A propulsion control system determines how much power is supplied by the generator and how much by the batteries. In a series hybrid, only the electric motor propels the vehicle. This technology is used in trains and diesel-electric submarines and also in large on-road vehicles such as buses and trucks.

In a parallel hybrid, either the IC engine or the electric motor can propel the vehicle. It also has batteries and a propulsion control system, with the latter determining how much power is supplied by the IC engine and how much by the electric motor. This type of system generally uses the motor to accelerate the vehicle and the engine to propel it at a steady speed. HEVs such as the Toyota Prius and the Honda Civic use this technology.

Energy storage in hybrids can be supplied by a variety of sources, but batteries are by far the most common. Lead-acid batteries are used in most large vehicles mainly because the technology is well known, they are relatively inexpensive, and recycling facilities are readily available. The drawbacks are that lead-acid batteries are relatively short-lived and heavy.

Small hybrid vehicles, such as the Toyota Prius, use nickel metal hydride (NiMH) batteries, which are more expensive but lighter and longer-lived. Other battery technologies in use include lithium ion and nickel cadmium. Energy storage devices such as ultracapacitors and flywheels also are under development, but these tend to be expensive or have other disadvantages that so far have prevented their practical application.

Hybrid technology also features regenerative braking, under which kinetic energy from the wheels is recaptured and transformed into electrical energy when the vehicle is slowed. The captured electrical energy then can be used to power the vehicle. The regenerative feature of hybrid braking also reduces wear and tear on the friction braking system, thus decreasing its maintenance costs over a vehicle's lifetime.

Economics of Cars & Light Trucks

Using publicly available information on initial costs, fuel savings, and other parameters of HEV automobiles, their economics can be assessed. As a specific example, consider the Toyota Prius. The closest comparable conventionally powered model is the Toyota Echo Sedan. The Prius gets an estimated 48 mpg, the Echo 34 mpg (EPA, 2002). I make the following assumptions:

1. The car is driven 13,000 miles per year and lasts for 12 years
2. The lifetime cost of gasoline is $1.50 per gallon
3. The incremental cost of the Prius relative to the Echo is $3,000[1]
4. The batteries are replaced once, after 8 years, at a cost of $3,000
5. Prius brake wear is less, saving $50 per year.

Under these assumptions, at an 8 percent rate of interest,[2] the net present value (NPV) of savings from driving the Prius over its lifetime, relative to the comparable Echo, is –$2,983. In other words, the fuel savings and reduced brake wear are insufficient to overcome the initial incremental cost plus the one-time battery replacement.

Table 1 shows the effects of different assumptions; for example, that no battery replacement is necessary over the car's lifetime, that the vehicle goes 20,000 miles per year rather than 13,000, that the interest rate is 6 percent, or that the lifetime cost of fuel is $2 per gallon. The results vary with the

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[1] See footnotes at end of text.

assumptions but are always negative, even with no battery replacement. The basic finding is that for this type of vehicle, whose conventional counterpart already gets high gasoline mileage, HEV technology does not provide net monetary savings.[3]

Table 1
Lifetime Net Savings, Prius versus Echo

Assumptions	NPV ($)
Base case	–2,983
No battery replacement	–1,363
20,000 miles per year	–2,305
6 percent rate of interest	–3,061
$2 per gallon cost of gasoline	–2,563

The hybrid Dodge Ram truck is a different kind of vehicle. Given what Daimler-Chrysler has said so far, we can expect an initial incremental cost of $5000, a 15% gain in fuel economy (from 14 mpg to 16 mpg) and a 15 year life. I assume further that there will be one battery replacement in the 8th year costing $3000.

There is an additional feature, however. The Ram hybrid will be capable of providing power off of the vehicle. In other words, it will be a mobile power generator as well as a passenger and cargo vehicle. That feature may have value to building contractors and others who otherwise use standalone generators at remote sites.

Table 2 below shows the results of the net present value analysis.

