AllianceBernstein

The Emergence of Hybrid Vehicles

Ending Oil's Stranglehold on Transportation and the Economy

Research Conclusions

- Hybrid vehicles will significantly reduce transportation-related oil demand.
- Hybrid power will make cars faster, cleaner and safer, as well as more fuel efficient.
- The next step for hybrid vehicles will be plug-ins.
- With plug-ins, *electricity* rather than *oil* will be the primary energy source for transportation.
- Technology and utility companies will gain most; oil-related firms will lose most; leadership in hybrids will be key to success in the auto industry.

Research on Strategic Change
JUNE 2006

About the Authors

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About Research on Strategic Change

Most fundamental research analysts cover an industry and the companies within it. AllianceBernstein's Research on Strategic Change group seeks to find investable ideas that stem from economic or technological changes powerful enough to profoundly influence corporate performance across multiple industries. **The Emergence of Hybrid Vehicles: Ending Oil's Stranglehold on Transportation and the Economy** is the group's fourth report. Prior publications include **Broadband: The Revolution Underway,** 2004; **China: Is the World Really Prepared?,** 2004; and **The New Industrial Revolution: De-verticalization on a Global Scale,** 2005.

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Executive Summary

The world is on the cusp of a major transition to hybrid-power vehicles, which use highly efficient electric motors to boost the fuel efficiency of vehicles powered by internal combustion engines. This is a game-changing technology that promises to increase energy efficiency substantially, make a broad range of fuels available for powering vehicles, and meaningfully reduce demand for oil from the transportation sector.

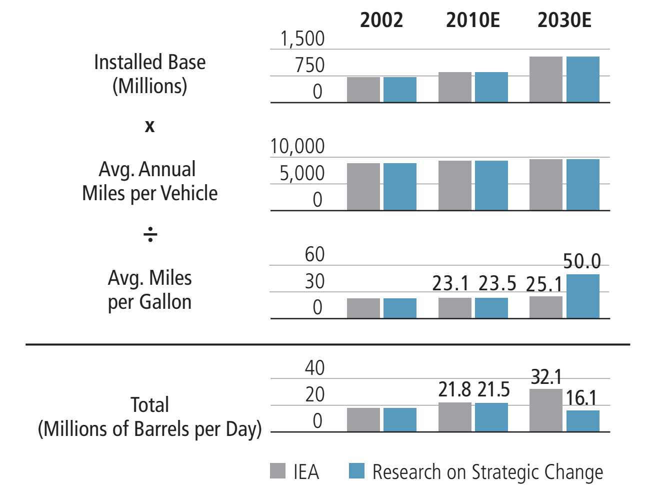
Over the last 30 years, many industries have either dramatically improved their energy efficiency or shifted to alternative fuel sources; transportation has been an exception. As a result, the composition of oil consumption has shifted dramatically toward transportation, from 33% of total oil demand in 1971 to about 50% today. Light-duty vehicles (passenger cars, sport-utility vehicles, minivans and light trucks) account for more than 45% of the transport sector's total oil consumption. With the emergence of hybrid vehicles, the end of rapid demand growth from this segment is in sight**.**

Improvements in vehicle fuel efficiency, owing to hybrid power trains, will eventually more than offset continued growth in the global stock of vehicles (*Display*), despite surging vehicle ownership in the emerging world. Our estimates of improved fuel efficiency and rapid adoption of hybrid vehicles lead us to estimate that global oil demand from cars and other light-duty vehicles will first rise slightly, to 21.5 million barrels per day in 2010, and then *fall* to 16.1 million by 2030. Our forecast for 2030 is 50% lower than the International Energy Agency's. If plug-in hybrid vehicles, which can be recharged by plugging into an ordinary electrical outlet, are quickly commercialized and adopted, the gain in fuel efficiency would be even greater.

Mass consumer penetration of hybrid vehicles will occur due to the superiority of these vehicles rather than an explicit effort to reduce oil consumption. In addition to increasing fuel economy by 20% to 80% over comparable conventional

Comparison of Oil Demand Forecast Assumptions for Light-Duty Vehicles

(Display 8, page 10)



Installed base, sales and mpg estimates are derived from the IEA/SMP base case model, in which the IEA/SMP held vehicle miles traveled constant for 30 years. In order to correlate these estimates to subsequent references from the agency, AllianceBernstein estimated the increase in this variable.

Source: International Energy Agency (IEA), Sustainable Mobility Project (SMP) and AllianceBernstein

vehicles, hybrids offer faster acceleration, lower emissions and the ability to more easily integrate a host of desirable safety and luxury electronic systems. High oil prices and fear of oil scarcity, as well as tax incentives and other policy measures, are likely to speed adoption, but will by no means be the only factors driving their success.

Hybrid technology is already commercially available. Toyota Motors is the clear leader, but within a few years, all major automakers will offer hybrid vehicles. In the near term, we expect most automakers to offer hybridization as an option. In time, there are likely to be a wide range of vehicles designed to make the most of hybrids' strengths. Our research suggests that manufacturers will be able to adapt much of their existing capacity to produce hybrid vehicles with fairly limited additional expense.

We expect the number of hybrid vehicles to grow rapidly over the next decade because hybrids offer a more attractive set of benefits than the alternatives. Unlike conventional diesel vehicles, hybrids improve both performance and fuel efficiency, and will not soon face tough challenges from clean air regulations in many regions. Unlike biofuel vehicles, hybrids do not require special pumps at refueling stations. Unlike all-electric vehicles, they do not limit driving range.

Gasoline-electric hybrids have just two weaknesses: load capacity and initial cost. Load capacity is an important concern for pick-ups and heavy trucks; over time, a diesel hybrid could emerge for these segments. We expect costs for this new technology—like so many others—to fall significantly as economies of scale set in, to approximately $2,000 per vehicle by 2010.

The shift to transportation systems largely powered by electricity will be the next phase in the broad transition away from relatively inefficient mechanical systems. The primary limitations on electric-powered transportation to date has been the size and weight of the batteries needed to store power for free-roaming vehicles, and the semiconductor technology necessary to efficiently manage the flow of voltage. Continuing technological advances in both of these arenas will only improve the outlook for hybrids.

Plug-in hybrid electric vehicles are likely to arrive as an extension of the hybrids available today. Like the latter, plug-ins are powered by both liquid fuel (gasoline or diesel) and batteries. But in addition to being charged by the gasoline engine and regenerative braking, plug-in hybrids may be recharged by plugging into standard electric outlets.

Development of high-energy batteries is likely to spur the commercialization of plug-ins capable of significant electric driving range. Unlike fuel-cell technology, which our research suggests is at least 15 years away from mass commercialization, plug-in technology has largely been developed.

The fuel-efficiency gains from plug-ins would be enormous for those people who typically drive only short distances each day—and could have dramatic implications for overall oil demand. Some 40% of Americans travel 20 miles or less per day; about 60% travel 30 miles or less per day. If these people could buy plug-in hybrids that could go 20 to 30 miles on the electric motor before recharging, they would almost never have to use gasoline for routine driving. However, they would still have the internal combustion engine for the occasional longer trip.

If most consumers recharge the batteries in their plug-in vehicles from the electrical grid, the fuel ultimately powering their vehicle is likely to be coal, natural gas or uranium, rather than oil. Such flexibility would be truly game changing. Economic growth, which is inextricably linked to transportation, could be almost entirely decoupled from oil. This could reshape the foreign policies of such oil-importing countries and regions as the US, Japan, Western Europe, China and India. The economic and political implications for the few oil-rich exporting nations, by contrast, are likely to be grim. Indeed, the transition to hybrid power could change the world!

The investment implications of the transition to hybrid vehicles are straightforward. The industries most affected will be automakers and their traditional suppliers, electronic and semiconductor companies, electric utilities, and oil and gas producers. ■

The Emergence of Hybrid Vehicles

Ending Oil's Stranglehold on Transportation and the Economy

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INTRODUCTION

> "We are facing an unprecedented problem. World oil production has stopped growing… We have already found most of the oil."
>
> Kenneth Deffeyes
> *Beyond Oil, The View from Hubbert's Peak,*
> 2005

> "It's going to be very difficult to get gasoline for transport. Food is not going to be getting through in enough quantities to the shops."
>
> Jeremy Leggett
> *Half Gone: Oil, Gas, Hot Air and the Global Energy Crisis,*
> 2005

> "The power of population is so superior to the power of the earth to produce subsistence for man, that premature death must in some shape or other visit the human race…war...pestilence… or famine [will] level the population with the food of the world."
>
> Thomas Malthus
> *An Essay on the Principle of Population,*
> 1789

> "No wood, no kingdom."
>
> Advisors to King James I,
> circa 1620

Will there be enough oil?

More than 35 years ago, Marion King Hubbert, a widely respected geologist who spent decades in research at Shell Oil, estimated that global oil production would peak in the year 2000—and then decline at an accelerating pace as pressure dropped in partially depleted oil basins.[1] Last year, using improved technology and methodology to estimate total global reserves, Hubbert's former colleague Kenneth Deffeyes estimated that global production would reach Hubbert's peak in 2005 or early 2006.[2]

Not all geologists agree. There are arguments over methodology, and some geologists estimate that global oil production may not peak for two or three decades—and that existing global oil reserves won't be depleted until 2100.[3] Nonetheless, anxiety surrounding impending shortages of oil has mounted, contributing to an 80% rise in the price of the commodity between December 2004 and May 2006.

If Hubbert and Deffeyes are even roughly correct, the economic outlook is indeed grim—*if* the world remains reliant on oil for transportation. But humankind has averted many resource shortages that were expected to be equally disastrous. In 1798, after a period of rapid population growth in Europe, Thomas Malthus predicted an unending cycle of poverty and misery due to food supply growing arithmetically, while food demand grew geometrically with population.[4] Malthus, an economist, did not foresee the technological advances in farming, storage and transport of food that would later allow rapid growth in food supply.

In about 1620, advisors to King James I of England warned that a coming shortage of wood would be catastrophic. At the time, wood was crucial for building shelter, ships and wagons, for home heating, and for fueling glass and metal production.[5] King James' advisors summed up the warning as "No wood, no kingdom."[6] Not long thereafter, Britons discovered how to use their country's abundant local coal deposits as a substitute fuel, and England went on to become a great industrial power and a vast empire.

In both cases, technological innovations led to sustainable transitions in basic economic functions and contributed to more efficient ways of accomplishing tasks, while averting potentially dire resource shortages. Our research shows that the world, once again, is on the cusp of a major and sustainable transition, thanks to technological innovation: namely, the transition to hybrid-power vehicles, which use electric motors to boost the fuel efficiency of vehicles powered by internal combustion engines. This is a game-changing technology that could dramatically reduce oil demand from the transportation sector in our lifetimes.

This is no pie-in-the-sky dream. Hybrid vehicles already roam our streets and highways, offering strong performance, as well as greatly improved fuel efficiency and cleaner emissions. We expect this transition to occur because hybrid vehicles are a *better, more convenient technology.* Right now, they cost consumers $4,000 to $9,000 more upfront than comparable conventional vehicles, but mass production and further technological refinements should rapidly reduce their current price premium. Lower prices, in turn, would make them more economically attractive for the average consumer and speed their adoption. High oil prices—and fear of oil scarcity—may also speed adoption of hybrid technology, even before enhancements such as home-rechargeable batteries make hybrids even more convenient.

In this report, we examine why hybrid vehicles are likely to replace traditional cars and light trucks, and how the transition is likely to unfold. We also examine the transformational potential of this transportation transition. While we don't predict anything quite as dramatic as war, pestilence or famine, we do foresee significant outcomes for both the global economy and the global balance of power—and sweeping investment implications that extend well beyond the oil and auto industries.

Note: Since hybrids represent a new era in automotive development, at times we delve into significant detail about their technology and components. Some readers may choose to skip the more technical sections, most notably "Hybrids and Performance" and "Hybrid System Components." Other readers may want to dig into the technology, but skip some of the historical or policy discussions, such as "Britain's Transition to Oil" or "The Impact of Public Policy." To the extent possible, we have written the report to facilitate such choices.

Also note that to enhance readability, we have placed footnotes that elaborate on an idea—usually marked with asterisks—at the bottom of the page (or the bottom of a box within a page). Numbered references to sources, however, are provided in the Endnotes on page 48.

TRANSPORTATION TRANSITIONS: A HISTORY

Although it is difficult today to envision a world not reliant upon oil for transportation, oil-powered transportation is just a century old. Over the millennia, humankind has made several epochal transportation shifts.

Initially, of course, people traveled on their own two feet and carried their own cargo. By 4500 B.C., people began to harness the physical power of wind to propel rafts and ships on local journeys and between continents. By 3000 B.C., people began to harness the physical power of animals: horses for passenger travel and mules or oxen for carrying bulk materials (*Display 1*).

In 1800 A.D., man first began to use a *mechanical* system for propulsion: Watt's steam engine. The first steam engines—designed by Thomas Savoy and Thomas Newcomen in the early 1700s—were used to pump water out of coal mines. These engines were too inefficient for transport: They converted less than 1% of fuel energy for work. James Watt discovered that the primary cause of this inefficiency was heat loss, due to the steam cylinder being heated and cooled at every stroke.[7] His ingenious solution to this problem—condensing the steam outside of the cylinder—made steam engines much more efficient and practical for widespread use in pumping water and powering locomotives, ships and factory machinery.[8]

Display 1

Humanity's Search for Greater Power

Date		Output in Horsepower
3000 BC	Human pushing a lever	0.05
3000 BC	Ox pulling a load	0.5
1000 BC	Water turbine	0.4
350 BC	Vertical waterwheel	3
1600 AD	Turret windmill	14
1712 AD	Newcomen's steam engine	5.5
1800 AD	Watt's revised steam engine	40
1837 AD	Marine steam engine	750
1854 AD	Water turbine	800
1900 AD	Rail steam engine	12,000
1903 AD	Airplane (Wright Brothers)	12
1906 AD	Steam turbine	17,500
1909 AD	Automobile (Model T)	22
1917 AD	Airplane (WWI Liberty Plane)	400
1969 AD	Airplane (747 Jet)	275,000
1973 AD	Coal-fired steam plant	1,465,000
1974 AD	Nuclear power plant	1,520,000

Source: Earl Cook, Man, Energy, Society*, 1976, Boeing Corporation, http://www.modelt.ca/faq-fs.html, http://wright.nasa.gov/overview.htm, http://www.pilotfriend.com/aero_engines/aero_pst_eng.htm*

The steam engine had many advantages for transportation uses. Unlike horses, steam engines do not fall ill; they do not require expensive upkeep; they can operate in a variety of weather conditions, and they can run for long periods of time without a break. Furthermore, Watt could use Britain's abundant coal supply, rather than wood, to fuel his steam engines; using the more energy-dense material contributed to the dramatic improvement in the speed and range of travel offered by steam engines and reduced operating costs.

Thus, it was the combination of a substitute fuel source (coal) and a new technology (steam engine) that transformed transportation and made possible the Industrial Revolution. With the rise of the steam engine, coal displaced wood as Britain's dominant fuel, and demand for coal exploded.

Indeed, in the late 19th century, William Stanley Jevons, a prominent economist and logician, predicted that Britain would soon deplete its coal supplies and therefore decline as an industrial power.[9] This disaster, too, was averted—thanks to the invention of the internal combustion engine. The internal combustion engine increased energy conversion efficiency by burning fuel *inside* the engine cylinder (unlike steam engines and other *external* combustion engines that burned fuel *outside* the cylinder) and by using oil, which has about twice the energy content of coal. Oil-burning internal combustion engines made possible more powerful, longer-range locomotives and ships, as well as such new forms of transportation as the airplane.

As a result of its improved efficiency and convenience, the internal combustion engine rapidly displaced the steam engine for transportation. Accordingly, oil's importance as a source fuel for industrial economies grew, and coal's relative importance declined. Countries such as the UK moved from coal to oil long before their coal supplies were exhausted, disproving Jevons' dire forecasts.

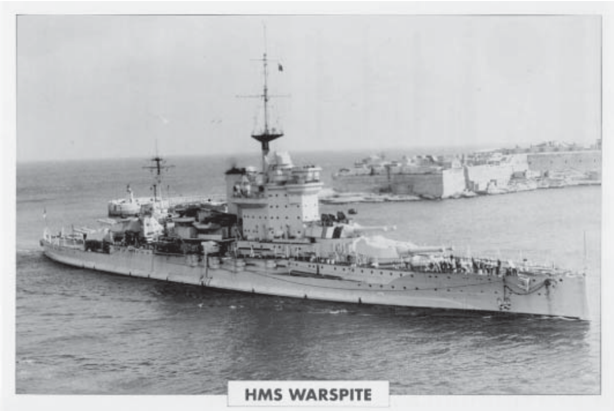
While fear of resource shortages has sometimes lent urgency to transportation transitions, such transitions only took hold with the discovery of a more convenient fuel source and a technology able to efficiently make use of it. The discovery of a new—and potentially more efficient—fuel source is not in itself sufficient: The

BRITAIN'S TRANSITION TO OIL

In 1912, on the eve of World War I, Winston Churchill, as head of the Royal Navy, took a fateful step to convert British battleships from burning coal to oil.[10] The advent of the internal combustion engine had made possible oil-powered ships with many advantages over coal-fired steamships: They were lighter, faster, more efficient, more powerful and generated less smoke, which made it easier to evade enemies.[11] But conversion to oil was risky, because the UK at the time had no domestic oil supply.

"To commit the Navy irrevocably to oil was indeed to take arms against a sea of trouble," Churchill later wrote. "If we overcame the difficulties and surmounted the risks, we should be able to raise the whole power and efficiency of the navy to a definitely higher level: Better ships, better crews, higher economies, more intense forms of war power. In a word, mastery itself was the prize of the venture."[12]

To secure long-term supplies, Churchill persuaded the UK government to purchase a controlling interest in a fledging oil company named Anglo-Persian, which became British Petroleum, later renamed BP. These moves conferred an important military advantage on Britain that contributed to its victory in World War I. After the war, British statesman Lord Curzon went so far as to say, "The Allied cause had floated to victory upon a wave of oil."[13]



The HMS Warspite: Commissioned in 1913, it was the first warship to use only oil fuel, the first to mount 15-inch guns and the first to reach a speed of 25 knots.

The move also heralded the age of oil. Energy historian Daniel Yergin notes that the Royal Navy's transition to oil was the first demonstration of how national security and economic well-being could be fundamentally linked to oil. Thereafter, economic power became increasingly reliant on oil-fueled machinery, and industries and military power on oil-fueled ships, tanks, trucks and airplanes.

The Royal Navy's shift to oil may have also helped oil producers to continue investing in production and innovation at a time when their main product, kerosene for lighting, was losing share to the electric light bulb, and when more automobiles were powered by coal-burning steam engines or electric batteries than by oil-burning internal combustion engines.* It was only after the introduction of the electric starter in 1912 that the internal combustion engine became the dominant standard for road travel, leading to sharp and sustained growth in oil demand.

