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Introduction

Motor vehicles are a core technology of our modern life and economy. But motor vehicles, motor fuels, and the road system unfortunately pollute our air, soil and water, depend on limited oil supplies and are implicated in warming the earth's climate.

In response, some car companies have introduced the biggest change in automotive technology since early in the last century. Hybrid electric vehicles (HEVs) reduce emissions and fuel use through increased fuel economy. So far, full-HEV technology has been used to reduce automotive fuel use by up to 40% and reduce emissions to meet California's (and thus, the nation's) most stringent air quality standards. The following study measures such benefits.

Americans are currently buying over 20,000 HEVs per month; one model, the Toyota Prius has reached sales volumes of over 100,000 units per year. However, total HEV sales are still small compared to annual sales of all vehicles and the total number of vehicles on the road. HEVs account for about 1.5% of the annual US market of 17 million new light-duty vehicles, and only 0.2% of the total US fleet of 230 million light-duty vehicles. The numbers of makes and models offered as HEVs are small, and sales are just getting started. To spread hybrid technologies across the entire market, and replace most vehicles on the road will take decades.

Still, HEVs are making an impact beyond their incipient number, primarily by being the first "green" cars on the market and setting a standard of achievement for high fuel economy and low emissions. HEV sales and their halo effect on Toyota and Honda have spurred a contest between automobile makers to supply the latest high-tech, clean, and green technologies. In the California market, hybrids account for 3% of total new light duty vehicles sales, and hybrid sales growth outpaces that of conventional models (Automotive News, 2006). If this contest is noticed by more car and truck buyers, it may well transform the automotive market, accelerating the introduction of alternative fuels and other electric drive technologies such as plug-in HEVs and full electric vehicles to market.

In the following sections, we review the problems motor vehicles cause, then describe the varieties of hybrid technologies. Then we analyze what difference HEVs are making right now and can make in the future for our air, water, security, and climate.[1]

[1] We note HEVs do little or nothing to solve the consumption and fragmentation of ecosystems caused by the road network.

Car problems

Pollution from motor vehicles

Crude oil, gasoline, and diesel fuel are poisons in their own right. Despite a century of experience building and operating production, refining, and distribution facilities, fuels spill out of ships, pipelines, storage tanks, refineries, fuel stations, and motor vehicles into waterways, onto the land, and evaporate into the air. In addition, the operation of production, refining, and distribution systems require energy that results in pollution, sometimes called "upstream" emissions.

Cars and trucks powered by internal combustion engines burn gasoline or diesel, creating new poisonous compounds that are pumped into the air including carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons (now classified as volatile organic compounds, or VOCs), and particulates. These compounds are themselves toxic. Further, NOx and VOCs combine with sunlight to create a complex chemical stew whose primary component is an even more insidious pollutant—ground-level ozone. Ground-level ozone is a powerful respiratory irritant that causes breathing problems, worsens respiratory illnesses like asthma, and even contribute to premature death in some vulnerable members of the population.

Ground level ozone and other pollutants concentrate in (and downwind of) populated cities, and especially cities such as Los Angeles where local climate and topography combine with high levels of emissions to create substantial amounts of ground-level ozone. Los Angeles is infamous for the nation's worst ground-level ozone problem. Less well known is how widespread this problem is in California. According to the American Lung Association, in 2005 the second, third, and fourth worst cities for ozone pollution in the nation were also in California: Bakersfield, Fresno-Madera, and Visalia-Porterville. In addition, Merced, Sacramento, and Hanford were also on this worst ten list. The air of the eastern San Joaquin Valley, southern Sacramento Valley, and Sierra Nevada foothills is frequently unhealthy for humans, plants, and animals.

Through careful science, advanced engineering, and stiff regulations, emissions from new vehicles have been substantially reduced. While the pollution from any one new motor vehicle is slight, together the more than 300 million vehicles in the USA generate a significant problem. Air pollution remains a problem in many regions (central California in particular) because of population growth and because many drivers are traveling longer distances in their cars. In addition, making motor vehicles less polluting doesn't solve the other problems that come with a transportation system that is 97% dependent on fuels derived from crude oil.