Table 2
Net Savings, Dodge Ram Truck HEV versus Conventional Model

Assumptions	NPV ($)
Base case	–4,638
30 percent fuel efficiency gain	–3,442
No battery replacement	–3,017
10 percent rate of interest	–4,637
Generator worth $400 per year	407

The fuel and brake wear savings from a Dodge Ram truck do not come close to paying for the vehicle. Even doubling the fuel efficiency gain or assuming no battery replacement does not much improve the economics. Instead, the value of onboard power generation determines whether the vehicle pays for itself. Given the assumptions used in the base case, a flow of services worth $400 per year over 15 years implies a small positive NPV for this vehicle.

These analyses show that HEV technology applied to cars and light trucks is unlikely to save money for the owners. Of course, fuel cost in the United States is lower than elsewhere, and hybrid fuel economy might improve with time. I next look at breakeven values for these parameters.

Breakeven Analysis

Table 3 presents values various parameters would have to reach in order for hybrids to break even in an NPV sense. I include three—the lifetime cost of fuel, number of miles per year, and fuel efficiency gain—and apply the analysis to the two vehicles discussed above. Other than the parameter in question, base case assumptions are used.

Table 3
NPV Breakeven Values

	Per gallon cost ($)	Annual miles	Efficiency gain (%)
Prius	5.05	43,800	nm
Ram	5.97	51,700	108

Note: nm = not meaningful; the gain would have to be such as to make fuel almost irrelevant.

The results indicate that for the Toyota Prius, which already is highly fuel efficient, the cost of gasoline would have to be $5.05 per gallon or the car driven 43,800 miles annually to break even. This breakeven fuel cost is high even for Europe or Japan, and the mileage much higher than most people drive.

Ram breakeven values are similar to those for the Prius, except that it can reach breakeven at a smaller increment in fuel efficiency. However, as mentioned earlier, the economics of the Ram truck probably will depend more on the value its owners place on onboard power generating capacity than the fuel and maintenance it will save them.

Heavy Duty Trucks

Though a variety of applications of HEV technology seem appealing for medium and heavy duty trucks and buses, there are few on the market. Garbage trucks, delivery vans and buses incur frequent starts and stops and so appear to be potentially promising applications. United Parcel Service and Federal Express are experimenting with prototype delivery van models, but so far have not committed to large-scale purchases. New York City, on the other hand, has been running 10 hybrid buses and has agreed to purchase at least 325 more. It is well in front of other U.S. jurisdictions in so doing.

One reason may be the still-high cost of hybrid buses and large trucks. There is little published information available, but British Aerospace Engineering, which is producing the buses for New York City, has indicated the incremental charge for the hybrid is $100,000. Separately, General Motors has indicated the per vehicle incremental cost of a Class 8 (large) hybrid truck will be at least $70,000 for some years to come.[4] For present purposes, I assume a $70,000 incremental cost and one battery replacement after 8 years at $10,000.

To see how these costs compare with potential savings, I examine data for a class of large U.S. Postal Service trucks. In 2001, a Postal Service 1997 Mack Truck averaged 46,933 miles and got 5.2 miles per gallon. Assuming a 15-year life, an 8% rate of interest, annual brake maintenance savings of $654[5] and alternative fuel costs and fuel economy gains, the table below shows the potential savings from a hybrid version.

Table 4
NPV of Savings, Large Postal Truck, Hybrid v. Conventional

Assumptions	NPV ($)
Base case[a]	-$36,690
50 percent fuel efficiency gain	-$31,172
$2.00/gallon cost of fuel	-$25,654
6 percent rate of interest	-$32,348

[a] $1.50/gallon fuel cost, 40% efficiency gain

Depending on assumptions, the net savings range between -$25,000 and -$37,000. Commercial entities will require lower upfront and operating costs to purchase large hybrid trucks.

Social Benefits from Emission Reductions

Hybrids offer social value from air emission reductions, which occur because fewer gallons of fuel are combusted per mile traveled. Arguably, additional social benefits are gained from reducing dependence on oil imports, but this concept is controversial and difficult to quantify and, therefore, is not pursued here.

Several emissions contribute to the formation of smog in urban areas. These are primarily hydrocarbons (HCs), nitrogen oxides (NO_x), and carbon monoxide (CO). Other important emissions include particulates that are 10 microns in diameter or less (PM10), sulfur oxides (SO_x), and carbon dioxide (CO_2). Particulates are associated with various lung disorders, including asthma, sulfur dioxide (SO_2) with acid rain, and CO_2 with global climate change.