Britain, of course, gained another benefit from Churchill's savvy investment: BP became one of Britain's largest companies, and by the time it was fully privatized in 1987, the British government had recognized a profit in excess of $20 billion. Its initial investment has thus been dubbed one of the greatest financial investments ever.[14]

* At the turn of the century, only 22% of the US auto market was gasoline-powered; 38% was electric-powered and 40% steam-powered; see Roland Chavasse, "Developments in Hybrid Vehicles and Their Potential Influence on Minor Metals," SFP Metals, 2005.

technology and infrastructure to support the innovation must also be in place. However, once the technology and infrastructure are in place and the benefits of the new system become apparent, the transition to the more efficient platform may be rapid. Often, the discovery sets off a virtuous cycle of innovation and increased demand that eventually creates economies of scale and lower prices, stimulating still more demand.[15]

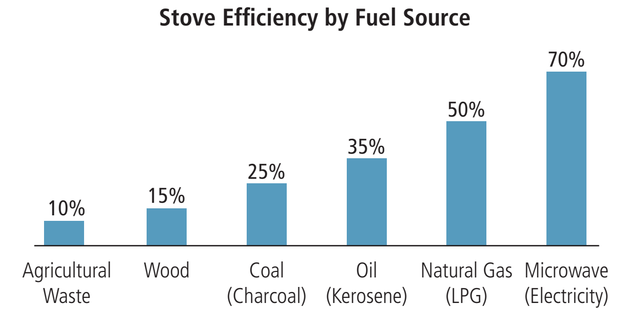
The Rise of Electricity

Over the course of the 20th century, oil became the key fuel for transportation, and electricity—whether generated by burning coal, natural gas or oil, or by splitting atoms—began to power almost everything else. Early in the century, Thomas Edison's light bulb displaced the kerosene lamp for lighting. By the end of the 1920s, electricity had become the largest source of power for US and European manufacturing, replacing steam engines and other forms of mechanical power.[16] In due course, electricity made possible the rise of entirely new industries, such as information technology and communications, that rely almost exclusively on electricity. It also had massive implications for a much older industry: finance. As a result, more than 85% of growth in US energy usage since 1980 has been due to increased electricity demand.[17] Other advanced industrialized countries have also witnessed similar transformations.

Electricity is a tremendously concentrated and fast form of power, as well as a highly ordered form of energy: That is, electricity can deliver more power in less space or weight than mechanical systems.[18] For instance, a high-voltage wire with a cross section of several inches can transmit 1 million kilowatts (kw) of power. By comparison, the mechanical power train in a car uses five times the area to convey merely 100 kw of power to the wheels. This unique trait allows electricity to deliver greater efficiency, power and speed over long distances, improving convenience and productivity, which account for its ascendancy in many spheres of economic activity. For instance, the efficiency of using paraffin candles or kerosene lamps for lighting was well under 1% in 1800s, compared to the 35% to 50% efficiency of electrical lighting systems today.[19] This not only massively increased aggregate demand for lighting, but also made life better and more productive. A more recent example is the evolution of the stove. The wood stoves of the 1800s had efficiencies of 10% to 15%, versus 50% for today's natural gas burning stoves—and 70% for the electric microwave, which can also warm food faster and more conveniently (*Display 3*).

Display 3

Higher-Density Fuels Boost Efficiency and Power



Efficiency is defined as the ratio of effective/useful output to total input.
Source: United Nations' World Energy Assessment—Energy and the Challenge of Sustainability *and AllianceBernstein*

Due to electricity's unparalleled efficiency, power and versatility, electrification enabled the use of continuous-process techniques in manufacturing, such as the assembly line. It thereby reduced task times and made mass production possible.[20] Electrification also improved productivity by enabling the use of smaller electric motors for powering individual machines and tools. It thereby reduced energy use per task and permitted more flexible and efficient factory design.[21]

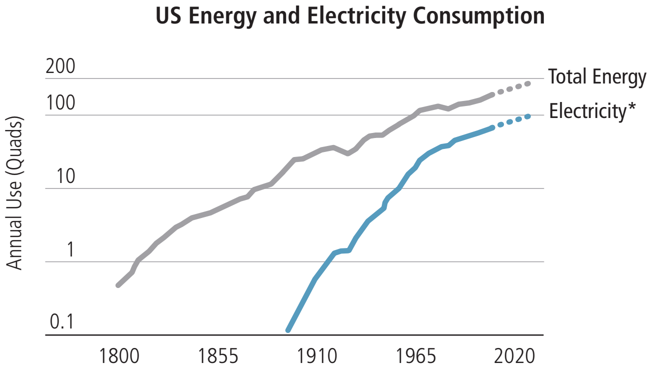
We expect the shift to electric power to continue as electronics and electrical systems replace mechanical processes in an ever-expanding number of applications. Innovations in power-chip technology, which afford more precise and reliable control of electricity, are enabling this transformation. We discuss the new power semiconductors in more detail on page 28, because they are important components of hybrid vehicles.

The massive growth in electronics has led to tremendous growth in demand for electricity worldwide. In the US alone, demand for electricity rose 30-fold in the 20th century, or three times as fast as overall energy consumption. In the last 20 years of the 20th century, as electronics proliferated, electricity consumption doubled from already high levels; this growth is projected to continue at relatively rapid rates (*Display 4, next page*).

The shift to largely electric-powered *transportation* systems will be the next phase in the broad transition away from relatively inefficient mechanical systems that rely solely on oil to more efficient and cost-effective electric power.

Display 4

An Increasing Share of Energy Demand Is for Electricity



**Energy consumed to produce electricity*

Source: EIA Annual Energy Review 2003, US Census Bureau, Historical Statistics of the United States, Colonial Times to 1970*, and Huber and Mills,* The Bottomless Well

Electricity in Transportation

One major limitation on electric-powered transportation to date has been the size and weight of the batteries needed to store energy for free-roaming vehicles: While electric cables or rails have powered propulsion of some trains and trams for about a century, battery-driven electric motors have only powered parts of peripheral systems in most automobiles, trains and boats. Inadequate semiconductor technology necessary to efficiently manage the flow of voltage has also been an obstacle until recently.

Increasingly, however, propulsion itself is being powered by electricity. Submarines have been all-electric for years, thanks to nuclear generators on board. The US Navy is now designing all-electric surface ships; several fuel sources in addition to nuclear are being considered for them. In addition, manufacturers are currently deploying hybrid buses, locomotives, tractors and trucks in meaningful quantities.

The emergence of hybrid power in passenger vehicles is far more significant, however, because the passenger market is far larger. The impact would be enormous if, eventually, every car sold were a hybrid, as predicted by James E. Press, president of Toyota Motors North America.[22] William Clayton Ford, Jr., CEO of Ford Motor, has said, "The 100-year reign of the gas-powered internal combustion engine could come to an end in our lifetime." [23]

We expect the hybrid automobiles now available to be just the first step toward the demise of the traditional internal combustion vehicle, which could eventually end oil's stranglehold on transportation, the economy and geopolitics. The electrical content in cars is likely to keep rising, thereby improving the energy efficiency of automobiles. In time, people may drive all-electric, battery-powered vehicles, plug-in hybrids or fuel-cell-powered vehicles. We are particularly optimistic about the opportunity for plug-in vehicles, although they are still several years away from being commercially viable. But we predict that even the hybrid technology that is currently or imminently available will have a significant impact on oil demand over the next 25 years.

OIL DEMAND YESTERDAY AND TOMORROW

Global oil consumption has increased from 49 million barrels per day in 1971 to 77 million in 2002 (*Display 5*) and 84 million in 2005, despite improvements in oil efficiency that were spurred by the oil shocks of 1973/74 and 1979/80. Oil efficiency, measured by real output per barrel of oil consumed, has improved by 50% in the developed world and 33% in the developing world since 1971.[24] Many sectors have simply moved to other fuels: Substitution has been most evident in electric-power generation, particularly in developed economies. Globally, oil has fallen from 25% of the total fuel input for electric generation in 1973 to about 7% in 2003[25] (*Display 6*). Substitution has also been widespread for residential and office heating.

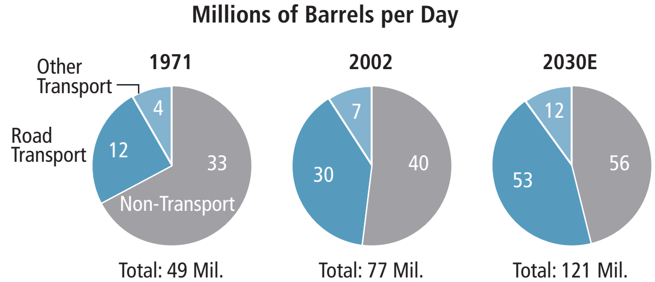
As a result, the composition of oil consumption has markedly shifted toward transportation. Within the transportation sector, the fastest growing category has been road transport (light-duty vehicles, medium and heavy trucks, buses and two- and three-wheel vehicles), which accounted for about 25% of global oil consumption in 1971 versus 40% in 2002,[26] as Display 5 also shows. In fact, road transport was responsible for nearly two-thirds of the incremental growth in oil consumption from 1971 to 2002.[27] Thus, accurately projecting oil demand for road transport is crucial to correctly calculating overall future demand for oil.

Forecasting Oil Demand for Vehicles

The International Energy Agency (IEA) forecasts that by 2030, global oil demand will increase by nearly half, from its current level of 84 million barrels, to reach 121 million barrels per day.[28] The IEA also projects transportation will continue to be a major factor in oil demand growth, accounting for nearly two-thirds of the incremental demand.[29] In conversations with IEA energy analysts, we learned that the IEA expects 82% of the incremental growth in oil consumption for transport uses over this period to come from road transport and 60% of the road transport consumption to come from light-duty vehicles.[30] From this disclosure and the IEA/SMP model, we infer that the IEA expects light-duty vehicles—passenger cars, sport-utility vehicles (SUVs), pick-up trucks and vans—to represent the largest subcategory within the transport sector at 32 million barrels per day in 2030, up from 18 million barrels in 2002* (*Display 7*).

Display 5

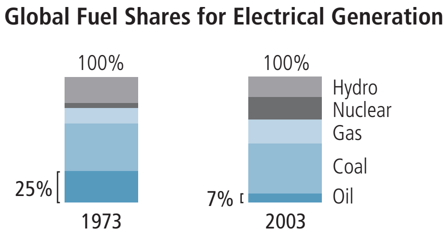
Transportation Drives Rise in Global Oil Demand



Road transport includes light-duty vehicles, medium and heavy trucks, buses and two- and three-wheel vehicles.
Sources: IEA, World Energy Outlook 2004, World Energy Statisics and Balances, and AllianceBernstein

Display 6

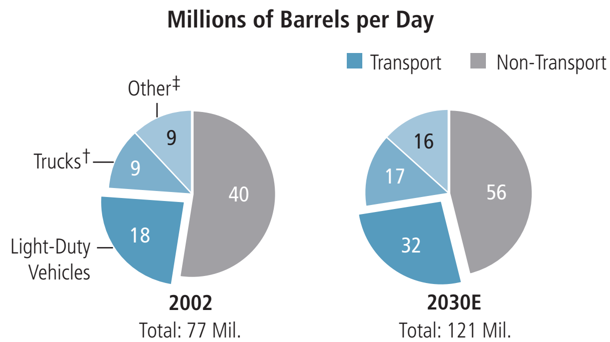
Electric Generation Has Become Less Reliant on Oil



Sources: IEA, World Energy Outlook 2004, World Energy Statisics and Balances, and AllianceBernstein

Display 7

Light-Duty Vehicles in Particular Will Be Critical to Oil Demand



†*Medium and heavy trucks only*
‡*Rail, air and shipping, buses and two- and three-wheel vehicles*
Source: IEA, World Energy Outlook 2004, IEA/SMP model, IEA analysts and AllianceBernstein

* In the World Energy Outlook (WEO) 2004, the IEA published its high-level forecasts for aggregate oil demand and oil demand for transportation uses, but did not disclose the underlying assumptions, estimates and calculations supporting these projections. However, the IEA's WEO model may be approximated by referencing the joint work between the IEA and the World Business Council on Sustainable Development's Sustainable Mobility Project (SMP) team. According to the IEA, these entities have worked together over the past few years to develop a global transportation spreadsheet model that both organizations use for making projections and policy analysis. The model can be obtained from the World Business Council; the detailed assumptions underpinning it are fully described in the "IEA/SMP Model Documentation and Reference Case Projections," by Lewis Fulton (IEA) and George Eads (CRA), July 2004. Since the IEA does not provide transparency to its WEO model, the IEA transportation projections referred to in this report are estimates based on the IEA's WEO headline projections, the IEA/SMP model (reference case), and subsequent disclosures from IEA analysts.

The IEA forecasts a shift in the geographic locus of demand growth, however, to rapidly developing nations. In particular, the IEA expects that rising incomes and infrastructure development in China and India will lead to more widespread vehicle ownership and road travel and therefore to greater demand for oil.

We agree with the IEA that the primary driver of oil demand growth will be higher levels of vehicle ownership globally. We disagree, however, with the agency's minimal projections for improvements in fuel efficiency.[31] (For more details of our forecast, see page 32).

As one would expect, the IEA calculates oil demand for cars and other light-duty vehicles by estimating the total number of vehicles in a given year, multiplying that figure by the average miles driven per vehicle and dividing it by the average fuel economy of the vehicles. For instance, the IEA estimates that the global stock of light-duty vehicles will increase from 707 million in 2002 to 1,289 million in 2030, and that annual miles driven per vehicle will grow from more than 8,800 to nearly 9,600.* Dividing the product of these variables by the global average fuel efficiency of 22.6 miles per gallon (mpg) in 2002 and the IEA's projection of 25.1 mpg in 2030 yields the IEA's estimate of oil use by light-duty vehicles of 18.0 million barrels per day in 2002 and 32.1 million barrels per day in 2030† (*Display 8*).

But these demand forecasts are highly sensitive to the projected fuel efficiency of the vehicles. If one assumes average fuel efficiency of 40 mpg (the current average for new light-duty vehicles sold in Europe[32]) instead of 25.1 mpg, global oil demand by light-duty vehicles would reach only 20 million barrels per day in 2030 (*Display 9*). Improving fuel efficiency to 60 mpg, which is feasible as hybrid technology improves, would *cut* oil demand by light-duty vehicles globally to 13.4 million barrels per day.

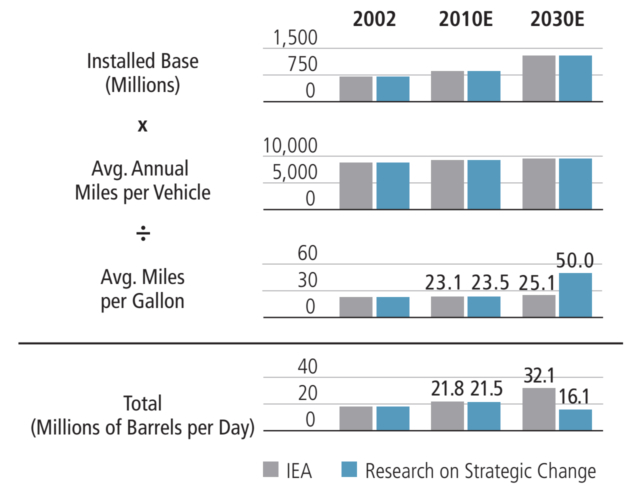
Indeed, we expect step changes in fuel efficiency as new technologies are introduced and adopted over the next 25 years. Therefore, we have focused on estimating the impact these new technologies may have on average fuel efficiency, and how fast the technology may be adopted, in order to estimate the outlook for oil demand.

Our analysis suggests that oil demand will be substantially *lower* over the long term than the IEA predicts, due to the improved efficiency and rapid adoption of hybrid vehicles, first by commercial and government fleets and other high-travel segments, and then by the mass market. Thus, we estimate that global oil demand for light-duty vehicles will rise to just 21.5 million barrels per day in 2010, and *fall* to 16.1 million in 2030, as Display 8 also shows. While our forecast for 2010 is only 0.3 million barrels per day (2%) lower than the IEA's, our forecast for 2030 is 16.0 million barrels (50%) lower.

In the following sections of this report, we outline the various types of hybrid vehicles, explain how they function, and discuss why we believe they will be widely adopted. We also explain why these vehicles are able to achieve higher fuel economies and highlight other likely technological developments associated with hybrids. Once we have made the case for mass adoption of hybrids, we will present our auto forecast in greater detail.

Display 8

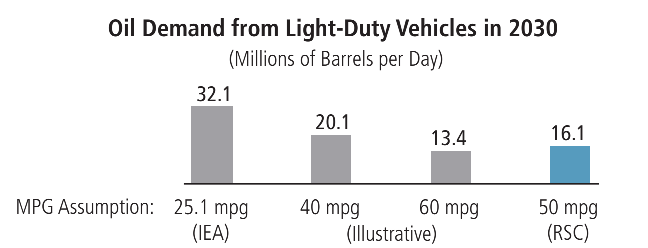
Comparison of Oil Demand Forecast Assumptions for Light-Duty Vehicles



Installed base, sales and mpg estimates are derived from the IEA/SMP base case model, in which the IEA/SMP held vehicle miles traveled constant for 30 years. In order to correlate these estimates to subsequent references from the agency, AllianceBernstein estimated the increase in this variable.
Source: IEA, SMP and AllianceBernstein

Display 9

Sensitivity of Demand Estimates to Fuel-Efficiency Assumption



All four forecasts based on IEA assumption of total global fleet of 1,289 million vehicles, traveling an average of 9,576 miles per year in 2030.
Source: IEA and AllianceBernstein

* IEA estimates of the installed base of vehicles inferred from the IEA/SMP transport model. Miles traveled estimated to correlate the IEA/SMP transportation model (reference case) with subsequent IEA disclosures.

† IEA estimates for the fuel efficiency of the installed base of vehicles derived from the IEA/SMP transport model (reference case).

HYBRIDS EMERGE

Many technologies and power trains may significantly increase fuel efficiency in the foreseeable future, including gasoline-electric hybrids, diesel, natural gas, flex-fuel (biofuel), all-electric (battery only) and fuel-cell vehicles. Over the next decade, however, we expect hybrid technology to be the most important. Lee Iacocca, the former CEO of Chrysler, has said, "I don't see anything on the horizon short term that can improve fuel economy faster than a hybrid."[33] We agree.

Hybrid-power technology offers a more attractive set of benefits than alternative power trains (*Display 10*). Hybrids offer improved fuel efficiency and performance—measured by acceleration and horsepower (hp)—lower emissions and greater convenience: Unlike diesel, hybrids do not sacrifice performance to gain fuel efficiency; unlike biofuel vehicles, hybrids do not require special pumps at refueling stations; unlike all-electric vehicles, hybrids do not limit driving range. Additionally, consumers should soon have a wide array of model choices.

Furthermore, the technology has been rapidly improving: Hybrids stand to benefit substantially from research underway on engine, electrical component and battery technologies. Finally, hybrids offer tremendous flexibility: Diesel and flex-fuel engines, as well as gasoline-burning engines, can be hybridized.