The oil security problem

While per-mile vehicle emissions of criteria pollutants have been reduced, oil consumption continues to create problems throughout the world. Oil is a finite resource, and many have predicted that we are reaching what is called *peak oil*, the point at which the rate of extraction of oil from all developable oil resources and reserves begins to slow. Once we reach peak oil, we will become increasingly reliant on supplies that are difficult to extract and process. These supplies include oil in deep-sea deposits, heavy oils, and tar sands. Ominously, because more energy is required to locate, extract, and refine these supplies, the production process is more expensive and generally more polluting than that of conventional petroleum.

Compounding the peak oil problem is the rapid growth of nations like India and China, which have small domestic oil resources, large populations, and fast-growing economies. Global demand for gasoline and diesel are increasing, while cheap sources of oil are disappearing. Unfortunately, the profit from high-priced oil has not created healthy oil-producer economies. The biggest oil producers in the world (Saudi Arabia, Iran, Russia, Venezuela, and Nigeria) are rife with corruption often fueled by oil revenues.

Climate change

The combustion of gasoline and diesel generates greenhouse gases, primarily carbon dioxide (CO_2). CO_2 levels, due to a broad set of human industrial and agricultural activities, have increased sharply in the last 200 years. Primarily it is the combustion of coal, oil, and other carbon-based energy sources that has lead to this increase. But CO_2 is an unavoidable output of burning a carbon-containing fuel, i.e., all hydrocarbons such as coal, oil, and natural gas, in an oxygen atmosphere. Unlike other emissions, CO_2 cannot be easily eliminated from vehicle exhaust. The only way to reduce CO_2 in most cases is to stop or greatly reduce the combustion of gasoline and diesel, that is, switch to non-carbon-based fuels or greatly increase the efficiency with which you use the energy from such combustion processes, or drive less.

Non-sustainable growth of automobility

Continued growth of demand for motor vehicle use and ownership in the US, Europe, Japan, and developing economies compounds all the problems discussed above. There are no nations in the world who are deciding to forgo automobility. And although the numbers of vehicles and gallons of gasoline used per person in places like Eastern Europe, China and India are still small in comparison to the US, Europe or developed Asia, the rate of growth of automobility in some of these nations is high. China, for example, had just 4 million automobiles in 1996, but is expected to have as many as 43 million on its roads by 2020 (National Academies of Science, 2003). As motor vehicles become more popular across the globe, even major advancements in fuel efficiency and pollution control may not be enough to stem increases in oil use and emissions. However, in some countries with rapid automobile adoption, HEVs can become a higher percentage of the vehicle fleet much faster than in US, Europe, and Japan, all of which already have large motor vehicle fleets.

What is hybrid technology?

Hybridization is a range of vehicle drive train strategies that combine multiple energy systems to better meet multiple (and sometimes conflicting) goals, such as increasing fuel efficiency or improving acceleration times. Current HEVs combine internal combustion engines running on gasoline or diesel with electric motors that use electricity stored in batteries. The purpose of these hybrid designs is to increase efficiency. This is done primarily in two ways. First, by recapturing some of the energy that is normally lost in braking or coasting through regenerative braking. Second, by downsizing the combustion engine and running it near its optimal efficiency range and obtaining additional power from an electric motor. Future designs may also use biofuels such as ethanol in the combustion engine, or may replace the internal combustion engine with a cleaner, more efficient fuel cell power plant and larger electric motor.

Hybrid technology is not new to transportation. Most diesel locomotives use combustion engines to charge large batteries, which then supply electricity to electric motors that actually propel the train. In a limited way, you could call all conventional vehicles HEVs, because they use alternators and batteries to generate and store electricity for starting the vehicle and operating accessories like the radio, lights, and cooling fans.

But modern hybrid technologies for light-duty vehicles take things further, going as far as shutting down the combustion engine when it is not needed and using electricity to actually propel the vehicle down the road. The main goal of this modern hybrid technology so far has been attaining higher fuel economy (miles per gallon), but the increased efficiency (more energy out of the drive-shaft per unit energy into the system) can also be used to boost power, or to drive a heavier or less aerodynamic vehicle while holding fuel economy constant.

Electric motor

Depending on their design, hybrid electric vehicles employ electric motors solely to assist the gasoline motor during brief periods of high demand, such as acceleration, or larger electric motors to power the vehicle by itself. Electric motors are mistakenly thought by many drivers to be weaker than gasoline engines. This is not true—remember the diesel electric locomotive.