The U.S. Environmental Protection Agency (EPA) and Department of Energy have published emissions data for conventional automobiles and trucks. These data can be used to estimate the emissions from conventionally powered vehicles, and gains in fuel efficiency then used to roughly estimate the potential reduction from hybrids.[6] For present purposes, I assume a proportionate reduction in emissions from hybrid fuel use reduction.

To illustrate how much hybrids can reduce emissions and estimate a social value of such reductions, three different types of vehicles are analyzed: an automobile, a light duty truck, and a heavy duty truck. In each case, I calculate the reductions in the six emission categories described above. For these purposes, I assume that the hybrid auto and light truck travel 13,000 miles per year while the heavy duty truck travels 47,000 miles, and that all of the vehicles are 40 percent more fuel efficient than their conventionally powered counterparts. Table 5 shows lifetime emission reductions for each class of vehicle under these assumptions.

Table 5
Emission Reductions from Hybrid Vehicles
(tons/service life)

	Auto	LD truck	HD truck
HC	0.073	0.074	0.372
NO_x	0.059	0.060	1.153
CO	0.994	1.007	7.790
CO_2	15.854	21.800	225.600
PM	0.002	0.002	0.134
SO_x	0.002	0.003	0.040

Note: LD = light duty; HD = heavy duty

The social value of most of these reductions depends on what value a particular community puts on them and how much it costs to reduce them by other means. In large urban areas, reductions in hydrocarbons and NOx have high value and alternative means of reduction cost many thousands of dollars per ton. In more rural communities, however, the reductions have less value. Finally, since climate change is a worldwide problem, the value of reduced carbon dioxide emissions is independent of location.

The literature on valuing emissions contains a wide range of estimates for the compounds listed above. For present purposes, I use intermediate values (medians of values found in the literature) for each of the six emissions. These range from several thousands of dollars per ton for hydrocarbons, NOx and PM to $50 per ton of CO_2. Table 6 below takes present values of emission reductions for each vehicle type and adds it to the private values for the Prius, Dodge Ram and heavy duty truck shown above.

Table 6
Social Value of Three Types of Vehicles ($)

	Prius	Dodge Ram Truck	Postal Truck
NPV[a]	–2983	–4638	-36,690
Emission reduction value	959	1,068	8,005
Total	–2024	–3570	-28,685

[a]Under base case assumptions.

By these calculations, adding environmental improvement to owner NPV still does not give these hybrids positive social value. However, in some areas environmental improvement is very costly and these costs may rise further as standards are tightened. Thus, while most hybrid vehicles probably are not socially cost effective at this time, there may be exceptions and these may increase with time.[7]

Military Application

The economics of applying hybrid technology to military vehicles are different from those for civilian vehicles. The cost of fuel to the military has two components: the direct cost of purchase and the indirect cost associated with a logistics network set up for delivery wherever an engagement might occur. The direct cost is similar to what a civilian agency or private party would pay. There are economies of scale in military fuel purchase, but by and large its cost is not much different from that of others.

The indirect cost is much the larger portion. It covers the airplanes, ships, fuel trucks, portable pipelines, portable storage tanks and other equipment necessary to move fuel to a theater of operations and distribute it there. This cost also includes fuel logistics personnel at home and on the ground where operations are mounted, with accompanying ancillary services such as cooks, medical aides and chaplains.

Estimates of the cost of fuel to the military vary. A recent Defense Science Board study put the average cost of delivering fuel to the U.S. military at $11 per gallon in 2001 (Defense Science Board, 2001). That study cited an estimate done by the Army Research Laboratory of $13 per gallon, in peacetime and at home. Also, a recent report by the RAND Corporation proposes a range of $5 to $15 per gallon (Bartis and Clancy, 2000). Given these various estimates, I use a base case value of $10 per gallon.

Application to a Military Vehicle

The U.S. Army's principal light duty vehicle is the High Mobility Multipurpose Wheeled Vehicle (HMMWV, popularly known as the "Humvee"). There are about 120,000 of these vehicles, comprising over half of the Army's total number of trucks.