Gasoline-electric hybrids (the most common offering today) have just two weaknesses: load capacity and initial cost. Load capacity is generally not a major issue for passenger cars. It *is* a concern for pick-up and heavy trucks, but over time, a diesel hybrid could emerge as an option for these segments. As for the initial price premium, we expect costs for this new technology—like so many others—to fall significantly as economies of scale set in. We address the price premium question in more detail on page 19.

Given their many advantages and limited, surmountable drawbacks, we expect the number of hybrid vehicles to grow rapidly over the next decade and eventually reach over 80% of new cars and light trucks sold worldwide (we include here both gasoline-electric and diesel-electric hybrids). In the sections that follow, we will explain hybrid technology and make the case for their mass adoption. We will also address the cost curve that hybrids are likely to trace, analyze the impact hybrids will have on the auto and technology industries, chart their future evolution, and assess the implications for oil demand and investment.

Display 10

Hybrids Are Far More Attractive than the Alternatives

Factor	Hybrid (Gasoline)	Diesel	CNG*	Flex-Fuel	All Electric
Fuel Efficiency	High	Medium	Low	Low	High
Performance (acceleration)	High	Medium	Low	Medium	Medium
Emissions/Air Quality	High	Low	Medium	Medium	High
Model Choice/Flexibility	High	Medium	Low	Medium	Low
Convenience (range, refueling)	High	Medium	Medium	Medium	Low
Load Capacity	Medium	High	Low	Medium	Low
Initial Cost	Low	Medium	Low	High	Low
Cost per Mile	High	Medium	High	Low	High
Representative Model	Toyota Prius	VW Jetta	Honda Civic	GM Monte Carlo	Toyota RAV4 EV

High / Medium / Low

**Compressed natural gas*

Comparisons based on commercially available vehicles.

Source: AllianceBernstein

IS DIESEL AN ATTRACTIVE ALTERNATIVE?

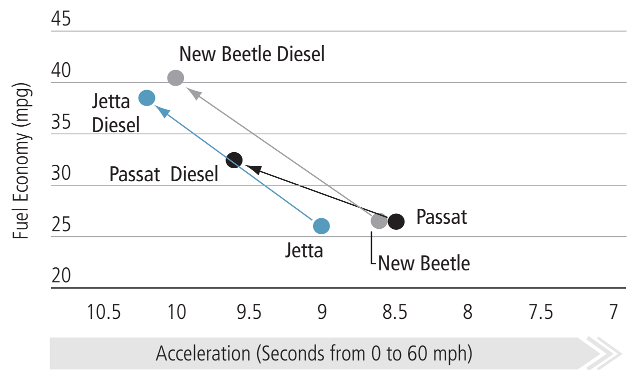
Diesel is the power train most often mentioned as a viable competitor to hybrids, due to its lower initial price, high fuel efficiency and high power torque at low speeds. In Europe, where stiff taxes make gasoline much more expensive than it is in the US, diesels' popularity has soared. Diesels' share of new light-duty vehicle sales in Europe has risen from about 20% in 1997 to over 50% in 2005. Our research suggests that over the longer term, the conventional diesel power train may be complementary—rather than competitive—to the hybrid power train in the passenger vehicle market, for several reasons:

First, although conventional diesel-burning engines are more fuel efficient than traditional gasoline-burning engines when measured over the full cycle from oil well to vehicle wheels (on a well-to-wheels basis), they are not as efficient as hybrids. A Toyota study comparing vehicles of similar weight and size concluded that the diesel car has a well-to-wheel efficiency of 19% versus 13% for gasoline, and 32% for the Prius hybrid.[34] Other studies provide similar results, though the magnitude of the hybrid's advantage varies somewhat by study.[35]

Second, conventional diesel engines require a trade-off between performance (acceleration) and fuel efficiency (*Display 11*); hybrids, by contrast, improve both performance and fuel efficiency (*Display 12*). Although diesels can deliver more torque in addition to higher fuel efficiency than gasoline equivalents, their higher torque is best used for accelerating to low speeds (e.g., from 0-30 miles per hour) and for carrying heavy loads. Diesels perform less favorably when judged by horsepower and acceleration to high speeds (from 0 to 60 miles per hour) than gasoline-powered vehicles. Compared to hybrids, diesels are disadvantaged in acceleration to low speeds, since hybrids produce maximum torque instantaneously while diesels need time to achieve maximum torque.

Display 11

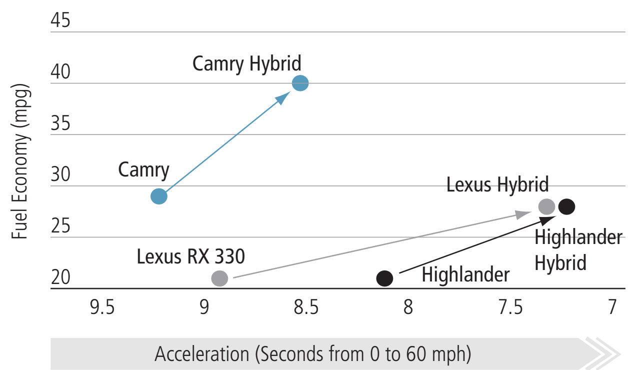
Diesels Sacrifice Acceleration to Improve Fuel Economy



Source: Autos.com, carsdirect.com and fueleconomy.org

Display 12

Hybrids Improve Acceleration *and* Fuel Economy



Source: Cars.com, carsdirect.com, Toyota and AllianceBernstein

Diesels are also likely to be disadvantaged in acceleration to high speeds because they generally have lower maximum horsepower than gasoline and hybrid vehicles. Therefore, diesels are not a "no-compromise" solution in terms of performance, as hybrids are.

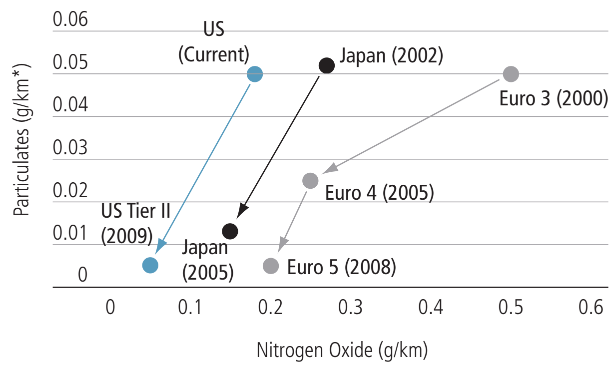
Third, and perhaps most important, conventional diesel vehicles face significant regulatory challenges in many regions. While diesel engines emit less carbon dioxide (purportedly the main cause of global warming) than gasoline engines, they emit more nitrogen oxide (a major contributor to smog) and particulate matter (linked to strokes, lung cancer and other respiratory problems). Thus, California, New York and several other states in the US have effectively restricted sales of diesel passenger vehicles. Clean diesel engines and fuels may be developed in the future, but this is likely to be an expensive effort—and it remains unclear if even these new engines and fuels can meet the increasingly stringent environmental requirements being adopted in many countries (*Display 13*). In fact, Nissan recently pulled two diesel models from its lineup rather than incur the expense of making their engines cleaner.[36] Additionally, Volkswagen has decided to drop the diesel versions of the Jetta, Golf and Beetle from its US line-up for the 2007 model year due to their inability to meet new federal standards.[37]

Competition from hybrids is particularly important in Europe, because Europe is where diesel has gained greatest market share. European Union environmental standards are set to become much tighter in the next few years, which will likely raise the price of diesel vehicles and could push automakers towards gasoline-electric or diesel-electric hybrids. Today, Europe is on the Euro 4 guideline; the proposed Euro 5 requirements would cut allowable emissions of nitrogen oxide and particulate matter for diesel by 20% and 80%, respectively, by 2008. Possible Euro 6 standards may go even further, particularly on nitrogen oxide, sometime between 2012 and 2015.[38]

The cost of compliance with the particulate standards alone has been estimated at $500 to $1,000 per vehicle. It could be higher if medical research shows that more effective particulate filters are needed on diesel vehicles to curb health risks.[39] New, more expensive catalytic converters may also be required to reduce nitrogen oxide emissions to the target level.

Display 13

Diesels Will Soon Face Stricter Emissions Standards



* *Grams per kilometer traveled*

Source: WRI Capital Research, www.dieselnet.com and AllianceBernstein

In addition, the European Union is targeting reductions in carbon dioxide emissions to 120 grams per kilometer (g/km) for all new passenger vehicles in 2012, versus 172 today for new gasoline vehicles and 155 g/km for new diesel vehicles. Several automakers have suggested that the cost of compliance with this new standard, which may become mandatory (today's standards are voluntary), could initially be more than $5,000 per vehicle.[40] If adopted, this new standard could further push automakers to embrace hybrids as a cost-effective alternative.[41]

Conventional diesel technology may remain the best choice for pick-up trucks and vans that carry heavy loads, but as price premiums for hybrid vehicles decline and the technology becomes standardized, manufacturers may introduce diesel hybrids that would provide the greater torque needed for such tasks, as well as the fuel efficiency and clean emissions associated with gasoline hybrids. Considering Europe's large-scale conversion to diesel over the past decade, automakers are also likely to introduce diesel hybrids into the European passenger car market, since they would offer better performance, fuel efficiency and emissions than either conventional gasoline- or diesel-powered vehicles could achieve. Peugeot and Volkswagen have announced plans to develop such vehicles.

Hybrid Basics

Hybrid vehicles combine an internal combustion engine with a generator, battery, and one or more electric motor(s) to reduce the wasted energy associated with an internal combustion engine and mechanical processes versus electronic systems.

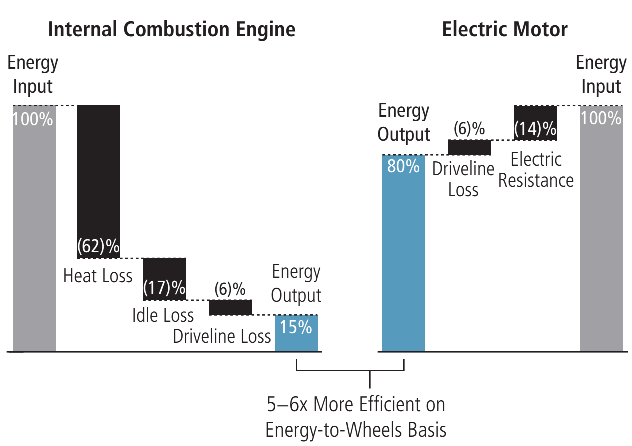
In a conventional engine, only about 15% of the energy generated by the fuel in the tank reaches the wheels to move passengers and power accessories, such as air conditioning. The other 85% of the energy content of the fuel is lost to engine and driveline inefficiencies, idling and braking (*Display 14*). According to the US Environmental Protection Agency, vehicles solely powered by gasoline-burning internal combustion engines lose over 62% of their fuel's energy in combustion, the process in which chemical energy is converted to mechanical energy.[42] The main components of this loss are engine friction, air pumping into and out of the engine, and wasted heat. Hence, the potential to improve the fuel efficiency of traditional vehicles is enormous.

Battery-powered electrical motors can be smaller, lighter, and up to five or six times as efficient as internal combustion engines at converting energy to motion. The main loss motors face is the resistance in the electric circuitry.

Thus, hybrids employ electrical power trains to improve fuel tank-to-wheel efficiency. The improved energy efficiency can be used to achieve varying combinations of increased fuel efficiency, enhanced performance (power) and/or the introduction of new electronic safety and luxury features. While there are many kinds of hybrids (see *Hybrid Variations*, page 15), in a full hybrid, four primary factors help improve efficiency.

Display 14

Electricity Is Far More Efficient Way to Power Cars



Source: Toyota, US Environmental Protection Agency (EPA) and AllianceBernstein

Electric Motor Drive/Assist. Using a battery more powerful than the lead-acid battery now used to start most vehicles, the electric motor propels the vehicle during low-speed acceleration from stop and during cruising; it also provides power to assist the engine in sudden acceleration, high-speed passing or hill climbing. This allows a smaller internal combustion engine to function at levels previously unattainable. Those Toyota hybrids designed to maximize fuel efficiency, such as the Prius, use a highly efficient, compact Atkinson-Miller cycle engine, whose fuel efficiency is further enhanced by the use of electronic variable valve timing and other electrical components, as well as lighter weight materials. In conventional vehicles, the low-output Atkinson engine would cripple performance; in a hybrid, the synergistic drive created by the engine and the high output motors and generators permits robust fuel efficiency and performance. The hybrid system can seamlessly switch among use of the motor, the engine or both as driving conditions warrant.

Start/Stop. The hybrid system automatically shuts off the engine when the vehicle comes to a stop, and restarts with the motor and battery when the vehicle launches or accelerates, preventing wasted energy from idling.

Regenerative Braking. When braking, the hybrid's electric motor applies resistance to the drive train, causing the wheels to slow down. The motor captures the energy from the wheels, functioning as a generator to convert into electricity the energy normally wasted as heat during braking. The electricity is stored in the battery until needed. In essence, normal braking recharges the hybrid battery.

Transmission Optimization. Since an automobile engine runs best at a certain range of revolutions per minute (rpm), the function of the transmission in a conventional vehicle is to deliver power from the engine to the wheels for a wide range of loads and output speeds, while keeping the engine within its narrow rpm range. That is to say, the transmission manages the speed ratio between the engine and the wheels of an automobile. It does this through the use of several gears and a limited set of gear combinations; without a transmission, automobiles would effectively have only one gear. By changing the gear ratio, the transmission makes better use of the engine's power as driving conditions change. But the fixed number of gear ratios, along with the mechanical parts and the low level of computing power in a conventional vehicle's transmission, limit the ability to shift smoothly and seamlessly for efficiency and performance. Hybrids seek to overcome this limitation to varying degrees, depending on the type of transmission (or substitute) they employ, primarily by expanding the set of gear combinations. More precisely, they increase the variability between highest and lowest gears with as few discrete steps or shifts as possible to obtain greater fuel efficiency and performance.

In full hybrids, the transmission manages the speeds of both the engine and the motor, directing power from either or both in various combinations to drive the wheels. Some automakers have used an ***electronically controlled transmission*** that can vary engine and motor speeds in infinite combinations quickly and reliably, while optimizing for fuel efficiency and performance. This exceptionally robust transmission system, also known as e-CVT, uses a power-split device (essentially, a modified planetary-gear system) to replace the traditional mechanical transmission; it eliminates belts, clutches, torque converters and transmission fluids. Toyota developed this advanced system and has extensive patent protection around the technology. It currently licenses its innovation to Ford and Nissan. We discuss power-splits in more detail on page 27.

Other automakers are seeking to use other, less robust solutions for transmission optimization in hybrid vehicles. ***Continuous variable transmissions*** (CVTs) provide a wide, but not infinite, range of gear ratios; they have been somewhat unreliable because of the inability of the CVT belt to handle high torque and horsepower. ***Dual clutch transmissions*** provide more gear ratios than an automatic transmission, but less than a CVT; because they appear to be more reliable than the CVT, they could be a viable option. It is too early to extensively evaluate this technique since it has yet to be introduced in a commercially available hybrid. Another alternative, the conventional transmission, delivers less performance and fuel savings than an e-CVT, CVT or dual clutch transmission, so those now used in some hybrid vehicles are likely to last only until better technologies are developed.

The combination of the four factors above enables hybrid vehicles to achieve 20% to 80% gains in overall fuel efficiency versus comparable conventional gasoline-powered vehicles. The fuel-efficiency benefit is likely to increase as the technology matures. The electric drive train in today's hybrid system also confers other benefits, such as improved performance, lower emissions and reduced operating costs. The performance improvement is largely the result of the electric motor's ability to produce instantaneous torque and relatively fast acceleration from stop, and to work with the engine to generate high output (horsepower) at high speeds (see *Hybrids and Performance,* page 20).

Hybrid vehicles also offer several other benefits. Electrical systems tend to break down less often than conventional mechanical systems, and typically cost less per mile traveled. Hybrids also generate significantly lower emissions. Vehicle emissions are a function of fuel purity, fuel efficiency and cold start. Hybrids achieve lower emissions from the use of smaller, more efficient engines and from the use of the electric motor for start-up, thereby reducing cold start. Emissions from hybrid vehicles are virtually zero when the car is being driven by the motor alone.

In the near term, we expect most auto manufacturers to offer hybridization as an option: Consumers today have the choice of buying a hybrid or conventional version of a Camry; they'll have a similar choice for many other models sold. In time, there are likely to be a wide range of vehicles specifically designed to capitalize on the strengths of the hybrid system.

Hybrid Variations

Hybrid-vehicle components can be arranged in a variety of ways to obtain different objectives, such as greater fuel efficiency, increased power, lower emissions or portable power generation for construction (perhaps in a hybrid pick-up truck).

In a ***series hybrid***, the gasoline engine is not directly connected to the drive train. Instead, the engine is used to drive an electric generator that provides electricity for an electric motor that moves the wheels: The power flows to the wheels in a series. The engine can charge the battery when necessary via the generator, enhancing fuel efficiency somewhat. However, the series hybrid offers inferior performance, since only the motor drives the wheels.

In a ***parallel hybrid***, the engine and the electric motor theoretically can drive the wheels independently or concurrently: The power flows to the wheels in parallel. While this construction is capable of decent performance, fuel efficiency can suffer because the battery is not automatically recharged whenever the engine is running.

A ***series/parallel hybrid*** combines both systems to maximize fuel efficiency and performance. This design allows both the engine and the motor to drive the vehicle, which is good for performance, and it allows the engine to charge the battery even when the motor is driving the vehicle, which is good for fuel efficiency.

Another key difference among hybrids is the degree to which the electric motor propels the vehicle and, thus, the level of electric power in the vehicle. As a point of reference, a conventional, non-hybrid passenger vehicle generates about two kilowatts of peak electric load from its battery for power electronics versus about 100 kw of peak power from its mechanical (non-electric) systems. It has a ratio of electric power to total power of about 2%.

Full hybrid passenger vehicles—in which the electric motor is capable of powering the vehicle by itself for some period of time—have a ratio of electric to total power of 30% or higher (*Display 15*).

Mild hybrids, which cannot run on electric power alone, typically have a ratio of electric to total power between 10% and 30%. Also called assist hybrids, mild hybrids primarily rely on their gasoline engines, with the electric motor only supplying supplemental power. Their engines stop when idling and can recapture energy from braking.

Weak hybrids, often used in pick-up trucks, also feature engine stop when idling and recapture of braking energy. However, they have a much lower ratio of electric power to total power than mild and full hybrids do, because they are not designed to use electric power for propulsion. Their considerable battery power can be used to generate electricity on site for power tools and other accessories.

Mild and weak hybrids are currently less expensive to build, but offer significantly reduced benefits than full hybrids. They appear to have been designed as a short-term solution; some manufacturers, including Honda and GM, appear to be moving from weak and mild hybrids toward full hybrid systems. We see the greatest potential for full hybrids. In this report, our use of the term hybrid refers to full hybrids unless otherwise indicated.