One big difference between combustion engines and electric motors is that combustion engines operate most powerfully at fairly high speeds of rotation (depending on design) in a narrow range measured in the thousands of revolutions per minute (rpm). In contrast, electric engines provide maximum torque (force) from zero rpm. This is why you can move a heavy train from dead standstill with electric motors. In contrast, a conventional vehicle, with only a combustion engine, must first start the engine with a small electric motor (remember, the starter motor is an electric motor powered by the vehicle’s 12-volt battery), then rev the engine to higher rpm, then engage the fast moving engine in a very low gear to move the vehicle.

In hybrid vehicle designs, designers try to match the best of both worlds; they use the electric portion of the system to keep the gasoline engine spinning near its optimal speed to maximize efficiency and lower emissions. One of the critical choices in hybrid vehicle designs is the relative size of gasoline engine and electric motor. Using larger electric motors allows you to downsize the gasoline engine, but will require more electricity, thus requiring a larger, heavier, and more expensive battery.

Blending power

Toyota's Hybrid Synergy Drive™ uses a special transmission to combine power from both the electric motor and gasoline engine under the direction of a pre-programmed computer. Computers are a big part of what makes HEVs work so well. The computer is always evaluating the amount of charge in the battery, sensing the power needs for driving, and then making choices for optimal power, efficiency, and emissions. The computer controls when the gasoline engine and electric motor are turned on and off, and when the batteries are charged or depleted.

Most designs use both the gas engine and electric motor together at periods of highest energy need, such as a hard acceleration on a freeway onramp. During times of lesser power needs, such as lower speed cruising, the vehicle relies on only the engine or motor, depending on the state of the battery and the size of the electric motor and battery. If an HEV has a big electric motor and if the battery is fully charged, the electric motor can be used exclusively until the computer decides the battery needs to be charged again. The Toyota Prius, for example, has a top speed of about 34 miles per hour using the electric motor alone; at higher speeds, the gasoline engine does much of the work. Also, the battery in the Prius only allows for about one mile of electric-only range before it begins to recharge the battery.

Regenerative braking and coasting

One of the big benefits of HEVs is the ability to recapture energy normally lost in braking and coasting downhill. In a conventional vehicle, when you apply the brakes, you mechanically squeeze two parts together—pads on a disk for disk brakes and shoes on a drum for drum brakes—to create friction to slow the car. The energy of the vehicle is converted into heat, which the brakes then dissipate into the air. HEVs are able to use their electric motors to brake the car by running using the motors to generate electricity that can be stored during braking or coasting downhill. This generation exerts drag like brakes. Hybrid vehicles still have conventional brakes, but the computer uses them only when the battery is full or braking action is strongest. Because they are used less often, the mechanical brakes on a HEV tend to last longer.

Hybrid types

There are many ways to design HEVs. The market right now has three main architectures currently referred to as "light," "mild," and "full". General Motors' Silverado truck is a "light" hybrid. It replaces the normal flywheel of a gasoline engine with an "integrated starter generator" that shuts the engine off whenever the vehicle is not moving, improving fuel economy by a few percent. The Honda Civic Hybrid is a "mild" hybrid that uses regenerative braking and some electric motor assist during acceleration, but does not allow driving with the electric motor only. The Toyota Prius is a "full" hybrid which means the battery and motor are large enough to allow some "electric-only" driving, however this design is not sufficient for all acceleration needs, such as an on ramp to the freeway.

Within these three main HEVs architectures there are many possible variants to serve different goals. Even now "performance" HEVs, like the Honda Accord, focus as much on increasing the power of the car instead of its fuel economy. The early mild hybrid designs from Honda and full hybrid designs from Toyota focused more on fuel economy and low emissions. The Toyota Highlander Hybrid represents a blend of performance and fuel economy, offering improvements in both over the non-hybrid versions.

<u>Costs of hybrid vehicles</u>

Depending on whether a car company is a making light, mild, or full hybrid, the cost of the added components can vary from several hundred to a few thousand dollars. The actual costs are company secrets, but the price of hybrid cars and trucks are between $1,200 and $7,000 more than conventional versions of the same vehicles, according to Edmunds.com.

Many analysts have questioned whether consumers would be willing to pay the extra cost unless they got it back in fuel cost savings in a few years. The high price of gas and generous tax credits makes the savings possible, but research at ITS Davis shows that HEV buyers are not all that calculating, and most buy HEVs for reasons other than economics: for example, to make an environmental contribution or to own the latest, most advanced technology.