Analysis of the hybrid Humvee requires that certain assumptions be made about the vehicle's cost and other characteristics. According to recent articles in the military trade press (*National Defense*, 2002) the conventional Humvee costs between $57,000 and $68,000 and manufacturers estimate the hybrid version will cost 25 to 40 percent more. For present purposes, I estimate an incremental cost of $20,000.

For the base case, I assume the following:

1. The Humvee has a lifetime of 20 years, and its hybrid version generates up to 33 kW of power to offboard systems (replacing two portable 15 kW generators, at an estimated cost of $10,000 each).[8]
2. The fuel cost to the Army is $10 per gallon.
3. Batteries last for 3 years and have a replacement cost of $3,000.[9]
4. The fuel efficiency gain is 30 percent, the objective of the Army's Humvee program.
5. A conventionally powered Humvee gets 9 mpg[10] and is driven 3,500 miles annually, in peacetime or in the field.[11]
6. The interest rate with which to discount streams of benefits and costs is 6 percent, slightly above the present 20-year Treasury bond rate.

Table 7 below shows NPVs of hybrid technology applied to the Humvee under varying assumptions. In each case, one assumption is varied, as indicated in the table.

Table 7
NPV of Hybrid Humvee Relative to Conventionally Powered

Base Case	$15/ gallon	4-year battery replace-ment	$2,000/ battery replace-ment	50% efficiency gain	5,000 miles/ year	7% interest rate
$90	$5,237	$2,312	$3,491	$4,665	$4,502	$121

From Table 7, in the base case, with the upfront incremental costs offset by savings from two fewer generators, the fuel savings just cover the cost of battery replacement. In this case, the lifetime savings from a hybrid version of the Humvee exceed costs by just under $100 per vehicle.

The results are sensitive to the cost of fuel and to battery replacement cost and frequency. At an assumed $15 per gallon for fuel, the NPV of the Humvee hybrid is over $5,200 (whereas at $5 per gallon, it is -$5,056). Alternatively, if battery replacement frequency increases to 4 years the NPV is over $2,300, and if battery replacement costs only $2,000 it reaches almost $3,500.

If Humvee hybrid fuel economy could be increased by 50 percent rather than 30 percent or if the Humvee were driven 5,000 miles per year rather than 3,500, the NPV would be over $4,500. The Army has set 50% as a longer term sought-for economy gain (with 30% the program goal) while trucks are used more intensively if they engage in actual operations. Thus, higher NPVs plausibly could occur. Finally, an increase in the interest rate to 7 percent does not much change the basic result.

The success of a military HEV will depend greatly on the performance of its batteries. To assess the sensitivity of the results to this performance, I conduct a form of breakeven analysis.

Table 8
Humvee Breakeven Combinations of Battery Cost and Replacement Frequency ($10 per gallon cost of fuel)

Replacement Frequency-Years	Replacement Cost Battery
1	$897
2	$1959
3	$3026
4	$4456
5	$5976

Table 8 shows combinations of battery cost and frequency of replacement for the hybrid Humvee that just achieve breakeven. For example, if the replacement frequency is 3 years, then breakeven is achieved at a battery cost of about $3000. Similarly, if the replacement frequency can be extended to four years, NPV breakeven can be achieved at a battery cost of about $4500. And if some other battery technology, perhaps Nickel Metal Hydride, could extend battery life to 5 years, breakeven would be possible at a battery cost of as much as $6000 per replacement. Thus, the military should be willing to pay a premium to extend battery life, but that premium is only about $1000-1500 per year added.

Other Considerations

Hybrid vehicles have other, difficult-to-quantify advantages in military use, e.g., extended range of operation. These provide added reason to consider them. On the other hand, there are disadvantages such as having to dispose of spent batteries, which contain heavy metals and thus can cause environmental damage if left unattended. These considerations go beyond the scope of this paper.

Conclusions

Hybrid electric vehicles offer a proven technology that can reduce motor vehicle fuel use and accompanying emissions. Many vehicle manufacturers are offering these vehicles and they are selling in several countries.