Display 15

Fuel Efficiency Rises with Ratio of Electric to Total Power

	Electric to Total Power	Fuel Economy Benefit	Representative Model
Conventional Vehicle	2%	Baseline	NA
Weak Hybrid	5–10%	5–20%	GMC Sierra
Mild Hybrid	10–30%	20–50%	Honda Civic Hybrid
Full Hybrid	30–50%	20–80%	Toyota Prius

Source: National Renewable Energy Laboratory, Dr. Menahem Anderman, Advanced Automotive Battery Conference (AABC), The New York Times, Car & Truck Test Monthly Buying Guide *and AllianceBernstein*

Compatibility with Other Technologies

Hybrid technology is unusual because it is compatible with many other fuel-saving technologies being developed for traditional gasoline or diesel engines, including cylinder de-activation, variable valve timing, direct fuel injection and advanced turbochargers, smaller engines and friction reduction. Each of these techniques is estimated to boost the fuel efficiency of conventional engines by 3% to 8%.[43] Innovations in the use of strong, lightweight materials, design improvements and flex fuels also have the potential to increase fuel efficiency without sacrificing performance. These technologies can be incorporated into hybrid vehicles, as well as conventional cars.

Promising research is underway on ways to reduce vehicle weight, while maintaining safety standards. Such materials as carbon-fiber composites, aluminum, magnesium, plastics and high-strength steel are central to this effort. Design changes are also important. A rule of thumb in the auto industry is that every 10% weight reduction leads to a 5% to 7% fuel-efficiency gain. Other potential improvements include reducing aerodynamic drag and rolling resistance through enhanced design and engineering, and the use of better accessory technologies: efficient alternators, pumps and compressors, and intelligent diagnostic systems.

Flex fuels are another promising development: Nearly 70% of new cars sold in Brazil are designed to run on either alcohol, gasoline or any combination of the two. Such vehicles are easy to equip; the marginal cost of such changes is currently about $100 per vehicle. However, considerable debate exists regarding the benefits of flex fuel use over a vehicle's life. While many experts agree that cellulose-based ethanol, made from all parts of various grasses and other plants, is an effective way to reduce oil consumption, the merits of using corn-based ethanol are questionable. Sugarcane-based ethanol and biodiesel from rapeseeds and palm oils are also options.

Other promising future technologies include controlled auto ignition (CAI) for gasoline, and homogenous charge compression ignition (HCCI) for diesel. While their benefits are expected to be sizeable, they are still not quantified.

In the future, the most fuel-efficient vehicles will be those that incorporate as many of these fuel-saving innovations as possible in conjunction with hybridization. We estimate that such vehicles could achieve fuel efficiency of 50 to 75 miles per gallon, two to three times more than a conventional vehicle.[44] With further technological advances, fuel efficiency could rise even higher.

OTHER HYBRIDS: BUSES, TRUCKS AND MILITARY VEHICLES

This report focuses on the hybrid opportunity in light-duty vehicles, since it is the largest component of oil demand within transportation. There are, however, significant developments in the hybridization of other modes of road transport.

Buses. About 1.4 million buses are on the road globally, accounting for about 5% of the fuel consumed for all transportation needs, according to the IEA/SMP. Buses travel 50,000 to 100,000 miles per year on average; they achieve only seven to nine miles per gallon. Several cities have recently begun to commission hybrid buses; the largest order placed so far has been for 500 buses by the New York City Transit Authority.*

An operating study by the National Renewable Energy Laboratory (NREL) of New York City found that hybrids had many advantages over competing power train technologies. Over an eight-month period, hybrid buses driving in rush-hour traffic delivered 45% better fuel efficiency than diesel buses and 100% better than natural gas buses, the NREL found.[45] Additionally, the hybrid buses were more reliable, requiring road calls every 10,000 miles versus every 8,000 miles for natural gas buses and 5,000 miles for diesel buses. Anecdotal evidence suggests that hybrid buses also have an acceleration advantage, which is helpful because they stop, start and re-accelerate frequently. They also have an emissions advantage, which is particularly important in densely populated areas and warm climates. As a result, we expect many cities to convert to hybrid buses.

Trucks. Medium- and heavy-duty trucks are a much larger potential market for hybrid technology. According to the IEA/SMP, there are about 46 million medium- and heavy-duty trucks on the road globally, consuming about 25% of the transport sector's total fuel. Most of these trucks are required for delivery, freight and garbage collection uses; they typically travel 50,000 to 100,000 miles a year. Since they often carry heavy loads, they typically run on diesel fuel, with an estimated fuel efficiency of four to 10 miles per gallon. Several automakers and parts suppliers, such as Eaton, Mitsubishi and Volvo, have announced plans to introduce hybrid diesel/electric medium- and heavy-duty trucks between 2007 and 2009. The expected fuel efficiency benefit is in the 30% to 70% range, depending on the size and weight of the vehicle, and whether it is used for city or highway driving. We expect hybridization of medium- and heavy-duty trucks to be a longer-term development because the technology has yet to be commercialized.

Military Vehicles. Light-duty armored trucks, medium- and heavy-duty supply trucks and tanks could also be hybridized. Global data on the number of these vehicles and their miles traveled and fuel efficiency are difficult to obtain for security reasons. Several auto-parts companies we interviewed said the US military is interested in hybridization to make its vehicles more efficient and reliable, as well as faster. These features are particularly attractive for use in mission-critical operations.

Greater fuel efficiency for military vehicles would reduce the logistical time, effort and expense involved in transporting fuel to sometimes remote locations. A Pentagon study found that fuel accounted for 70% of the cargo tonnage in most US military supply convoys; it estimated that fuel delivery to operations in Iraq cost "hundreds of dollars per gallon" since fuel convoys have to be guarded by combat troops on the ground and helicopters above. The *Financial Times* reported that the total cost of refueling a military vehicle in Afghanistan was $600 per gallon and $150 per gallon in Iraq two years ago.[46]

The Abrams tank, one of the most powerful tanks ever made, is a telling example. It features turbine engines designed in the 1960s that have never been updated. As a result, its engines burn about one gallon of fuel per mile.[47] According to the *Financial Times*, it costs $60,000 to drive the Abrams tank 250 miles from southern Iraq to Baghdad, at a cost of $240 per mile. It even consumes 12 gallons an hour when standing still. Small wonder the US Army is reportedly considering hybrid technology for the Abrams tank! We expect military establishments around the world to seek to deploy hybrid technology rapidly.

* New York City uses Orion VII-series hybrid buses sold by DaimlerChrysler. They contain a hybrid propulsion system from BAE Systems and an ultra-low-sulfur diesel engine from Cummins.

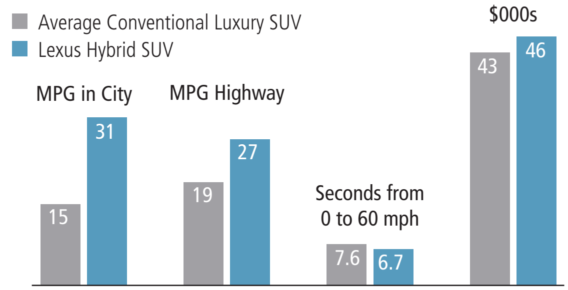
THE CASE FOR MASS ADOPTION OF HYBRIDS

Since 1997, only about 820,000 hybrid vehicles have been sold worldwide (representing less than 0.2% of total new car sales). In 2005, 68% of hybrid sales were in the US; 20% were in Japan. Our research suggests, however, that within 10 years, more than half of all new cars sold in developed markets will be hybrids. A significant reason for our confidence in their rapid adoption is that automakers can configure hybrid systems to meet diverse customer preferences for fuel efficiency and performance. For example, for customers who most value performance, manufacturers can pair a large engine with an electrical motor to achieve superior performance and/or functionality compared to conventional vehicles. For customers who most value fuel efficiency, manufacturers can utilize significantly smaller engines and still provide customers with the performance characteristics they are used to from a conventional car. In all cases, however, full hybrid technology enhances both fuel efficiency *and* performance, while reducing emissions.

The Toyota Camry hybrid is optimized for the more energy-conscious consumer who does not want to sacrifice performance. By contrast, the Lexus SUV hybrid (also made by Toyota) is targeted for customers who want better performance and luxury. The Lexus hybrid surpasses all of the other luxury SUVs (V6 and V8) on fuel efficiency by a wide margin and almost all of them on power, yet it costs only about 8% more than the average luxury SUV (*Display 16*). We expect the limited range of hybrid offerings today (in terms of attribute selection, performance and costs) to expand dramatically over the next several years, as automakers mount a steep learning curve in this technology.

Display 16

Hybrids Offer Huge Benefits for a Modest Price Premium



Average for conventional luxury SUVs includes Acura MDX, BMW X3, BMW X5, Cadillac SRX, Hummer H2 SUT, Infiniti FX, Land Rover LR3, Land Rover Range Rover HSE, Lexus GX 470, Lexus RX 330, Lincoln Aviator, Mercedes ML350, Porsche Cayenne, Saab 9-7X and Volvo XC90.
Lexus Hybrid SUV is Lexus RX 400h.
Source: Autos.com, Consumer Guide: Car and Truck Monthly and Road & Track Buyer's Guide

A recent survey by R.L. Polk indicates that 78% of US consumers would consider buying a hybrid, implying that current demand for these vehicles could be in the millions, far above current annual production capacity of less than 600,000.[48] In fact, at one point during 2005, Toyota's inventory of the Prius dropped to what could be sold in several hours.[49]

The reason for the current capacity shortage is twofold. First, in the past, some auto manufacturers viewed hybrids as a "transition technology;" therefore, they did not invest in the research and development necessary to offer a variety of high-quality products today. This situation should change soon, because the benefits of hybrid technology are now widely recognized by virtually all industry participants. Second, those automakers that have made significant R&D investments in hybrid technology are improving their systems so rapidly that they don't want to make large-scale investments in production facilities that will soon be out of date. Their limited investment in production capacity is a sign of their confidence that further efforts at innovation will succeed, not a sign of skepticism about hybrid technology's potential.

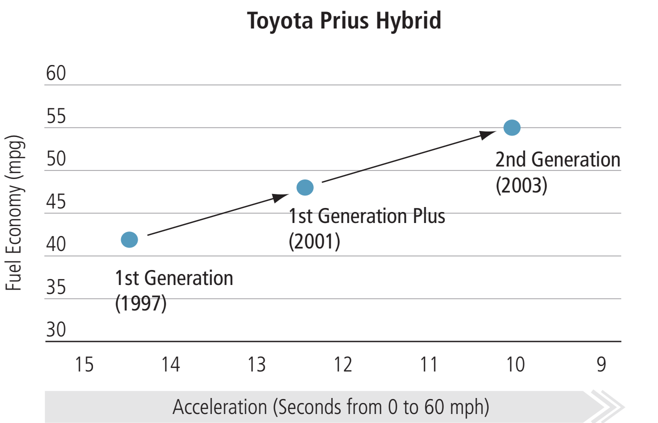
Our research suggests that with the release of new generations of hybrid technology over the next few years, production capacity and unit sales should increase significantly.

Technological progress has already been dramatic, as shown by the evolution over the last seven years of the Prius (one of the longest-selling hybrids). The Prius (a full hybrid vehicle) has significantly improved both fuel savings and acceleration from 0 to 60 mph (*Display 17*). It has also become larger and roomier: A subcompact in 1997, it became a mid-size vehicle in 2004. Finally, its emissions have declined by over 30%. As a result, the Prius now qualifies as an advanced technology zero-emissions vehicle, the second best of seven ratings under the stringent California standards.* The 1997 version of the car would likely have been rated a low-emissions vehicle, the second lowest California rating.

* In 1970, the federal Clean Air Act established nationwide air quality standards and granted California the authority to set its own standards to target five pollutants: hydrocarbons, nitrogen oxides, carbon monoxide, particulate matter and formaldehyde. Other states began adopting California's more stringent standards in 1990. Under the California system, vehicles are placed into one of seven ratings: The best is a zero-emissions vehicle, which is 98% cleaner than the average new 2003 vehicle. Full hybrids generally fall into the second highest category, and are about 90% cleaner than the average new 2003 car.

Display 17

Hybrids Are Improving Rapidly



Source: Toyota and AllianceBernstein

Lessons from History

Since the invention of the internal combustion engine automobile 100 years ago, no new technology introduction in the auto sector has been as revolutionary as we expect hybrid technology to be; thus, history is a poor guide to forecasting hybrid penetration rates. Nonetheless, the introductions of common-rail diesel in Europe and of automatic transmission, front-wheel drive and fuel injection in the US, do provide some useful comparative data (*Display 18*).

The launch of the common-rail diesel system in Western Europe in the late 1990s is probably the closest analogue. Diesel-powered vehicles represented only about 16% of new passenger car sales in Western Europe in 1992, and the penetration rate flattened out after reaching about 22% in 1995. In 1997, when prices at the pump increased by about 10%, tax-advantaged diesel became 30% cheaper than gasoline. Thus, when the common-rail technology was introduced, it improved diesel's already superior fuel efficiency and carbon-dioxide emissions versus gasoline-powered cars. Diesel is a lower-quality fuel than gasoline: Diesel particles are larger and heavier, and thus more difficult to pulverize in combustion. As a result, fewer particles are burnt, which increases pollution while reducing power.[50] Common-rail technology improved the process through the use of high-pressure, direct fuel injection via a common rigid pipe (hence the names common rail or direct injection). The result was a dramatic rise in market penetration: Diesel vehicles rose rapidly from 22% of new cars sold in Western Europe in 1997 to over 50% in 2005.

Display 18

Likely Pace of Adoption: Lessons from History

	Years to Achieve Penetration Rates of:		
Technology/Innovation	**20%**	**50%**	**80%**
		European Auto Sales	
Common-Rail Diesel	<5 yrs	<10 yrs	NA
		US Auto Sales	
Airbags*	3 yrs	5 yrs	7 yrs
Front-Wheel Drive	6	9	13
Fuel Injection	5	9	13
Multi-Valve Engine	3	10	20
Radial Tires	3	4	4

**Required by law*

Source: EPA, National Research Council, Wards and AllianceBernstein

In the US, several technologies have achieved 50% penetration in 10 years or less without being required by law.[51] None of them offer benefits as compelling as hybrids, suggesting that hybrids may achieve significantly faster adoption than most analysts currently predict.

Surmounting the Price Premium

Most projections of low adoption rates for hybrids assume their price premiums will remain a significant obstacle. Most analysts note that it would take six to 10 years for the average driver to recoup through lower fuel consumption the upfront price premium for a hybrid, even with the benefit of tax incentives. They conclude that the payback is too long to induce rapid adoption, without considering the potential for costs to fall, and the other benefits hybrid vehicles offer, such as improved performance, lower emissions, and time savings from fewer trips to the gas station.

The payback calculation—modeled perhaps on calculations applied to insulation-related home improvements—is a new phenomenon for auto analysts. When four-wheel drive, air conditioning and other innovations were introduced, analysts did not try to calculate "payback periods." Rather, they determined (correctly) that consumers would want these features and that the price premiums for them would fall as manufacturers achieved economies of scale. Eventually, most automakers were forced to make the advanced features part of the standard package, or lose market share. We expect hybrid technology to follow the same path.

Furthermore, since demand for hybrids continues to outstrip supply, we don't know their true clearing price. Hybrid price premiums are currently in the range of $4,000 to $9,000[52]: The Honda Civic hybrid requires a $4,000 premium; the Prius, about $6,000 over a

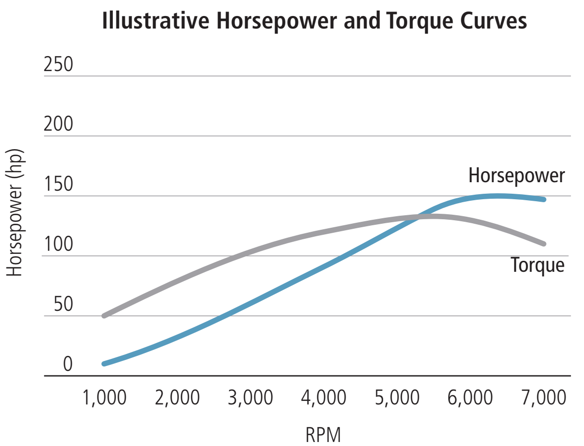
HYBRIDS AND PERFORMANCE

Torque is a measure of rotational force; horsepower is directly proportional to torque and revolutions per minute (rpm).*

In gasoline-powered vehicles, the torque and horsepower of the engine vary greatly over the rpm range (*Display 19*). As combustion occurs, torque typically increases rapidly from relatively low levels, causing the pistons to rotate the crankshaft and drive the wheels. At faster speeds, air intake issues cause engine torque to peak. Horsepower also increases steadily as rpm rise; it peaks after the maximum torque is attained because the benefit of higher rpm initially offsets the impact of declining torque. For instance, the gasoline-powered Toyota Camry produces a peak torque of 153 foot pound (ft lb) at 4,000 rpm and peak horsepower of 160 hp at 5,700 rpm.

Display 19

Gasoline Engines Rev to Maximum Speed and Power



Based on 1999 Chevy Neon
Source: Ed Lansinger, Horsepower vs. Torque, Allpar.com

Diesel engines, by contrast, typically have much higher torque at low rpm due to their heavy weight and larger compression ratios. This is particularly useful for vehicles carrying heavy loads at low speeds, such as trucks and construction equipment. However, the same characteristics limit diesel engines' ability to accelerate at high rpm and produce torque at higher speeds. The smaller effective rpm range of diesel engines results in less horsepower. For instance, the Volkswagen Passat has a maximum torque of 247 ft lb at 1,800 rpm, but its peak horsepower is only 134 hp at 4,000 rpm. While the Passat has significantly higher torque at low rpm than the Camry, it has less horsepower and hence longer acceleration times.

By combining a gasoline engine with an electric motor, gasoline hybrids deliver better performance than either gasoline or diesel engines. Since they do not rely on combustion for starting, and instead draw on the battery, they can utilize the power of their motors to produce instantaneous torque at low rpm. For instance, the Camry hybrid produces 203 ft lb of torque from 0 to 1,500 rpm, more torque than conventional gasoline or diesel vehicles can achieve at those engine speeds (*Display 20*). To date, most automakers have

* Horsepower is equal to (torque x rpm)/5250.

comparable gasoline vehicle. With supply far below demand, the premiums have been stable to rising. But their cost of production has fallen sharply: Prius production costs have fallen by more than 50% over the last seven years. Toyota is targeting a further 50% cost reduction with the next-generation Prius, which is targeted for launch in 2008.

According to studies commissioned by the California State Energy Commission and California Air Resources Board, automakers and hybrid component manufacturers expect hybrid costs to decline by about 30% to 50% per generation at least until 2012.[53] Their estimates assume steady increases in sales volumes due to scale, learning curve effects, and improved technology and design. Several automakers and auto parts suppliers, as well as academic studies, have confirmed this projected cost curve.[54]

We estimate that by 2010, the cost premium of a "typical" hybrid power train will fall to about $2,000 (all else being equal), largely due to a sharp drop in component costs. Other potential opportunities to reduce costs include eliminating the transmission in current vehicles and the lead acid battery. Automakers will also utilize smaller, lesser expensive engines without sacrificing performance, because the electric motor more than compensates.