<u>What about diesel, bio-fuels and other alternative fuels?</u>

In theory, HEV technologies can make all vehicles use less fuel than a normal combustion design, whether they burn gasoline, diesel, bio-fuels, natural gas, or hydrogen. Hybrid vehicle designs improve the environmental performance of all of these vehicles and stretch their potential to meet demand in the future. However, no HEVs are sold yet using one of these other fuels.

As part of their approach to the threat of climate change, Europeans have shifted almost half of their motor vehicle gasoline consumption to more efficient diesel engines. While diesel is still made from crude oil, it has higher energy content per gallon and is burned more efficiently in diesel engines, yielding higher fuel economy and lower CO_2 emissions per mile. However, while modern diesel engines are much cleaner than their predecessors, they still have higher levels of NOx emissions. In addition, Europe has reached the limits of how high a percentage of crude oil can be refined into diesel. Hybrid technology might appear in the current marketplace to be in competition with diesel, but in reality they can be complimentary technologies. Some manufacturers, including Peugeot-Citröen, have developed diesel-hybrid prototypes that attained 70 MPG (Green Car Congress, 2006). Hopefully, other manufacturers will also apply hybrid technologies to diesel vehicles, further increasing diesel engine efficiency and reducing NOx emissions.

The high price of gasoline has brought ethanol to the news and, to some extent, to the marketplace. Biofuels made from sustainable crops can be CO_2 neutral—the growing plants absorbing about as much CO_2 as the system to grow crops, produce fuels, and power vehicles produces—as long as fossil fuels are not used for fertilizer, to harvest feedstocks or convert feedstocks to biofuels. But there are questions about how much land is required and whether this is an efficient strategy. There are a few success stories; Brazil has replaced much of its gasoline with ethanol. But while Brazil and the US are blessed with abundant farmland, nations like India and China have lower percentages of arable land and an ongoing struggle to feed their people. In addition, since ethanol has lower energy content per gallon than gasoline, cars using ethanol attain fuel economy that is as much as 20% lower than gasoline. Because of these issues, the future of biofuels may be primarily in blends with gasoline or diesel used in a flex-fueled vehicle. Currently, no flex-fuel HEVs exist, although Ford has demonstrated a prototype Escape hybrid with flex-fuel capability.

Hydrogen combustion and hydrogen fuel cell electric vehicles are promising, but hydrogen production is small right now compared to US automotive energy use, and it will be a significant challenge to provide cheap hydrogen for many years. Also, much of the current hydrogen is made from hydrocarbon feedstocks such as natural gas. Other hydrogen sources include coal, which while abundant will require complex strategies to sequester the large amounts of CO_2 that result during hydrogen production from coal. Finally, a whole new infrastructure of hydrogen distribution and production must be developed before hydrogen vehicles can be widely used.

Electric vehicles and HEVs

Electric vehicles run on electricity, and thus generate no tailpipe pollution. However, these vehicles use energy from the electric grid, and the generation of this energy results in pollution from power plants. Therefore, electric vehicles are only as clean as the power that is put into them. Because the emissions of power plants vary greatly by region, the potential benefits and costs of electric vehicles are not the same everywhere. For example, coal is a major component of the electricity mix nationally, but in California and much of the West very little electricity is produced using coal. Thus, electric vehicles that use Western electricity are relatively clean and produce low greenhouse gas emissions.

Electric vehicles depend on batteries to store energy. Currently batteries that are able to power a conventional size car or truck at freeway speeds remain expensive. In addition, battery life—the number of times the battery can be discharged and charged while still providing full energy storage and power—remains too short for one battery to last the life of the vehicle. Also, car and truck owners must have a practical place to recharge their vehicle, like a driveway, garage, or parking spot at work. Most importantly for the market, battery powered vehicles have a limited driving range before they must be recharged. While conventional vehicles typically can travel more than 250 miles without refueling, electric vehicles often have a range of less than 100 miles. Adding more battery capacity can increase range, but this additional storage is expensive. Because of these issues, major automobile companies have been reluctant to produce electric vehicles without improvements in battery costs and performance.

HEVs pave the way for electric vehicles in the future in several ways. First, HEVs familiarize consumers with the performance characteristics of electric vehicles. Remember that high torque from zero rpm? That provides quick acceleration from a stop that internal combustion engines have difficulty matching. Second, producing hybrid vehicles builds engineering competence and spurs investment in critical areas such as batteries, electric motors, and other electric drive components.