My analysis suggests that buyers of hybrids are unlikely to secure sufficient fuel or maintenance savings to offset the incremental costs of these vehicles. This is so under a wide variety of assumptions regarding enhanced fuel efficiency, annual mileage, fuel cost, and battery replacement cost. The additional costs of a second motor, an energy storage system, and a propulsion control system tend to overwhelm the potential savings.

The analysis also shows that even if the value of emission reductions is factored in, hybrid vehicles generally do not pay for themselves. A possible exception occurs when a vehicle owner highly values onboard power generation. In this case, a hybrid vehicle may have positive economic value to its owner as well as to the community in which it is located.

Of course, people buy vehicles for reasons other than economic return. Some like being among the first to try out a new technology, and others want to reduce emissions and save fuel for their own sake. Tax and other incentives provide additional motivation. Also, communities with high costs of reducing emissions may look seriously at municipal hybrid buses, garbage trucks, and the like to meet federally mandated pollution reduction goals. Thus, I do not suggest there will be no market for hybrids in the United States or elsewhere but conclude that, given present and foreseeable costs of producing hybrid vehicles, the civilian market will be largely based on non-economic factors.

Given the much higher cost of fuel to the military than to civilians, the technology can yield savings in applications such as the Humvee. However, my analysis relies on several uncertain parameter values. More complete analysis of the implicit cost of fuel to the Armed Services and results from hybrid Humvee prototype testing should help resolve these uncertainties and provide a clearer picture of the extent to which the technology is cost effective. Although not enough is known to be confident of the outcome, the analysis suggests that if certain parameter values turn out favorably—such as initial hybrid vehicle cost, battery cost, and battery replacement frequency—the economics will be favorable as well.

Footnotes

[1] This is on the low side. With some of the less expensive Echo models, the difference is closer to $5,000.

[2] This is a rough estimate of the cost of financing a vehicle.

[3] I have also analyzed the economics of the Honda Civic and Ford Escape hybrids as compared to their conventionally powered counterparts. For the Civic, the hybrid is assumed to get 50 mpg, the conventional vehicle 33 mpg. Under base case assumptions, the NPV of savings is -$2225. For the Escape, the hybrid is assumed to get 35 mpg and the conventional vehicle 21 mpg. The economics are slightly better but the NPV of savings still is -$1445 in the base case.

[4] Presentation to the United State Postal Service, Washington DC, January 2002.

[5] Based on U.S. Postal Service data for electric vehicle brake repair costs.

[6] The estimates are rough because EPA standards for most emissions are expressed in terms of grams per mile. Less fuel per mile should result in fewer emissions, but automakers could invest less in hybrid emission controls, resulting in increased grams per gallon, so that grams per mile would not fall proportionately. CO_2 emissions, however, would fall directly with the decrease in fuel utilized.

[7] Various federal and state incentives for hybrids are an indication that they provide social value that exceeds private. The incentives include a federal tax deduction of $2000 and tax credits or deductions in a few states. They also include access to high occupancy vehicle lanes in other states. Such access provides time savings to vehicle owners which, over a vehicle's lifetime, are of considerable value.

[8] A Honda 12 kW portable generator sells for $8,640 (www.Honda.com). Scaling up to 15 kW yields a cost of around $10,300, which I round to $10,000. The actual savings may be greater than $20,000 because an incremental vehicle needed to tow standalone generators possibly can be dispensed with.

[9] The lifespan and cost of batteries depend on the type and the state of battery technology. Lead-acid batteries remain the cheapest, but they are relatively short-lived; Lithium Ion and NiMH last longer but are much more expensive. The hybrid Humvee test program presently is utilizing lead-acid batteries so I assume that is the battery of choice.

[10] Like other vehicles, a Humvee's mileage varies with its driving cycle. In tests using the Federal Urban Driving Standard, the Humvee averaged 9.1 mpg ("Technology Roadmap for the 21st Century Truck Program," p. 4–40, December 2000). I round this to 9.0 mpg.

[11] The U.S. Army has about 238,000 vehicles, which recently accumulated 823 million miles in a single year, an average of about 3,460 miles per vehicle, which I round to 3,500.

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