Display 20

Hybrids More Quickly Gain Power and Speed

Mid-Size Power Train Comparison

	Diesel (Turbo)	Gasoline	Hybrid (Gasoline)
Maximum Power	134 hp @ 4,000 rpm	160 hp @ 5,700 rpm	188 hp @ 4,000–4,500 rpm
Maximum Torque	247 ft lb @ 1,800 rpm	163 ft lb @ 4,000 rpm	203 ft lb @0–1,500 rpm
Acceleration (seconds from 0 to 60 mph)	10.5	8.8	8.5
Combined MPG (city/highway)	32.5 (27/38)	29 (24/34)	40 (43/37)

Diesel (turbo) vehicle represented by Volkswagen Passat; gasoline-powered vehicle by Toyota Camry and hybrid (gasoline) by Toyota Camry. All three have 4 cylinders; Passat has 2-liter engine; both Camry's have 2.4-liter engines.

Source: ConsumerGuide, Greencarcongress.com and Toyota

not released data regarding total system-level torque for their hybrid vehicles, therefore we cannot draw an exact torque curve.* We can say, however, that the torque of the motor is likely to dominate the system at low rpm, while the torque of the gas engine will likely dominate at higher rpm. This suggests gasoline hybrids have higher torque at low rpm, though lower torque at high rpm than their traditional diesel and gasoline engine counterparts.

Lower torque at high rpm is not a limiting factor for the performance of most hybrids, since many offset this disadvantage with the ability to rev their engines to high rpm ranges, which enables them to generate higher system horsepower than their diesel or gasoline counterparts and hence have better acceleration over the rpm curve. For example, the Camry hybrid produces maximum horsepower of 188 hp after 4,000 rpm, considerably more than the gasoline Camry or the diesel Passat.† Moreover, the horsepower achieved by the Toyota hybrid system stays relatively flat at high vehicle speeds, as the system holds the engine at its optimum speed for fuel efficiency and draws on the motor for additional power. In conventional vehicles, horsepower falls sharply after reaching a certain rpm. It is the combination of the motor and engine working together that allows the hybrid to achieve high horsepower at faster vehicle speeds, resulting in quick acceleration from 0 to 60 miles per hour and impressive high-speed acceleration (as is needed for passing on the highway), while achieving superior fuel efficiency versus other power trains.[55]

* We can not accurately estimate the system torque using the standard equation, since hybrids that employ CVTs or e-CVTs have both mechanical and electrical power inputs and outputs and the electrical part is too variable for consistent measurement.

† While it is best to compare vehicles with the same number of cylinders, liters and displacement, lack of data make such comparisons impossible.

Manufacturers are likely to still try to charge a premium for these vehicles; we expect consumers to be willing to pay this premium to gain increased efficiency, better performance, more advanced safety and luxury features, higher resale values and reduced maintenance costs. Over time, hybrids may actually offer higher margins than conventional vehicles for automakers farther down the hybrid cost curve. We predict that auto companies that cannot offer a wide range of hybrids will lose market share or be forced to cut prices and margins to compete.

While automakers do not release data on the profitability of individual models, our research suggests that today, only Toyota and Honda are making profits on hybrids, although their profits per hybrid vehicle sold are subpar. Toyota's profitability is rooted in its highly efficient and flexible manufacturing operation and its higher volumes; Honda's profitability reflects its focus on mild hybrids, which are less expensive to produce. Toyota is likely to be garnering higher profits on its Lexus RX 400h than on the Prius, since the Lexus hybrid is only sold with a wide array of high-margin extras, such as leather seats and advanced audio and navigation systems. With demand outstripping supply, Toyota could raise prices to increase profits on the Prius, but has chosen not to, in

(continued on page 24)

THE IMPACT OF PUBLIC POLICY

For nearly a 100 years, governments around the world have recognized that depending on a single scarce resource—oil—could have significant implications for economic and employment growth and competitiveness, as well as the environment and national security (if the resource was sourced abroad). Since the oil price shocks of the 1970s and 1980s, governments have adopted a wide range of policies to reduce oil dependency.

In response to the oil shocks of the 1970s, the US passed fuel-economy standards. Brazil mandated the production and distribution of sugarcane-based ethanol and encouraged the use of flex-fuel cars. Many European nations adopted high taxes to encourage a shift to diesel, and Japan and other countries adopted taxes to promote smaller, fuel-efficient cars. Many countries have also set explicit standards to improve air quality and reduce climate-change pressures, often implicitly targeting fuel economy in the process. Many countries have also pursued policies to nurture, advance or protect their domestic auto industries; these policies have sometimes conflicted with and at other times furthered their energy policies.

Many of these policies have been successful. Automobile fuel economy in the US improved by nearly 70% from 1975 to 1987. (Progress on automobile fuel economy ceased after 1987 with the surge in sales of SUVs, which were exempt from the fuel-economy standards.) In Brazil, 70% percent of new cars sold employ flex-fuel technology. In Europe, more than 50% of new light-duty vehicles sold are diesel-powered.

We expect government policy with respect to hybrid vehicles to a*ccelerate* mass adoption that would otherwise occur more gradually as economies of scale eroded the price premium and as hybrids' technological superiority became widely appreciated. In monitoring the likely speed of mass adoption, there are several different types of policies to watch: purchase incentives, fuel and vehicle taxes, mandated purchases by fleets, and fuel-economy and/or clean-air standards.

Purchase Incentives

With the Energy Act of 2006, the US is offering federal tax credits of $250 to $3,400 per hybrid vehicle purchased, depending on their fuel economy. However, in an effort to help US automakers catch up with Japanese counterparts that currently lead in hybrids, the credits only apply until a given manufacturer reaches 60,000 in hybrid sales; thereafter, the credits are gradually eliminated. If, as some people fear, hybrid purchasers who are subject to the alternative minimum tax (AMT) cannot receive the tax credits, the credits would have less stimulative impact on hybrid sales. Exempting hybrid purchases from the AMT would require a congressional action. Most policy analysts believe this is unlikely to occur.

Many state governments in the US are also offering state tax credits or deductions for hybrid purchasers; they range in size from $300 in Maine to $4,713 in Colorado.[56]

Ten states and eight local governments also offer or plan to offer such benefits as reduced parking, registration, taxes and/or toll fees for hybrids. Maryland and Washington may offer exemptions from emissions testing. Other states may join California and Virgina in offering access to high-occupancy lanes regardless of the number of passengers. A few states also have specific tax incentives aimed at private fleet owners.[57]

In Japan, tax credits of up to $3,500 have been available to hybrid buyers since 1998, but are now being phased out. Germany and the Netherlands offer tax incentives of about $500 for clean vehicles, such as hybrids.[58] Some European automakers are reportedly lobbying to have hybrid incentives eliminated, since their Japanese competitors have a significant technological lead in hybrids.

Indirect Tax Incentives

In many countries, ownership taxes—charges on the acquisition, registration, inspection and retention of a vehicle—vary based on the fuel, engine size, efficiency or emissions of a given vehicle. Fuel taxes levied at the pump also vary by fuel type to stimulate purchase of one over another. For instance, many European countries have much lower ownership and fuel taxes for diesel than they do for gasoline in order to encourage a shift to more fuel-efficient diesel vehicles. Europe's relatively high fuel taxes versus those in the US are a way to discourage driving altogether. In Europe, China, Japan, South Korea and Taiwan, taxes are lower for smaller, fuel-efficient cars. In the US, the so-called gas-guzzler tax aims to discourage use of the most fuel-inefficient vehicles.

London, Stockholm, Singapore and other cities have also implemented congestion taxes to reduce traffic and travel times, and improve air quality. London charges drivers £8 ($14.25) on weekdays and £3 ($5.35) on weekends. It has recently agreed to waive the tax for fuel-efficient hybrids. Private fleet owners are reported to be extremely interested in hybrids as a result.

Mandated Purchases

US federal fleets are required to select the most fuel-efficient vehicles. Under Executive Order 13149 (signed April 2000), each federal agency with an operating fleet of 20 or more vehicles was charged with reducing its oil consumption by at least 20% from baseline levels. Switching to hybrid vehicles is among the options permitted. Several states also mandate the purchase of hybrid vehicles: Massachusetts requires that, starting in 2010, 5% of all new state fleet vehicles purchased be hybrids.[59]

New York requires that, starting in 2010, all state vehicles purchased be "clean"; hybrids qualify. Connecticut requires state agencies to purchase light-duty vehicles that are fuel efficient, defined as 40 miles per gallon or more. San Francisco requires all city-owned cars and light trucks to be low-emission vehicles, such as hybrids.

In New York City, the Taxi & Limousine Commission is evaluating a mandated conversion to hybrids over the next five to 10 years. Other taxi commissions could follow suit; in Japan and India, some have converted to liquified petroleum gas or compressed natural gas.

Some broad mandates addressing several types of clean vehicles could also increase hybrid sales and spur additional hybrid research and development.

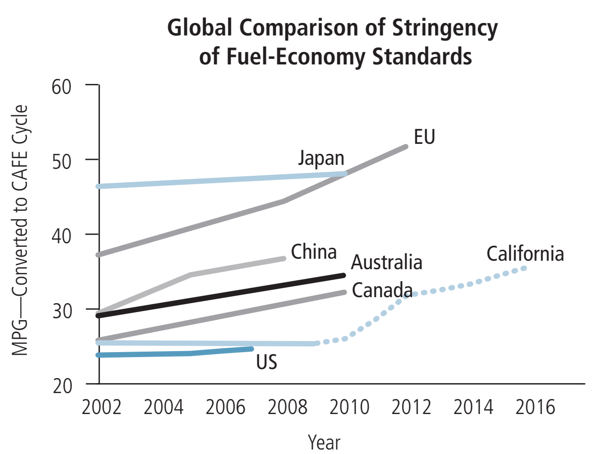
The most important is California's requirement that 10% of all new vehicles sold by automakers be zero-emission vehicles (ZEVs).[60] The mandate has been effectively softened to allow 2% ZEV, 2% advanced technology partial zero-emission vehicles (AT-PZEV) and 6% partial zero-emission vehicles (PZEV). Measurement of the target has also been weakened: Instead of counting vehicles sold by type, each sale earns credits toward the target according to a complex formula. Many of today's hybrids qualify as AT-PZEV; future plug-ins may qualify for either AT-PZEV or ZEV, depending on the electric driving range achieved. However, plug-in hybrids will earn automakers much higher credits than a PZEV. Maine, Massachusetts, New York and Vermont have expressed an interest in adopting California's ZEV policy, but court challenges could invalidate it.

Standards

Automobile fuel-economy standards have proven to be very effective in reducing oil demand and greenhouse gas emissions from the transposition sector in many parts of the world. Most countries have fuel-economy standards; only the EU and California have greenhouse gas standards (*Display 21*). The Pew Center has found that EU standards will be the most stringent, followed by those in Japan, China and California.[61] The least stringent standards are within the US.

Display 21

US Federal Fuel-Economy Standards Lag Far Behind



Source: Feng An, Pew Center for Global Change and WRI Capital Markets Research

(continued from page 21)
order to establish a strong foundation for future market growth. Anecdotal evidence suggests that Honda and Toyota are also benefiting from their hybrid offerings through increased traffic to their show rooms.

Other automakers, such as Ford and Nissan, are probably losing money on their hybrids because they are paying relatively high license fees to Toyota for components. Honda has yet to license its systems to other automakers. New entrants to the hybrid market will likely face losses or lower profits per hybrid vehicle sold until they or their suppliers climb further up the learning curve and achieve greater economies of scale. Despite the near-term limited profit profile of this market, the longer-term growth opportunity it represents requires continued investment by all automakers. We expect that over time, success in this segment will have a significant impact on stock-price performance for both automakers and their suppliers.

HYBRID SYSTEM COMPONENTS

The main components of hybrid systems are batteries and related electrical systems, electric motors/generators, power-split device, and power and control and other electronics. For a compact or mid-compact full-hybrid, we estimate these components cost automakers about $4,500-$6,000[62] (*Display 22*).

Display 22

Hybrid's Price Premium Has Several Sources

Manufacturers' Cost of Components	2005
Battery and Related Electrical Systems	$1,400–$2,500
Electric Motor and Generator	$900–$1,300
Power-Split Device	$500–$1,000
Electronics (Power, Control and Other)	$2,000–$2,100
Savings (Smaller Engine, Transmission)	($300–$900)
Total Added Costs in 2005	**$4,500–$6,000**
Estimated Added Costs in 2010	**$2,000**

Sources: California Energy Commission, Energy Conversion Devices, Energy and Environmental Analysis, JPMorgan, University of Michigan Transportation Institute and SAFT

Toyota and Honda now manufacture many of these components themselves or through in-group companies; Ford and Nissan are licensing systems and buying parts from Toyota and its group companies; GM and DaimlerChrysler are seeking to share parts and technology. Peugeot, Volkswagen and others are turning to independent suppliers for hybrid expertise. As one would expect, traditional auto suppliers, as well as new entrants, are trying to capture this new and growing market.

Here are the various components of the hybrid system.

Battery Systems and Related Electrical Systems

The most expensive single hybrid component is the energy storage system, which includes a battery pack (containing 100 to 250 cells), a cooling system and a battery control unit. Together, these parts represent about 30% to 50% of the total cost of a hybrid system today.

By definition, batteries facilitate electrochemical reactions in which electrons flow from negative to positive materials to discharge energy in the form of direct electric current. In rechargeable batteries, electrons also flow in reverse from positive to negative materials to store energy. The battery chemistry that dominates the hybrid-vehicle market today uses nickel metal hydride (NiMH), rather than the lead acid used in traditional auto batteries, or the lithium batteries used in lap-top computers and cell phones.

Unlike lead acid batteries, nickel batteries are environmentally benign, yet they have twice the energy density (energy held relative to weight) of a lead acid battery, and three times the power density (speed of energy release).

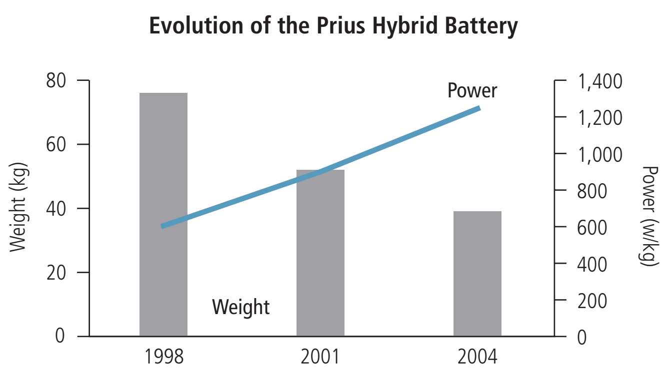
Nickel batteries perform well through many cycles of charge and discharge, and most manufacturers provide warranties for eight to 10 years in the US; lab tests suggest a 10 to 15 year life is possible. To last this long, nickel batteries must be kept in an ideal state of charge, which the battery control unit ensures. In the Prius, the battery system only uses 20% to 25% of the battery's energy in order to maintain the charge necessary for optimal power over its long life. While nickel batteries tend to lose some power after extensive use, having more cells than needed at the beginning ensures sufficient capacity throughout operation.

To date, most automakers pursuing the hybrid market have focused on maximizing the power density of hybrid batteries, since higher power densities enable a hybrid's electric motor to accelerate faster and boosts fuel efficiency by displacing the gas engine during low-speed acceleration. By contrast, batteries developed for pure electric vehicles (with no gasoline or diesel engine) have emphasized energy density since they require the greatest possible range between rechargings to be practical. Given the energy density limitations of today's battery technologies, we do not expect pure electric vehicles to be a feasible mass-market alternative within the next decade.

Manufacturers of hybrid batteries have been able to reduce costs and enhance performance in recent years (*Display 23*). Cost and performance—in terms of

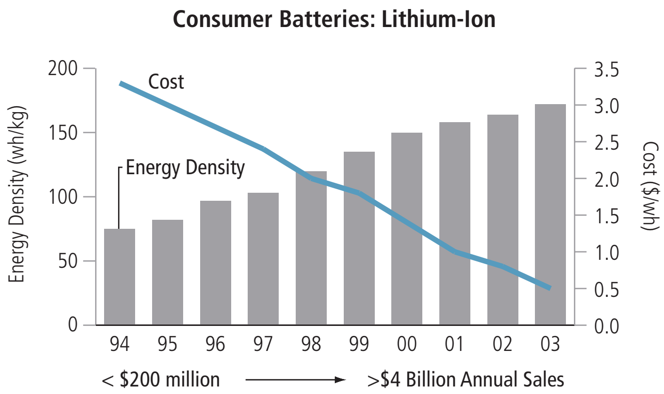
Display 23

Hybrid Batteries Are Getting Better and Cheaper



Source: AABC (2005) and Toyota

Display 24
Costs for New Products Tend to Fall Rapidly



Source: AABC (2005), AC Propulsion and AllianceBernstein

energy, power and volume/weight—improve about 10% per year, depending on which attribute manufacturers are seeking to optimize and the scale of production. Trade-offs inherent in battery design make it difficult to improve all variables simultaneously, but better performance on multiple fronts is likely over the next several years. Industry executives expect costs to fall by up to half the current level of $1,400 to $2,500 per vehicle for a mid-size passenger car as production reaches high volumes.* Although the large cost reduction envisioned may seem optimistic, costs for consumer lithium batteries fell far more—86%—as manufacturers achieved economies of scale (*Display 24*).

Many analysts think that batteries are the limiting factor in the proliferation of hybrid technology: The nickel batteries available today simply do not offer enough energy storage or power to allow a vehicle to run long distances on electricity alone, which is key to higher fuel efficiency. We disagree. To date, investment in improving battery technology has been restrained in anticipation of technological advances in composite materials, particularly lithium. We expect significant performance improvements as lithium-based batteries replace nickel-based batteries before the end of this decade.

Lithium batteries have many advantages. They offer twice the energy density and two to three times the power density of nickel batteries. This means that, for any target level of performance, they are lighter and smaller than nickel batteries, which enhances fuel efficiency and allows greater flexibility in design. At the 2006 North American Auto Show, Johnson Controls displayed a lithium battery that was 50% lighter and 30% smaller than a nickel battery of comparable power and energy density. Preliminary data suggest that lithium-based batteries last through more cycles of charging and discharging, charge faster, and allow for charge and discharge at deeper levels, which should be helpful in the next generation of hybrids.

Their drawbacks are safety and cost. The safety issue arises because traditional lithium batteries use lithium cobalt oxide, which can explode. Explosions occur if charging and discharging—particularly overcharging or high-temperature charging—cause degradation that allows oxygen to escape and react with lithium ions or electrolytes.[63] Many companies are actively searching for practical solutions to overcome this well-known risk.