Plug-in hybrids

Most importantly, it is only a short step from full HEVs to what are called "plug-in hybrid electrics." Plug-in HEVs have larger batteries than other full HEVs but smaller batteries than EVs. Like EVs, they can be plugged into the electric grid to recharge their batteries. Engineers at ITS-Davis have designed several PHEV prototypes, as have manufacturers including Daimler-Chrysler. Also, some manufacturers have announced plans to develop such vehicles; Nissan said they would have a design by 2010.

Meanwhile, a few maverick engineers have converted Toyota Priuses into PHEVs by substituting a much bigger lithium-ion battery for the 1.3 kWh nickel metal hydride battery that comes in the new Prius and by hacking into the computer of the Prius to get it to use the larger battery in a new way. These converted Priuses can drive as far as 100 miles on the combined energy of one gallon of gas and electricity stored in the lithium battery. Because most Americans seldom drive 100 miles per day, this means many drivers could reduce their gasoline consumption considerably by supplementing with cheaper electricity. If you drive only a few miles per day, say under 20, you might be able to drive completely on electricity many days.

Additionally, if you were in a situation where you parked your car at night to recharge the battery, you could take advantage of lower cost nighttime electricity. Because most electricity demand happens in daytime, power companies, like PG&E will also benefit from PHEV owners charging at night, using what is now excess capacity. The cost to drivers of this nighttime electricity will be low, perhaps less than half the cost of gasoline.

In California, electricity production is generally clean, meaning plugging into the grid saves on greenhouse emissions as well as local emissions. Other parts of the country can be dirty, because they use aging coal plants. Hopefully, by the time PHEV and BEVs are significant in the sales column, electricity production will have become cleaner and many

PHEV owners can use wind or solar derived electricity to charge their batteries. Some EV and PHEV owners have already put photovoltaic cells on their home, business or garage roofs to charge their vehicles with solar electricity.

Benefits of Hybrids

The HEV market now and in 2010

In the first three quarters of 2006, hybrids accounted for 1.5% of the US new automobile market and 3.1% of the California new vehicle market[2]. However, hybrids are only available in a few models and brands; we will not know the real market potential until hybrids are available in all vehicle types such as pick-up trucks, minivans, and from all major brands. Some forecasters are bullish, projecting up to 85% market penetration by 2030 (Raskin and Shah, 2006)[3], and others are more cautious, expecting hybrids to stall after a strong early market because they are too expensive.

How we did this study

Hybrid vehicle sales volumes from 1999-2006 were compiled using monthly nameplate sales data from *Automotive News* and CNW Market Research. For some time periods, these data sources did not separate certain hybrid sales (such as the Ford Escape Hybrid) from conventional model sales; in these cases, manufacturer data was consulted to determine the portion of a nameplate's sales that resulted from the hybrid version. Hybrid models that were marketed primarily to fleet buyers (such as the Chevrolet Silverado Hybrid) were excluded from this analysis, as were all medium-duty and heavy-duty hybrid vehicles.

Once sales data were collected, monthly nameplate sales figures were aggregated into annual totals for each model, and annual totals then were combined into an eight-year sales total for each model. A grand total of 573,681 hybrid vehicles were sold in the United States from December 1999 through August 2006. Eight-year sales totals for all models are shown in Table 1.

[2] Based on sales data published by Automotive News, October 2006.
[3] J.D. Power has been more cautious, saying that continued growth of the hybrid market will depend on cost cutting of hybrids. Toyota has said several times that they intend to cut costs dramatically.

Hybrid Model	Eight-year Sales Total ('99-'06)
Honda Accord Hybrid	22,135
Honda Civic Hybrid	108,630
Honda Insight	13,853
Toyota Camry Hybrid	17,386
Toyota Prius	298,229
Toyota Highlander Hybrid	41,463
Lexus 400h	34,601
Lexus GS 450h	349
Saturn Vue	0
Ford Escape Hybrid	34,635
Mercury Mariner Hybrid	2,400
GRAND TOTAL	**573,681**

But we did not use the eight-year sales totals; we based the mix of hybrids and year-to-date 2006 sales. Future hybrid sales volumes were obtained from a review of forecasts conducted by hybridcars.com (Berman, 2006). The review analyzed 21 reports that forecasted HEV sales from 2004 to 2015; report authors included industry analysts such as JD Power as well as publicly-funded researchers, such as Oak Ridge National Laboratory. While the hybridcars.com review does not assess the assumptions implicit in each of the 21 volume estimates, it does provide a useful comparison of these estimates, and constructs its own trend line forecast using the 21 volume predictions. Our study uses the trend line forecast (rather than one particular provider's data) as a forecast for the future HEV market. This trend line places hybrid sales at roughly 800,000 units in 2010, and 2 million units in 2015. Annual sales of all light duty vehicles (cars and small trucks) in the US average around 17 million per year.

Calculating the benefits of hybrids

In this section, we estimate how much the entire fleet of hybrid vehicles will reduce oil use and pollution in the year 2010. Then we speculate on how much more could be saved if there were a larger variety and number of hybrids.

The basic method is straightforward. The percentage reduction in oil use or pollution is equal to the average percentage reduction per mile of travel multiplied by hybrid vehicles' percentage share of total travel by light-duty vehicles (LDVs). It turns out that while the per-mile reductions can be significant – in the range of 30% or more – the hybrid share of total LDV travel in 2010 will be very small – on the order of 1% – and that as a result the total reductions in pollution and oil use will be much less than 1%.

To estimate the per-mile changes in fuel use and emissions HC, CO, and NO_X with hybrid vehicles, we used a computer model called ADVISOR to simulate the fuel economy and emissions of the conventional gasoline version of each hybrid. Where there wasn't an exact gasoline version, as in the case of the Toyota Prius, we used the closest counterpart (the Toyota Corolla in the case of the Prius).

The ADVISOR simulations indicate that hybrid vehicles reduce fuel use by 20-40% compared with their conventional counterparts, with an average reduction of 35%. (We based our average on the sales share of each hybrid in the year 2006 to date.) On average, hybrids reduce lifecycle emissions of greenhouse-gases (GHGs) by about 30%, similar to the reduction in oil use.

How do these changes affect the fuel use and emissions of the whole LDV fleet? To answer this question, we have to estimate how big of a share hybrids have of the total LDV travel. To do this, we used projections of national sales of hybrids from 2006 to 2010, discussed above. We assumed that the mix of hybrid models remains what it has been in this year (2006). We then estimated how much all of these hybrids (sold from 2006 to 2010) traveled in the year 2010, and compared this total with grand total travel by all LDVs in the year 2010.

Results are summarized in the following table. Note that the primary results were estimated for hybrids nationally. Because the sales share of hybrids is higher in California than it is nationally, the VMT share of hybrids will be higher too – perhaps in the range of 2 to 3%. This means that all of the estimated benefits estimated above may be about twice as high in California.

Hybrid vehicles are estimated to account for 1.2% of all LDV travel in the U. S. in the year 2010. This means the impact of hybrids on total oil use by the LDV fleet in 2010 is equal to 35% (the percentage reduction per mile) multiplied by 1.2% (the hybrid percentage of total LDV miles), or 0.4%.

Table 2: Estimated percent changes

	2010, United States	2010, California
VMT	-1.2	-2.4
Oil consumption	-0.4	-0.8
GHG	-0.4	-0.8

Note, though, that the reduction in oil use is a larger fraction – 1.2% – of projected imports of oil from the Persian Gulf in the year 2010.

How many gallons of gasoline and tonnes of CO_2 does that save?

So in 2010, hybrids will save 0.4% of total oil and GHGs; that equals 498 million gallons of gas per year. If that were in tanker ships (SuezMax tankers carry 1 million barrels, that is 42 million gallons), that is about 10 large tanker ships fewer per year. The estimated reduction of CO_2 is 5.1 million metric tonnes.

The California Air Resources Board offers some additional calculations of greenhouse gas equivalents for California. They note that removing one million metric tonnes of CO_2 is equivalent to taking 179,000 passenger vehicles off the road in California for a year and is equal to 114 million gallons of gasoline. [4]

What if there were more hybrids in 2010, how much gasoline and CO_2 would that save?

Hybrids are expected to remain a small percentage of sales even in 2010, and because vehicles last so long nowadays, are even a smaller percentage of the over all fleet of vehicles in the US.

But what if hybrids accounted for more than 1.2% of vehicle miles traveled (34,545 million miles) in 2010? Suppose hybrids accounted for 10% of VMT (289,960 million miles) in 2010. First, we would have to change some assumptions; we would have to assume that hybrids were available in all makes and models. 289,960 million miles of VMT by the average vehicle mix would equal 14,300 million gallons of gasoline per year. (EIA Supplemental Table 33). With the calculated 35% overall reduction in fuel use per mile in this study, (0.35 times 14,300 million gallons) hybrids would then save just over 5,000 million gallons per year. That is 119 large SuezMax tanker ships fewer per year – almost one every three days. If instead of 10%, hybrids accounted for 20% of VMT, fuel savings would double to 10,000 million gallons per year.