Two approaches that appear to be making progress involve substituting other materials for cobalt oxide. The first entails replacing the cobalt oxide with either manganese oxide (spinel), a combination of nickel, cobalt and manganese (NCM), or a combination of nickel, cobalt and aluminum (NCA). This approach has garnered substantial research dollars; automakers have used it in several vehicle prototypes. The other approach involves replacing the cobalt oxide with a phosphate-based cathode material. Phosphates are more stable in overcharge or short-circuit conditions and are less prone to thermal runaway and combustion. Several companies have demonstrated some success with this approach in power tools and vehicle prototypes.† Both approaches, however, increase charge times and cost, while somewhat decreasing battery life and performance. Other more experimental approaches involve the use of lithium polymers and lithium sulfur. They potentially offer greater energy densities, but are too early stage to evaluate.

* With annual global hybrid sales under 500,000 per annum and therefore fairly limited economies of scale, the aggregate cost of the nickel battery pack used in today's hybrids is currently estimated at about $1,400 to $2,500 per vehicle. The actual cost depends on how much assembly and integration an automaker does. A completely outsourced solution could cost the automaker $2,500 or more.

† Full disclosure: AllianceBernstein has invested in A123Systems, a private Massachusetts-based developer of a new generation of lithium-ion batteries.

Industry experts expect lithium batteries to initially cost as much as 30% more than nickel batteries, but to become cheaper with scale production.[64] Some experts believe that if they attain comparable scale production, lithium batteries could be substantially cheaper than nickel batteries with similar performance attributes, or offer significantly higher performance attributes at equivalent cost. After extensive research on this subject, we are optimistic that the higher cost of lithium batteries will be more than offset by their superior characteristics, and that some kind of lithium battery will become the standard for hybrid vehicles.

Today only a few firms produce batteries for hybrid vehicles: Panasonic EV, a joint venture between Matsushita Electric Industrial and Toyota Motors, accounts for 70% to 80% of total capacity. The rest of the market is divided among three players: Sanyo; Cobasys, a joint venture between ChevronTexaco and Energy Conversion Devices; and a newly formed joint venture between Johnson Controls and SAFT. We expect the number of battery manufacturers to increase as the shift to lithium takes place and the market grows. Hitachi, NEC and Toshiba have also announced lithium-battery research projects.

Electric Motors and Generators

These are the primary workhorses in a hybrid vehicle. The generators draw on the engine to create high power output by rotating at fast speeds to charge the batteries and operate the motors. The motors produce the torque to drive the wheels. There are several types of motors and generators: induction, permanent magnet and switched reluctance. Each requires the presence of a magnetic field. Induction and reluctance motors use electronic circuits to create a magnetic field, while permanent magnet motors use permanent magnets for this purpose.

The critical factors for these components are efficiency, power, cost, controllability and durability. Permanent magnet motors are more efficient, especially at lower speeds and lighter loads, and more controllable; however, they are also more expensive than their counterparts.[65] Induction motors are less efficient than permanent magnet motors because they circulate an induced current over the rotors to generate a magnetic field; this undermines the structural efficiency of the motor. Switched reluctance motors are less efficient than permanent magnet motors and less controllable, which results in noise and oscillation problems.

Focused on fuel efficiency, Honda and Toyota have used permanent magnet motors in their hybrid vehicles. Since motors in full hybrids need to have the power to propel one to two tons, they need to produce considerable torque; doing so requires over a kilogram of neodymium, one of the strongest magnets available.[66] Generators and other electric applications, such as electric steering, also require magnets.[67] We estimate that Toyota's hybrids use about one to two kilograms of neodymium per vehicle at a cost of $100 to $200, largely depending on the number of motors they have.

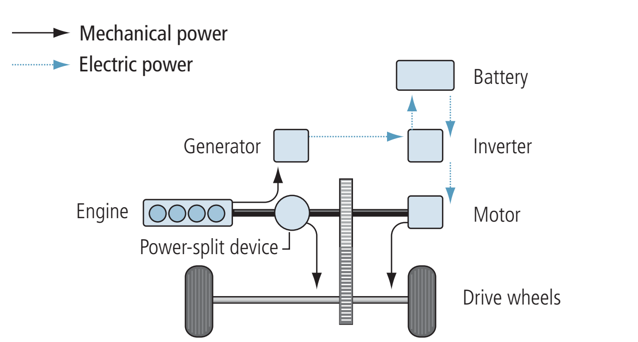
Toyota hybrids also employ a high-voltage power circuit to boost the voltage of the generator, which further increases efficiency. Since power is equal to voltage multiplied by current, doubling the voltage results in a 50% reduction in current if the power to propel a vehicle stays constant. And because energy loss is equal to current squared multiplied by resistance, a 50% reduction in current produces a 25% reduction in energy loss (efficiency gain) if resistance is held constant.[68]

Power-Split Devices

Power-split devices, which are modified planetary-gear systems, are robust ways to optimize the transmission function in full hybrids for fuel efficiency and performance. They replace the traditional transmission, acting as a virtual gearbox between the engine, motor and generator. They allow the motor and engine to power the vehicle separately or jointly, in infinitely variable ratios, without a hitch.

The power-split device links the engine, generator, electric motor and drive shaft, which drives the wheels. It also divides the power of the engine into two paths: a mechanical route and electrical route (*Display 25*). The mechanical route connects the engine to the wheels and

Display 25
Hybrid Power Trains: A Schematic



Source: Toyota Motors

to the generator; the electrical route connects the generator to the battery and the motor, which can also drive the wheels via the drive shaft. With the use of electrical controls, the power-split device can continuously vary the ratio of power going to the wheels and the generator. As a result, it can change a vehicle's speed by either continuously varying the rpm of the engine or the rpm of the generator and electric motor.

The main value of this design is that engine speed can operate independently of vehicle speed. As a result, the power-split device can run the gas engine very efficiently by constantly maintaining the engine at its optimal speed, adjusting the speed of the generator and motor as driving conditions warrant. When required, the device can speed up the generator and use the greater output to deliver more power from the electrical motor to drive the vehicle—in an instant. Additionally, the device can supplement the generator's own power with power from the battery system. If the battery has low charge, surplus power from the engine can be used simultaneously to power the motor via the generator, drive the wheels and charge the battery. If even more power is required, the engine can be called upon to provide additional power, and even speed up to provide greater output (in this instance at the expense of fuel efficiency). As a result, the power-split device improves both fuel efficiency and acceleration time.

Lastly, the power-split device is readily scalable. It can be used on a variety of automotive models, because it can accommodate greater power requirements without meaningful loss of fuel economy. With this system, automakers can continue to build hybrids with greater power by using higher output generators and motors, and/or increasing the voltage in the system by installing more powerful batteries or circuits. These actions allow the electrical motors to drive the vehicles to higher speeds before the gasoline engines kick in, helping to increase performance while maintaining or increasing fuel efficiency. By contrast, the typical path to better performance in conventional vehicles is to employ a larger, more powerful engine, usually at the expense of fuel efficiency.

Since Toyota appears to have strong patent protection around this component technology, other automakers may seek to use either continuously variable, dual clutch or conventional automatic transmissions. Should the fuel efficiency, performance or reliability of these other transmission solutions not match the robustness of the power-split device, it is conceivable that other automakers may seek to license the technology from Toyota.

Electronics (Power, Control and Other)

These components efficiently regulate the power within a hybrid system by managing the flow of voltage and current among components. In conventional vehicles, electronic control units control airbags, batteries, brake systems, engines, locks, navigation systems, windows and other devices.

In hybrid vehicles, an additional ***electronic control unit*** serves as the "brain" of the hybrid, managing the power flow among the battery, generator, motor and transmission or power-split device. By constantly monitoring driving conditions and switching from motor to engine accordingly, the control unit enables hybrid vehicles to optimize power and fuel consumption. The ***inverter*** controls and delivers electric power from the direct-current battery to the alternating-current motor. The ***converter*** receives high-voltage direct current (typically up to 300 volts) from the main hybrid battery and produces low-voltage direct current (typically 12 volt) for the lead-acid battery to help power headlamps and other low-voltage equipment. This is necessary since the lead-acid battery is no longer charged directly by the engine, but rather by the hybrid battery.

The ***insulated gate bi-polar transistor*** is a semiconductor-switching device that controls the highly variable electricity flow among the motor, generator and battery. The transistor also boosts the voltage from the battery and converts the boosted direct current into alternating current, supplying drive power to the motor. For instance, in the Prius, the transistors enable a voltage increase from 204 to 500 volts, resulting in a substantial increase in motor output without an increase in battery output or motor size.[69] By using higher voltages at low currents with minimum heat loss, these transistors allow hybrids to use more power with higher efficiency. Since 1994, these transistors have been used for an increased variety of applications in addition to transportation. Consequently, their size has decreased by about 66% and their prices have fallen significantly.

The ***wire harness and safety circuit*** make wiring smaller, lighter, safer and more compact. This is crucial, because the average passenger sedan has over 1,000 electrical wires totaling a mile in length and weighing several hundred pounds; hybrid vehicles have even more wire.[70] With so much wiring onboard, hybrids need to have many safety circuits to prevent potential damage from a short circuit. Engineers are now trying to reduce the size and weight of wiring by using lighter materials, new technologies and networks that can send multiple signals on a given wire, which should also decrease costs.

The costs of non-battery hybrid components are likely to decline rapidly as automakers outsource production, expand volumes and invest more heavily in component research. As with other electronic products, standardization, modulation and/or miniaturization, and competition are likely to drive down prices as systems mature. Many auto-part suppliers and consumer-electronic companies have already expressed interest in entering the hybrid market. Some of the latter would be new entrants to the automobile market attracted by the more predictable growth and profit profile of the auto sector versus traditional consumer electronics. Furthermore, the Taiwanese government, forecasting that auto electronics would be the next $1 trillion market, is encouraging local semiconductor and technology companies to enter this market by helping them meet automakers' requirements for tier one suppliers.[71]

Assuming that volumes increase, we expect cost reductions of about 30% to 50% every few years for hybrid systems, in line with the historical experience of introducing other power trains and automotive electronic systems. As previously noted, the cost of lithium-ion batteries for consumer applications fell by 86% in less than a decade after their introduction. Additionally, Denso's costs for common-rail diesel and car-navigation systems have fallen by about 50% with volume increases over the past seven to eight years.[72]

ELECTRIFICATION OF THE AUTOMOBILE

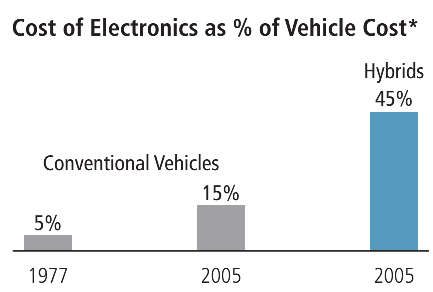
For decades, automobiles were almost entirely mechanical devices. Over the course of the last three decades, however, an increasing number of systems and functions have become electronically controlled. Electronic components provide more precise control, greater reliability and higher efficiencies by eliminating loss due to friction. They are also less expensive, because they are smaller and lighter. "X-by-wire" is a generic term to describe the displacement of mechanical systems by electronic components such as sensors, controllers, power circuits, motors and actuators.

In 1977, the average value of electronic components per vehicle was $110, well under 5% of the total cost of materials and components to automakers.[73] By comparison, today's conventional vehicles contain $1,400 to $1,800 in electronic components, about 10% to 20% of the total cost of materials and components[74] (*Display 26*). In full hybrid models, the electronic content (including the battery and battery control system) costs about $5,900 to $7,800 per vehicle today, or 40% to 50% of the total.[75]

Vehicle electrification is likely to continue. Industry experts claim that 80% to 90% of automotive innovation is based on electronics;[76] they predict that electronics and electrical systems could account for 40% to 50% of the total cost of future conventional vehicles[77] and 70% to 80% of the total cost of hybrid vehicles in the next five to 10 years.[78] Freescale, a leading automotive semiconductor supplier, notes that electronic innovation may lead to "smart" vehicles capable of acting autonomously, resulting in safer, more comfortable and more efficient driving. CLSA, a financial firm, estimates that the expected annual long-term growth rate for the auto-electronics market is 8% to 15%.[79]

Display 26

Electronic Content of Hybrids Is Huge



* *Excludes auto manufacturers' final assembly costs*
Source: CSLA, Leen and Heffernan, Merrill Lynch and AllianceBernstein

The semiconductor content of the vehicle is also increasing rapidly. Semiconductors presently account for $225 to $300 of the cost per non-hybrid vehicle today, and $525 to $900 per hybrid vehicle, depending on the number of electrical motors/generators used.[80] The automotive-semiconductor market is estimated to have $15 billion to $20 billion in annual revenues, with an anticipated long-term growth rate of 8% to 11%.[81]

The growth rates for the auto-electronics and auto-semiconductor markets would substantially exceed these forecasts if our projections of hybrid penetration prove to be correct.

Sensors are used to monitor and analyze data to help the driver and/or the vehicle make faster decisions. Today, there are between 100 and 200 sensors in a vehicle, with luxury vehicles at the top end of the range, versus 50 to 100 per vehicle five years ago.[82] Sensors make possible anti-lock brakes, air bags, battery monitoring, air quality and climate control, crash-avoidance systems, electronic stability control, engine management, lane-departure warnings and tire-pressure monitoring.

Similarly, the number of ***microcontrollers*** per car has increased from 3 to 20 a decade ago[83] to about 30 to 70 today.[84] Advances in semiconductor technology have made possible more affordable, dependable, and powerful microcontrollers and microprocessors that are able to perform tasks previously done by mechanical systems, as well as entirely new tasks. For instance, the microprocessor transistor count has risen from one million in 1997 to over 30 million today.[85] Today's engine controllers optimize fuel and air intake combinations to maximize gas mileage and minimize emissions based on tables with several thousand entries. In the future, these controllers may factor in temperature, humidity, gasoline quality and the vehicle's weight, speed and age to adjust engine parameters in real time. Microcontrollers are more reliable, cheaper and lighter than the relays, switches and other mechanical parts they displace.

Display 27

How Electronics Are Displacing Mechanical Functions

Mechanical Displacement	Description	Benefits
Steering-by-wire	Replaces traditional hydraulic steering system (consisting of a hydraulic pump, fluid, hoses and fluid reservoirs) with a fault-tolerant controller and electrical motors.	Smaller and lighter (and hence more fuel efficient), safer, more responsive and more reliable. May be paired with electronic vehicle-stability and skid-control systems. The motors are powered by the car's battery and not the engine, which also improves fuel efficiency.
Throttle-by-wire	Replaces cable that connects throttle valve and gas pedal with an electrical connection.	More efficient than traditional throttle systems and safer; provides electronic stability and traction control.
Braking-by-wire	Replaces hydraulic-braking system with an electrical-component system that connects the four brake corners with the brake pedal and each other.	Enhances driver control in braking, provides greater uniformity in distribution of brake force, and enhances stability and traction control.
Shift-by-wire	Replaces conventional transmissions with electronically controlled variable transmissions.	Improves efficiency and performance.
Suspension-by-wire	Replaces mechanical damping with active electronic control of damping stiffness.	Improves vehicle stability by active support of wheel traction and by counter adjustments to pitch and roll when braking or cornering.
Integrated starter/alternator	Combines the alternator and starter functions into an electrical generator.	Reduces part count, weight and cost, and offers fast start times, stop/start and regenerative braking capabilities. Improves fuel efficiency and lowers emissions.
Variable valve control	Replaces cams on an engine-powered camshaft with electrical control from the motor; each cam and perhaps each valve can be powered separately.	Improves fuel efficiency and performance; reduces emissions.
Electric catalytic converters	Replaces the mechanical heating of catalysts needed to convert emissions into safe by-products.	Reduces emissions by more quickly achieving high temperatures.
Electric devices	Replaces belts connecting air conditioners, oil pumps, cooling fans and water pumps to the engine for power; provides power from electric motor/generator.	Virtually no impact on performance, but better fuel efficiency.
Electrical accessories (heated windshields, advanced seats and personal settings)	Replaces mechanical processes with electrical power and adds new functionality.	Greater comfort, efficiency and integration of systems.

Source: Jim Lipman "Silicon Fuels the Automative Industry" SemiView*, March 29, 2004, Nathan Trevatt, "X-by-Wire, New Technologies for 42V Bus Automobile of the Future," (2002), and Nico Kelling and Patrick Letinturier, Infineon Technologies, "X-by-Wire: Opportunities, Challenges, and Trends" (SAE, 2003)*

The demand for electrical power within vehicles is increasing at about 4% per year, putting increasing pressure on the 12-volt architecture of automobiles today.* Hybrids are better positioned than conventional vehicles to accommodate more electrical systems because they can use their hybrid batteries for power. Thus, they are likely to be the first vehicles to electrify braking and steering, as well as pumps, valves, suspensions and other mechanical systems (*Display 27*). Toyota already offers many of these electric systems in its hybrids. Conventional vehicles could only follow suit if they convert to a battery system with 42 or more volts. While conversion to a 42-volt system was much discussed several years ago, automakers appear to be cautious: They would rather wait until demand growth stabilizes and convert only once, perhaps directly to a 300-volt battery. Hybrids already use 300-volt batteries, which could pressure automakers to convert to a new standard sooner in conventional vehicles as consumers discover the benefits of electrification.

Providers of electronics and semiconductors for the automotive market should benefit immensely from this trend and from further penetration of hybrids. Sales to the automobile sector tend to be more stable (because automotive sales contracts typically deliver benefits over the vehicle's product life) and more profitable for vendors than sales to many other consumer markets.

* *Leen and Heffernan (2002). The pressure has eased more recently through increased design efficiency via circuits and wiring, but this may be short-lived if power demand continues to rise.*

IMPLICATIONS OF HYBRIDS FOR OIL DEMAND

To date, most demand for hybrid vehicles has come from consumers particularly concerned about fuel efficiency and environmental impact. The limited supply of vehicles and general lack of market knowledge/understanding makes it difficult to gauge the true extent of demand.

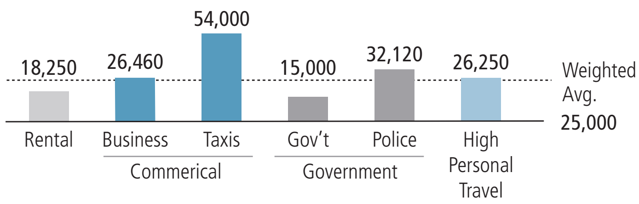
In the near term, we expect the strongest demand for hybrid vehicles to come from those individuals or organizations most likely to recoup the upfront price premium quickly through fuel savings: those with above-average travel per vehicle, such as government, police and commercial fleet drivers, including taxis and delivery personnel. Fleet vehicles with extensive stop-and-go city driving are particularly likely to see the benefits.