Total CO_2 from cars and small trucks in 2010 is expected to be 1,273 million metric tons. Under our initial assumptions about the size of the HEV fleet, HEVs reduce GHG emissions by 5.1 million metric tons. If hybrids replaced an average mix of vehicle types in the 2010 US fleet of vehicles and accounted for 10% of VMT in 2010, the reduction in GHG would be 42.4 million metric tons, or at sea level on a sunny spring day in California, 5.5 cubic miles of CO_2.

Since each car creates about 8 tons per year of CO_2 (USDOE, 2007), thus reducing CO_2 by 42 million tons would be similar removing 5 million vehicles from the road. If it takes one mature tree to offset a ton of CO_2, reducing CO_2 by 42 million tons is like planting and growing to maturity 42 million trees[5].

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[4] For additional comparisons, check this fact sheet from the California Air Resources Board: http://www.arb.ca.gov/cc/factsheets/1mmtconversion.pdf

[5] This is a high number for tree CO2 sequestration. The reported offsets of CO_2 by planting and growing a tree to maturity can vary greatly as to where (tropics or northern climates) and what sort of tree over what

How soon can hybrids gain big market shares?

Projections of the market share for hybrids are extremely uncertain and varied right now, some bullish, some cautious. Toyota considers hybrid technology to be a basic strategy for all its drive trains in the future. Other manufactures are less enthusiastic, especially since Toyota appears to have a lead in the market.

Car and light duty truck (pick-ups, SUVs and minivans) sales are around 17 million per year in the US. Berman (2006) puts the HEV market at about 800,000 units in 2010 and 2 million units in 2015, creeping up to 20% of the market.

Ultimately, the number of hybrids bought each year is limited by their availability across all makes and models of vehicles. Currently hybrids are available in 10 models from 3 manufacturers. Hopefully that number will double in the next couple of years with new manufactures and new types of vehicles such as pick-ups and minivans. Toyota's success is forcing many other manufactures to follow.

How soon can hybrids replace 10, 50 or 80% of the vehicle miles traveled in the US?

There were 230 million cars and light duty trucks in the US in 2006 (Davis, 2006). It takes at least 10 to 15 years to replace most of the vehicles in that fleet with newer vehicles. However, new vehicles are driven many more miles than older vehicles. On average, a new light truck is driven 17,000 to 19,000 miles per year. Trucks older than 15 years are driven 9,000 miles per year. New cars are driven an average of 15,000 miles per year. By the time they are 15 years old, cars are driven 5,000 miles per year.

Here we make educated guesses to envision one possible future for hybrids to replace VMT of the U.S. Fleet. If we imagine an admittedly bullish scenario in which hybrids reach 50% of annual sales, VMT by hybrids could approach 25%. If hybrids become 80% of the market by 2030, then we imagine hybrids might account for 50 to 60% of total VMT by cars and trucks. Such a scenario could significantly offset petroleum imports, reduce CO_2 emissions, and make alternatives like biofuels more feasible by reducing the total demand for transport fuel in the United States.

Alternative assumptions that would affect findings

The prior analysis assumes that HEV drivers use their cars like anyone else. Some research suggests that these assumptions might underestimate the impact of HEVs on fuel savings and emissions.

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period of time. Many environmental organizations quote the 1 ton per tree, figure. Carbonneutral.com offers a 5 trees per ton figure, and a study of North American hardwood and pine forests results in a range of figures from 3 to 15 lbs per year. If we assume a life of 100 years, the higher number would be 1,500 lbs. (Forests and Global Change, Vol. 2, Forest Management Opportunities for Mitigation of Carbon Emissions. Neil Sampson and Dwight Hair, Washington, 1996.). Not being forest sequestration experts, we give trees the benefit of the doubt and use the 1 ton per tree figure.