In the US, the high-travel segment, comprising business and government fleets and high-travel individuals, represents 30% of new light-duty vehicle sales annually (*Display 28*). Fleet vehicles represent most of these sales. They typically drive an estimated 15,000 to 54,000 miles per year. We estimate that high-travel individuals, who account for about 10% of all personal travelers in the US, represent 8% of light-duty vehicle sales per year. This segment drives an estimated 26,250 miles per vehicle per year, more than double the 12,500 miles per vehicle per year average for light-duty vehicles.[86] Since most countries around the world do not report vehicle sales or miles driven by the high-travel segment, we have had to use the US data as a global proxy.

Display 28

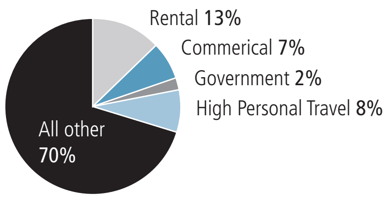
Adoption Will Be Fastest in High-Travel Segments...

Annual Miles Driven (US)



...in Aggregate a Significant Part of US New Vehicle Sales

Share of New US Sales



Miles traveled was increased by 0.5% per year to reflect current year.
Source: Argonne National Laboratory, Center for Automotive Safety, Ford, Hertz, US Department of Transportation and AllianceBernstein.

Contrary to popular belief, both commercial and government fleets have tended to be early adopters of new technologies, even when the initial costs were high, if the operating costs and tax incentives were attractive. For instance, in Great Britain, following the introduction of

Display 29

For Taxis, the Payback on Price Premium Is Very Rapid

Hybrid Analysis by NYC Taxi & Limousine Commission

	Baseline Vehicle	Hybrid					
Model Make	**Ford Crown Victoria**	**Ford Escape**	**Toyota Highlander**	**Toyota Prius**	**Honda Accord**	**Honda Civic**	**Lexus RX 400h**
Tank Size	19.0	16.5	17.2	11.9	11.1	11.9	17.2
Fill Cost ($2.97/gal)	$56	$49	$51	$35	$51	$35	$51
MPG (City)	18	36	33	60	29	47	31
Miles per Tank	342	594	568	714	496	559	533
Gas Cost/Year*	$7,259	$3,629	$3,959	$2,178	$4,505	$2,780	$4,215
Savings	n/a	$(3,630)	$(3,300)	$(5,081)	$(2,754)	$(4,479)	$(3,044)
Purchase Price	$27,570	$26,900	$33,030	$20,975	$30,140	$19,900	$49,060
Premium (as per April 2006 Consumer Reports)		$6,322	$7,185	$5,698	$5,678	$3,976	$8,765
Implied Payback (Period) (Excludes Tax Incentives)		**1.7**	**2.2**	**1.1**	**2.1**	**0.9**	**2.9**

All data in first seven rows from the NYC Taxi & Limousine Commission analysis.
**Assumes each taxi travels 43,992 miles per year*
Source: Consumer Reports, *New York City Taxi & Limousine Commission and AllianceBernstein*

common-rail diesel systems, the share of diesels steadily increased from 16% in 1997 to 37% in 2005; nearly 70% of the incremental growth in diesel sales came from fleets.[87] The diesel systems cost more upfront (an estimated $1,000 to $2,000 more) but offered reduced fuel bills due to improved fuel efficiency and somewhat lower registration taxes. The UK is one of the few countries in Europe where diesel is *not* cheaper than gasoline at the pump, so the conversion to the diesel from gasoline was mainly due to the fuel-efficiency benefit, not tax incentives.

Similarly, we expect fleets to embrace hybrids despite the upfront premium because it will be offset relatively quickly by reduced fuel bills. A recent study by the New York City Taxi & Limousine Commission suggests that taxis in New York City could recoup the hybrid price premium for hybrids today in two years or less through fuel savings of $3,000 to $5,000 per year—even without federal and state subsidies (*Display 29*). The study rather conservatively estimated only 44,000 annual miles of driving per taxi.[88]

We expect mainstream buyers looking for performance plus improved fuel efficiency to begin to adopt hybrids en masse after hybrids improve and their price premium is somewhat eroded by economies of scale.

Our forecast of staggered adoption, with high-travel segments coming first, implies a greater near-term impact on aggregate oil demand from hybrids than most observers currently expect. Most forecasts look at the impact of hybrids on oil demand by focusing only on the number of new hybrids purchased and the improvement in fuel efficiency. But if the first hybrid buyers drive two or three times as many miles per year (on average), the fuel savings would be roughly two or three times as great. How much stop-and-go driving they do would also have an impact.

Rapid, widespread adoption of hybrids, of course, will have a much greater impact on oil consumption, although less impact per vehicle sold. We looked at a variety of scenarios to assess the potential impact. For example, if mass adoption is driven primarily by concerns for maximum fuel efficiency, the impact would be far greater than if performance-improvement was the main attraction. Even in the latter case, however, we estimate that the average hybrid vehicle is likely to be about 50% more fuel efficient than its non-hybrid counterpart, with significant potential impact on global oil demand.

As we have discussed, there are three main variables that determine annual oil demand by cars and light trucks: the number of vehicles on the road (vehicle base), the average number of miles traveled per vehicle, and the average fuel efficiency per vehicle. The equation for calculating oil demand is vehicle base multiplied by average number of miles traveled per vehicle divided by average fuel economy. The significant differences between our estimates and IEA's estimates of the values of these variables result in dramatically disparate projections for future oil demand from this crucial segment (*Display 30*).

Display 30

How Our Oil Demand Forecast Assumptions Differ from IEAs

Global Oil Consumption Forecast

New Vehicle Sales	**2010**	**2020**	**2030**
All Light-Duty Vehicles (units, mil.)			
IEA/SMP	60.9	71.5	87.2
AB RSC	60.9	71.5	87.2
Hybrid Share (% sales)			
IEA/SMP	**0.3%**	**0.7%**	**1.0%**
AB RSC	**10.6%**	**64.5%**	**85.0%**
Vehicle Base			
All Light-Duty Vehicles (units, mil.)			
IEA/SMP	833.0	1,068.6	1,288.6
AB RSC	833.0	1,068.6	1,288.6
Hybrid Share (% base)			
IEA/SMP	**0.2%**	**0.4%**	**0.7%**
AB RSC	**1.8%**	**30.0%**	**72.0%**
Miles Traveled			
All Light-Duty Vehicles (avg. miles per vehicle in base)			
IEA/SMP	9,293	9,434	9,576
AB RSC	9,293	9,434	9,576
Hybrids (avg. miles per hybrid in base)			
IEA/SMP	**9,293**	**9,434**	**9,576**
AB RSC	**18,895**	**11,808**	**11,146**
Fuel Efficiency			
All Light-Duty Vehicles (avg. mpg per vehicle in base)			
IEA/SMP	23.1	**24.1**	**25.1**
AB RSC	23.5	**30.6**	**50.0**
Hybrids (avg. mpg per hybrid in base)			
IEA/SMP	**32.6**	**33.9**	**35.0**
AB RSC	**42.6**	**55.3**	**62.2**
Global Oil Consumption			
Light-Duty Vehicles (mbd)			
IEA/SMP	**21.8**	**27.3**	**32.1**
AB RSC	**21.5**	**21.5**	**16.1**

Source: IEA, SMP and AllianceBernstein

Vehicle Base

The IEA forecasts that the installed base of vehicles will grow from about 707 million in 2002 to 1,289 million in 2030, for a compound annual growth rate of 2.2%; this estimate is highly dependent on continued growth in vehicle demand by emerging countries like China and India. For the purposes of this report, we have assumed the IEA is correctly projecting the future aggregate demand for cars and light-duty vehicles.

We differ sharply, however, on hybrid penetration. The IEA assumes that hybrid purchases will remain a niche product, representing only 0.7% of all light-duty vehicles on the road globally in 2030. We expect hybrids to become a mainstay in the auto market: We estimate that they will represent 85% of new vehicle sales and 72% of the installed base by 2030. Our estimate does not distinguish between type of hybrid (series or parallel, full or mild) or fuel source (gasoline, diesel, biofuel, electricity or fuel-cells); it includes all of these combinations.

Miles Traveled

As previously explained, IEA and SMP data imply that the average number of miles traveled globally was about 8,800 miles in 2004 and that this will increase at about 0.2% per year to reach 9,600 in 2030. We accept their aggregate forecast, but forecast a short-term divergence in the miles traveled by new hybrid and non-hybrid buyers: Until mass economies of scale kick in, the price premium for hybrids will remain relatively high and therefore early consumers of these vehicles will most likely be in high-travel segments that benefit most from the greater fuel efficiency of hybrids.

Early conversion of fleets and other high-travel vehicles will frontload the impact of hybrids on aggregate oil demand. Our oil forecast assumes that new hybrids will, on average, travel far more than new conventional vehicles. We estimate that by 2011, the entire stock of hybrids will travel nearly 20,000 miles, versus just under 9,000 for all non-hybrids. This gap will narrow over the next eight years, as a lower price premium induces more ordinary consumers to buy hybrids. The gap will begin to widen again after 2019, as the market migrates to hybrids en masse, largely leaving only the low-travel segment driving conventional vehicles. By 2030, we forecast that 72% of the global vehicle fleet will be hybrids, traveling more than 11,000 miles on average and accounting for over 80% of total miles driven and 70% of the gallons consumed. Our forecast takes into account that initial demand for hybrids will most likely be stronger in developed economies, such as the US, where annual miles driven per year is above the global average.

While it may appear that we are forecasting that individual non-hybrid owners will drive less than they do today, this in not the case. Because we use the IEA's estimate for total aggregate miles traveled (e.g., vehicle base multiplied by average miles traveled per vehicle), hybrid adoption by the high-travel segment mathematically results in lower miles traveled for the non-hybrid vehicles. That is to say, the decline in average miles driven per non-hybrid vehicle simply reflects a changed mix and not any change in behavior.

Fuel Efficiency

The most important driver of the difference between our forecast and the IEA's is our more optimistic assumptions about fuel efficiency. The IEA assumes the average on-road mpg of the global base of vehicles will only increase slightly, from 22.7 in 2004 to 25.1 in

Display 31

**Key Milestones Ahead:
A Road Map to Mass Adoption of Hybrids**

Year	
2007	More automakers launch own hybrid systems
2007	Tighter diesel standards adopted in US
2007	Diesel hybrids introduced
2007	Advanced gasoline engines introduced
2008	Toyota launches 3rd generation Prius, creating new benchmark
2008	Full hybrids become standard in US
2008	Lithium-based hybrids launched
2008	Tighter diesel standards adopted in Europe
2009	Plug-ins commercialized using high-power batteries
2010	OEMs will have introduced over 50 hybrid models in US
2010	Toyota offers hybrids as option on all models
2010	Hybrids take 10.6% share of new sales globally
2011	Plug-ins commercialized with electric driving range of 5 to 10 miles
2012	Toyota introduces 4th generation Prius
2012	Tougher emissions controls due to climate-change concerns
2013	Plug-ins driving range increases to 20 to 30 miles
2013	Advanced materials introduced
2013	Automakers offer hybridization as option on most models
2014	Nickel battery displaced
2015	Hybrids take 50% share of new sales globally
2020–25	Plug-ins driving range increases to >50 miles
2020–25	Fuel-cell vehicles commercialized
2030	Hybrids take 85% share of new sales globally

Source: AllianceBernstein

2030. Our estimates assume that the on-road average fuel efficiency of the global base of hybrids will increase dramatically, from about 40 miles per gallon in 2004 to about 62 miles per gallon in 2030, due to more efficient batteries, engines and electronic components, as well as safe, lightweight materials, and eventually the introduction of plug-in hybrid vehicles. Since we estimate that by then, hybrid vehicles will represent more than 70% of the global fleet, their greater efficiency would bring the overall average for the global fleet to 50 miles per gallon.

Based on our assumptions for the above variables, we estimate that oil demand from the crucial light-duty vehicle segment will reach 16.1 million barrels per day in 2030, about 50% less than the IEA's demand forecast of 32.1 million per day. If plug-in hybrids garner mass acceptance quickly, the gain in fuel efficiency would be even greater.

Other Forecast Details

As a reference, we have listed some of the milestones related to hybrid development and market penetration we expect in the next 10 years or so (*Display 31*). This roadmap has assisted us in the formulation of our assumptions. For instance, we expect that lithium-ion batteries will start to be deployed in hybrid vehicles in the 2008/09 model year. Further, we expect plug-in hybrid vehicles to be sold commercially as early as 2009. Both of these developments inform our fuel-efficiency assumptions. Similarly, our projection that automakers will offer hybrid versions of most car models by 2013 has a significant impact on our assumptions about hybrid penetration.

Our optimism that hybrid technology will fairly rapidly have a significant impact on oil demand reflects the progress industry participants have made to date: After nearly a decade of research and development, the major automakers are on the verge of being able to mass produce hybrids. Toyota is the clear leader, but every major automaker has launched or announced plans to launch at least one hybrid vehicle in the near term (*Display 32*).

Leading auto suppliers, too, are preparing to capitalize on the opportunity this creates: Johnson Controls has formed a joint venture with SAFT to produce batteries, while Continental AG has formed a joint venture with ZF Friedrichshafen to produce hybrid systems and components. Given this progress, we expect that by the 2008/09 model year, the global automotive industry as a whole will have the components, infrastructure and technical ability to mass produce a wide variety of hybrid vehicles. We expect automakers to continue to improve their production processes subsequently, thereby increasing the efficiency of the systems, lowering costs and creating a virtuous cycle of demand.

Display 32

Most Automakers Offer Hybrids or Plan to Do So

1999–2005	2006 (Scheduled)	2007–2009 (Announced or Expected)
Ford: Escape, Mariner **GM:** Sierra, Silverado **Honda:** Accord, Civic, Insight **Toyota:** Alphard, Crown, Estima, Highlander, Kluger, Prius, Lexus RX 400h	**DaimlerChrysler:** Ram **GM:** Equinox, Saturn VUE **Honda:** Acura TL **Nissan:** Altima **Toyota:** Avalon, Camry, Tacoma, Lexus GS 450h, Lexus LS 600h	**Audi:** Q7-SUV **BMW:** X3 **DaimlerChrysler:** Dodge Durango, Mercedes S **Ford:** Fusion, Futura, Marina, Milan, Zephyr, Mazda Tribute **Geely:** Maple **GM:** GMT900, Malibu, Sierra*, Silverado*, Tahoe, Yukon **Honda:** Acura, MDX, CR-V, Fit, Pilot **Hyundai:** Accent, Getz **Kia Motors:** Rio **Mahindra & Mahindra:** Scorpio **Peugeot:** 307, Citroen **Porsche:** Cayenne, Panamera **Saab:** 9-3 **Subaru:** Legacy, Outback **Toyota:** Corolla, Land Cruiser, Sequoia, Sienna, Tundra, Lexus ES 330, Lexus LS 430, Lexus LX 470 **Volkswagen:** Jetta, Passat, Touareg

**Upgrade from mild to full hybrid*

Source: BofA, Forbes, greencarcongress.com, HSBC, hybrid.com, hybridcenter.org, hybrid-cars.org, hybrid-vehicles.net, Prudential, UMTA and AllianceBernstein

Our research also suggests that manufacturers will be able to adapt much of their existing capacity to produce hybrid vehicles with fairly limited additional expense. Toyota easily integrated assembly of the Prius, a hybrid-only model, on its existing product lines. A tour of the Toyota plant that assembles the Prius along with seven other models was telling: The Prius only requires four new parts and 11 additional procedures (out of 200), or 5% additional complexity; several assembly functions take only 120 seconds versus 60 seconds for a similar non-hybrid vehicle. Assembly of hybrid versions of conventional models could be even simpler. Because hybrids do not call for a completely new approach to propulsion and fueling, as fuel cells do, adjustments to the manufacturing process are limited. As a result, hybrid power is not a disruptive technology for automakers, and massive capital-investment requirements are not a limiting factor.

PLUG-IN HYBRIDS: THE REVOLUTION CONTINUES

Plug-in hybrid vehicles are likely to arrive as an extension of current hybrid technology: They may represent a second phase in this transportation revolution, with tremendous consequences for future oil demand, the cost of transportation and geopolitics.

Like hybrids available today, plug-ins are powered by both liquid fuel (gasoline or diesel) and batteries. But in addition to being charged by the gasoline engine and regenerative braking, plug-in hybrids can be charged directly from the power grid we all use to power our refrigerators, computers and television sets: They may be—quite literally—plugged into standard electric outlets.

Fuel-Efficiency Benefits

The fuel-efficiency gains from plug-ins would be enormous for those people who typically drive only short distances each day—and could have dramatic implications for overall oil demand. Transportation studies have found that 40% of Americans, for instance, travel 20 miles or less per day for work, school and routine errands; about 60% travel 30 miles or less per day.[89] If these people could buy plug-in hybrids that could go 20 to 30 miles on the electric motor before recharging, they would almost never have to buy gasoline: They'd just have to charge the vehicle's battery in their own garages each night to power the next day's driving requirements.

When they decided to take a longer trip to visit their in-laws or take a vacation, however, plug-in hybrid owners wouldn't face the inconvenience that owners of pure electric vehicles with comparable performance characteristics face from having to stop every 60 to 80 miles to recharge the battery (which can take hours). Instead, they would rely on the plug-in hybrid vehicle's traditional engine for long-distance trips. In essence, people would use plug-ins primarily as electric vehicles; they would employ the engine only as needed to extend their driving range and boost performance, thereby overcoming the shortcomings of pure electric vehicles.

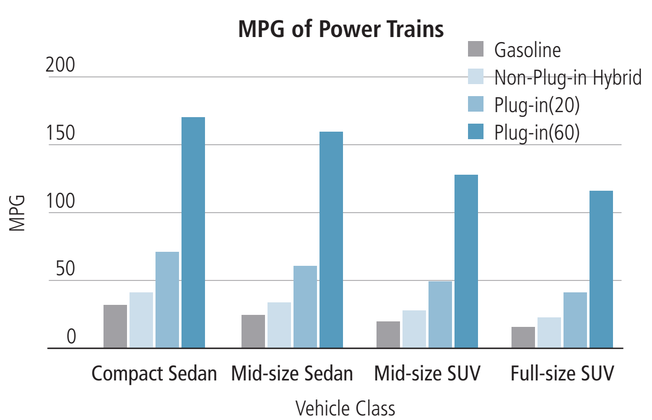
A plug-in vehicle's tank-to-wheel efficiency is high: somewhere between the efficiency of hybrid and pure electric vehicles, depending on what portion of driving is powered by electrical charge versus diesel or gas. The same consideration drives any comparison of the fuel source-to-tank efficiency of plug-ins versus conventional hybrids or pure electrical vehicles. On this basis, however, standard plug-ins are less efficient, because the process of producing and transporting conventional fuels today is more efficient than the process for generating and delivering electricity. The efficiency of electricity varies by region, however, and new technologies and renewable sources may dramatically boost the efficiency rates of electricity.

As now envisioned, plug-ins would be about 50% more fuel efficient than standard hybrids, because they could run much longer on electricity alone. Several groups, such as Energy CS, have created prototype plug-ins by modifying a Prius. These modified vehicles have been able to achieve about 75 miles per gallon on average, versus about 50 for a typical hybrid Prius. The Electric Power Research Institute has estimated the impact on miles per gallon of going hybrid and plug-in for several vehicle classes based on today's technology[90] (*Display 33*).