The assumption in our analysis above, and indeed in probably all other analyses of HEV fuel use is that the vehicle that would have been purchased or used had there been no hybrid on the market is something close to the size and performance of the HEV. For example, the closest vehicle to a Honda Civic Hybrid is presumed to be the non-hybrid Honda Civic. And the closest replacement to a first generation Toyota Prius is presumed to be a Toyota Corolla. However, when we interview buyers of hybrid vehicles, we rarely find these presumptive choices were made. For example, among buyers of the first generation Toyota Prius, none we interviewed had replaced a Corolla or considered one when they bought their Prius. In fact, many had owned much larger and luxurious vehicles, and the Prius was a purposeful attempt to reduce their use of gasoline and production of emissions. In the absence of a Prius, most would have bought something like their previous vehicle.

A second assumption in the analysis is that HEV buyers use their new HEVs just as average new buyers of any vehicle. On average, new cars and trucks are driven more than older vehicles. We have included this average effect in our model. However, HEV drivers may drive their HEVs even more than other new car drivers. Anecdotal evidence from research at ITS-Davis suggests that multi-vehicle households switch more of their driving to the HEV than they would with another vehicle. This may be because of the dramatic improvement in fuel economy over their previous vehicle. The effect may be greater when gasoline prices are high.

<u>Factors that might reduce hybrid vehicles impact on oil consumption and GHG emissions</u>

There are technologies in the market that could reduce hybrid vehicle impacts. These technologies compete with hybrids in the market, e.g., engines that turn off and on at stoplights. Additionally, automotive designers could use hybrid technology to increase power of vehicles instead of fuel economy. This has happened with other technologies, e.g., fuel injection.

Additional benefits of HEVs not quantified in this analysis

HEVs provide a broad set of benefits to consumers including better fuel economy, quiet operation, low to zero emissions in sensitive locations such as schools and enclosed parking areas, better fuel economy instrumentation, longer lasting and better braking designs.

HEVs get consumers excited in a way that previous technology, e.g., catalytic converters, oxygen sensors, displacement on demand did not: this is important. Consumers are not volunteering to pay more for partial zero emissions vehicles (PZEV), even though these vehicles yield real environmental benefits. Consumers are apparently willing to pay more for a vehicle that is a hybrid.

HEVs have initiated a clean market, set new standards for low emissions and fuel economy. By offering consumers the first green vehicle, manufacturers created the first "feedback loop" for the value of clean and efficient vehicles. Like the market for safety in vehicles, manufacturers were initially cautious to put much safety in their vehicles, believing that consumers would be unwilling to pay for safety such as airbags and ABS brakes, Now, crash ratings and safety equipment are top concerns of many buyers and a normal part of both marketing and the ongoing improvement of vehicles. The same thing is now happening with green vehicles. Eventually, the emissions and efficiency of vehicles could become a normal aspect of car marketing. Now many automotive manufacturers are convinced that car buyers are interested in green vehicles and willing to pay for the increased costs.

Summary

To summarize the finding of this paper, hybrid electric vehicles are a broad set of technologies aimed at combining the attributes of gasoline combustion vehicles with electric vehicles. A number of hybrid vehicle designs can increase the fuel economy and emissions of conventional vehicles. While the cost of such vehicles is higher than conventional internal combustion only vehicles, buyers have been enthusiastic about these designs and the market has developed for HEVs faster than many anticipated.

We conduct a detailed analysis of potential HEV impacts on US oil consumption and CO_2 emissions for 2010, first using an average projection of sales based on current offerings. Secondly, we analyze a hypothetical scenario in which a broad market mix of HEVs account for 10% of the vehicle miles traveled (VMT) in 2010. Those results are summarized in Table 3.

Table 3: Summary of HEV Impacts

	HEV % of VMT	Oil reduction	CO_2 reduction
Projected HEVs in 2010	1.2%	498 million gal	5.1 million metric tonnes
Broad mix of HEVs accounting for 10% of VMT in 2010	10%	5,000 million gallons ≈ 119 SuezMax size oil tankers	42.4 million metric tonnes ≈ 5.5 cubic miles of CO_2 gas ≈ 42 million mature trees

This report shows that it will take decades for hybrids to replace a high percentage of VMT and therefore to have large effects on oil consumption and CO_2 emissions. But, even if HEVs account for only one to 10% of light-duty vehicle VMT (as currently projected), they loosen the stranglehold of petroleum on US consumers. Moreover, HEVs have had an energizing effect on vehicle technology and markets that extends well beyond their current numbers. HEVs have raised the bar on fuel economy and emissions.

They create competition that will improve conventional gasoline and diesel vehicles, as well as encouraging improvements in electric drive trains and battery technologies for plug-in hybrids, fuel cell hybrids, and full battery electric vehicles.

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