In cooperation with the University of Chicago, Argonne National Laboratory has developed an industry-leading model for calculating the energy intensities and emissions profiles of various power trains and fuels on a fuel-source-to-wheels basis. The model takes into account many types of energy inputs and outputs in the fueling and propulsion processes, but does not explicitly include plug-in hybrids. It does, however, evaluate both hybrids and electric vehicles. Using the figures for these vehicle types, we can estimate the relative merits of plug-ins.

Display 33

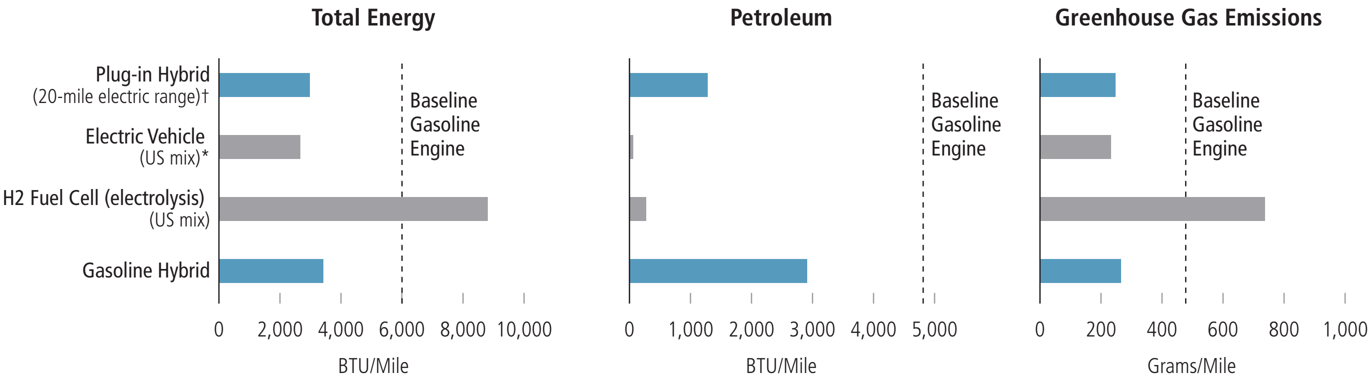
Fuel Efficiency of Hybrids Varies by Vehicle Type



Plug-in(20) assumes 20-mile driving range before charging; Plug-in(60) assumes 60.
Source: Electric Power Resource Institute and Hybrid Electric Vehicle Working Group

Display 34

Comparison of Oil Demand Forecast Assumptions for Light-Duty Vehicles



Based on average midsize car

* *Reflects average mix of electric generation in US, which is more than 50% reliant on coal*

† *Plug-in data estimated by AllianceBernstein using Argonne's hybrid and electric vehicle results, assuming a daily driving cycle of 35 miles.*

Source: Argonne National Laboratory, GREET model (default assumptions) and AllianceBernstein

Our extension of the Argonne analysis shows that plug-ins vastly reduce total energy and petroleum consumption relative to most other alternatives (*Display 34*).* For instance, we estimate that a plug-in capable of a 20-mile driving range on electric power alone would use less than 1,300 BTUs of petroleum per mile traveled and less than 3,000 BTUs of total energy per mile traveled—50% of the energy and 27% of the petroleum of a standard gasoline engine. The only other power train options with lower scores on both measures are pure electric vehicles and hydrogen-powered fuel-cell vehicles that use steam reformation and natural gas to produce hydrogen. Neither of these alternatives are commercially viable in the near to medium term. For electric vehicles, battery technology weaknesses limit potential driving range and impair performance. Fuel-cell vehicles have a host of performance, range and reliability issues to overcome, and require hydrogen production, distribution and storage, and infrastructure development (see *Is the Fuel-Cell Alternative Commercially Viable?*, on page 39).

Other Benefits

Plug-ins could also reduce the cost of transportation. The Argonne model suggests that plug-ins not only require less total energy, they can use *cheaper* energy, at least at current fuel prices. Plug-in hybrids may also lead to the full electrification of the automobile: The presence of even larger batteries would enable drive-by-wire technology that further enhances the performance, comfort, reliability and safety of vehicles. Because most of the necessary infrastructure for plug-ins is already in place—many homes and garages have outlets capable of recharging plug-ins—the transition to plug-ins should be low cost.

Widespread, global introduction of plug-ins would have complex, but mostly positive, ramifications for electric power systems. While plug-ins could stress electric generating capacity, we estimate that at least in the US, there is sufficient slack in generating capacity today to support widespread adoption of plug-ins, if most of them were charged during off-peak, or late night, hours. In fact, by boosting demand at off-peak hours, plug-ins could help utilities achieve level loading, which would enhance their overall generating efficiency and possibly reduce unit costs for electricity. Plug-ins may be particularly helpful for utilities with nuclear plants and certain kinds of coal-fired generating plants, because these facilities typically generate a steady flow of power regardless of demand. Finally, plug-ins would help utilities expand their revenue base by extending the use of electricity to a new category—road transport. The resulting profits could be used to upgrade the grid and invest in cleaner and more efficient power plants.

* The Argonne base model is US-based and the results shown reflect the efficiency of the US grid. Absolute values may vary considerably across countries due to the relative efficiency of the grid, but relative values should be similar.

Given their low carbon fuel profile, plug-ins are also very attractive from an emissions perspective. Depending on the electric driving range achieved, plug-ins could reduce emissions of greenhouse gases by 50% versus a comparable gasoline vehicle, even with today's relatively dirty power plants.† The emissions-reduction benefit would increase as utilities invest in emissions-reducing technologies, nuclear power and renewable energy sources, such as wind and solar.

Perhaps even more important is the *fuel flexibility* that plug-in hybrids would offer. Today, the transportation sector is almost entirely dependent on oil for its fuel needs. Given the crucial importance of transportation to the economy, gaining and preserving access to oil has been central to geopolitics for the last century. Plug-in hybrids would change this situation by making electricity (which can be generated from multiple fuel sources) a viable alternative to oil for road transport. Needless to say, there would be profound implications for the much-discussed problem of depending on foreign oil sources/energy security and for current concerns about oil supply and refining capacity.

Current Status

Prototype plug-in technology already exists. Dr. Andrew Frank of the University of California (Davis) has been making plug-ins for the past decade. More recently, several plug-ins have been created and tested by several start-up firms and by DaimlerChrysler. The main limitation lies in battery technology, namely the range afforded on electrical charge, recharge time, life and cost premium (currently estimated at $4,500 to $6,750 per battery). The Prius battery now allows one to drive only one or two miles on the battery alone, because its electronic control unit seeks to maintain the ideal state of charge needed to maximize battery life. However, at least one battery manufacturer has reportedly developed a lithium-ion (phosphate) battery capable of propelling a modified Prius 20 miles on a single charge, after which the gas engine would take over and it would drive like a standard hybrid.[91] Furthermore, DaimlerChrysler is introducing plug-in commercial vans in several cities; the vans use a 14 kilowatt/hour nickel battery capable of propelling a van 18 miles on a single charge.

The projected life of a plug-in battery is estimated to be six to 10 years, which could be an obstacle to mass adoption, given their high cost. While the lead acid batteries in conventional vehicles only last about three to five years on average, they typically cost only $100 to $150 each. However, new battery technologies likely to emerge would extend plug-in battery life.

For plug-in applications, greater energy density is more important than power density, because energy density provides longer driving range without using the engine. Higher-density batteries, however, typically provide less power. A potential solution could be to pair ultra capacitors or flywheels that deliver significant power but have little energy density with high-energy batteries; this would free the battery from having to provide high levels of power. New lithium battery technologies on the horizon also appear to promise longer life, faster recharge times, greater power and lower cost; they could be ideal for plug-in vehicle applications. As a result, we expect technological innovations and scale to continue to drive down battery costs and improve performance, improving the outlook for plug-ins.

Automakers may also make design changes to realize significant cost reductions in plug-ins' non-battery systems. For instance, Toyota may conclude that series or parallel constructions for plug-ins deliver similar performance attributes as the more expensive series/parallel construction it currently uses. If so, it could introduce plug-ins with somewhat different architectures than it employs in hybrids today.

The industry is at the very beginning of a long period of continuous innovation and improvement. Development of high-energy batteries is likely to spur the commercialization of plug-ins. Unlike fuel-cell technology, which our research suggests is at least 15 years away from mass commercialization, plug-in technology has largely been developed. Prototypes have already been deployed, at an estimated cost of less than $50,000 per vehicle, versus the $500,000 to $1 million deployment cost for an experimental fuel-cell vehicle.

† Any comparison of vehicle emissions has to take into account the fuel source and technology of the electric-generating plant. On a fuel source-to-wheel basis, a plug-in that is charged from a high-emissions coal-fired plant might emit more particulates or smog-causing sulfur dioxide than a gasoline hybrid. The plug-in, however, would shift the emissions from the area where it is driven to the area where the electric power is generated, perhaps many hundreds of miles away.

IS THE FUEL-CELL ALTERNATIVE COMMERCIALLY VIABLE?

If viable, hydrogen-powered fuel-cell vehicles would seem to be the ultimate answer to the world's oil problem because one need never worry about supply. Fuel cells, like batteries, are electrochemical devices; they use hydrogen and oxygen to create electricity without combustion. Unlike batteries, however, fuel cells never lose charge: They generate electricity as long as hydrogen and oxygen are available. Thus, fuel cells used for transportation would dramatically cut oil consumption and emissions. Ballard, GM and other firms have claimed that commercialization of such vehicles is close at hand. In the absence of a demonstration vehicle, we doubt this is true, for several reasons:

Hydrogen, while freely available, does not exist in a form that is readily usable: It must be captured and produced, which in itself requires considerable energy. The two common methods to produce usable hydrogen today are electrolysis and steam reformation. Electrolysis uses electricity to liberate hydrogen from water; steam reformation uses steam to create hydrogen from natural gas. Electrolysis uses more energy than it creates and results in relatively low fuel source-to-wheel efficiencies and high emissions. Steam reformation is more efficient and produces lower emissions, but the process is expensive and requires relatively scarce natural gas. Using renewable energy to create hydrogen would be very clean, but such supply is now limited, and its costs are high.

Even after the hydrogen is produced, it must be made easily available for consumers to refuel while traveling. The distribution challenges are significant, requiring new infrastructure, even at existing gasoline refueling stations. Building the required hydrogen infrastructure in the US alone has been estimated to cost as much as $600 billion, resulting in a sizeable chicken-and-egg problem: Oil companies may not want to make the investment until the vehicles are on the road; automakers may not invest in production until the infrastructure is place.[92]

Safe storage of hydrogen on board the vehicle in sufficient amounts to fuel acceptable travel ranges has proved technically challenging.

The cost of meeting these requirements may make fuel-cell vehicles too expensive for consumers, when both initial price and maintenance and operating expenses are considered.

Fuel-cell vehicles have yet to achieve the performance and range that consumers desire. Our research suggests that pure fuel-cell vehicles are many years, if not decades, away from mass commercialization, unless a major government mandate gives them a boost. Any fuel-cell vehicles commercialized soon are likely to be hybrids, in which case the fuel cells are assisted by a battery-powered motor. Finally, wide adoption of hybrids and plug-ins could further delay the introduction of fuel-cell vehicles, because the efficiency gains from switching from such vehicles to a fuel-cell vehicle would be less dramatic.

GEO-POLITICAL CONSEQUENCES

To repeat, we expect the transition to hybrid vehicles to be primarily market-driven, rather than due to government policies aimed at reducing oil dependency: Demand will be spurred primarily by the inherent benefits of this technological innovation, including faster acceleration, better fuel efficency, increased customization and the potential inclusion of new electronic systems that enhance functionality and safety. Government incentives may accelerate mass adoption, but we do not expect many consumers to act against their own self-interest in the name of some "greater good." Most consumers will buy these vehicles because they are *better value propositions.*

Nonetheless, hybrid vehicles' dramatically better fuel efficiency will have important geo-political consequences. As hybrid systems improve, they will utilize more powerful batteries, allowing them to travel greater distances without using gasoline or diesel. By the year 2030, mass adoption of hybrid vehicles could lead to a *decline* in transportation-related demand for oil, reducing total oil consumption meaningfully, assuming miles traveled stays constant or increases at historical rates.

As plug-in vehicles become feasible, consumers will have more choices on how to charge their hybrid batteries. If most consumers opt to charge their batteries from the electrical grid, rather than from the vehicle's internal combustion engine, the fuel utilized for charging (and therefore for transportation) could possibly be coal, natural gas or uranium, rather than oil. This new flexibility is truly game-changing: Until now, transportation has been one of the only major sectors that has *not* substituted less expensive fuels for oil. Plug-in vehicles make that substitution possible.

Since we are investors and not political pundits, we are hesitant to opine too much on the specific geo-political ramifications of this transition. Given the current highly charged political landscape and concerns about dependence on foreign oil, however, it is hard to overstate the implications of the trend to hybrid vehicles: Economic growth, which is inextricably linked to transportation, could be almost entirely decoupled from oil. This could reshape the foreign policies of such oil-importing countries or regions as the US, Japan, Western Europe, China and India. The economic and political implications for the few oil-rich exporting nations, by contrast, are likely to be grim. Indeed, the transition to hybrid power could change the world!

Whether individuals decide to charge their vehicle batteries from the electric grid or from the internal combustion engine will ultimately depend on the relative price of electricity and oil. If scarcity continues to drive oil prices up, many consumers will certainly opt to charge their batteries from the grid. If electricity prices rise for some reason and oil prices fall, this option will be less attractive.

We expect oil demand growth from transportation to first slow and then shrink. As the trend becomes evident to an increasing number of investors, fears of oil shortages will dissipate, which may lead to a sharp drop in the price of oil.

Of course, oil demand will not fall to zero. If investment in oil exploration and production rises significantly during this perceived time of crisis, and demand from the transport sector slows or declines, oil prices may fall far enough to let oil once again be a competitive alternative for such uses as home heating. But the improved fuel economy of hybrid vehicles and the *fuel flexibility* that plug-in vehicles make possible will still free the world from being captive to its hunger for oil.

INVESTMENT IMPLICATIONS

Display 35
Affected Industries: Winners and Losers

Power Train/Fuel	Near	Mid	Long	Comments
Hybrid-Battery Manufacturers*	+++	+++	+++	Significant demand acceleration
Automotive Suppliers (Electronic)	++	+++	+++	Market acceleration
Power-Semiconductor Suppliers*	+	++	+++	Significant demand acceleration
Traditional Semiconductor Suppliers	+	+	+	Modest demand increase
Electric Utilities	NA	+	+++	Transition to plug-ins may lead to increased demand; load-balancing opportunities
Natural Resource/Commodity Suppliers (excl. oil)	+	+	+	Somewhat increased demand for nickel, lithium, etc.
Automakers (OEMs)	+++/–––	+++/–––	+++/–––	Market share shifts intra-sector
Automotive Suppliers (Traditional)	+/–––	+/–––	+/–––	Market share shifts intra-sector, but decelerates overall
Electric-Power Equipment Makers*	NA	NA	++	Increased demand for electricity
Fuel-Cell Providers	–	–	–	Delay demand
Oil and Gas Exploration and Production Firms	NA	–	––	Slower demand growth
Retailers with Gasoline Sales	NA	–	––	Slower demand growth
Oil and Gas Refiners and Distributors	NA	––	–––	Slower demand growth

+++	Highly Positive
++	Very Positive
+	Positive
–	Negative
––	Very Negative
–––	Highly Negative

**No publicly traded pure-play investment opportunities available at this time.*

The investment implications of our thematic research are often complex and fairly imprecise. This is *not* the case with this topic. The investment consequences of the transition to hybrid vehicles are straightforward and can be summarized succinctly. In *Display 35*, we list the affected industries in order from biggest winners to biggest losers. In the text that follows, we list them alphabetically. Since the transition to hybridization of the global fleet of automobiles will be gradual, our time horizons for the investment implications are slightly longer than normal. In this report, we classify "near term" as less than five years, "mid term" as five to eight years, and "long term" as more than eight years.

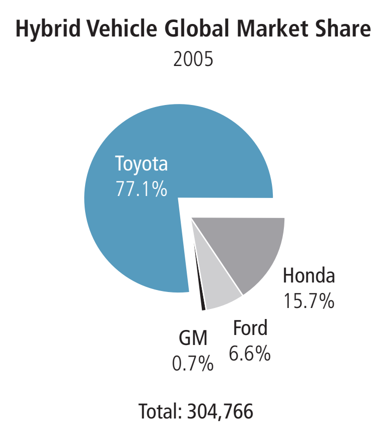
A word of caution: The market is a terrific mechanism for discounting the impact of even long-term trends. Once the trend becomes clear, it is likely to be reflected in stock prices—even before it affects companies' profit and loss statements.

Automakers (Original Equipment Manufacturers)

A wide discrepancy in hybrid expertise exists among the major automobile manufacturers. Toyota clearly dominates the market at this time, capturing 77% of all hybrid vehicles sold globally; Honda is a distant second with only 16% share (*Display 36*). In the near to medium term, Toyota (and its suppliers) should benefit the most from the transition to hybrid vehicles.

Toyota has conducted extensive research and development on hybrid technology, and successfully engineered a highly robust, scalable and proprietary hybrid system. Despite their higher prices, Toyota's hybrids outsell all rival models, because they offer consumers greater fuel efficiency and performance across more vehicle classes than rival offerings do. We expect Toyota to retain a dominant position (but probably not a 77% share) as the hybrid market grows, due to its core competencies in advanced electronics and technologies, manufacturing

Display 36
Toyota Dominates the Hybrid Market Today



Source: Honda, HSBC, Hybrid-cars.org, Toyota and AllianceBernstein and strong supply networks. The strong likelihood that Toyota will achieve greater economies of scale and progress on the hybrid cost and learning curves than its competitors will also help it retain its current dominance. In addition to continuing to improve its best-selling Prius hybrid, Toyota plans to offer hybridization as an option on more of its conventional vehicles. Toyota's success with hybrids is likely to help the company become the largest global automaker in terms of vehicles sold: Market survey data suggest its conventional vehicles are already benefitting from a halo effect and increased traffic to the showroom.[93]

Ultimately, we expect all automakers will have to produce hybrids to survive and prosper. Moreover, they will have to act fast since Toyota and Honda will soon be on their third-generation hybrid systems.

Honda is likely to continue moving toward full hybrids as their costs decline, which erodes the relative cost advantage of its mild-hybrid technology. The company may seek to introduce its mild hybrids in the low-end of the market in the near term because this segment is likely to be more sensitive to upfront price rather than fuel efficiency or performance, and other automakers may avoid the segment for some time. The continued success of Toyota in the hybrid market should accelerate Honda's efforts: Honda is highly vulnerable to new competition from hybrids because it now has the global industry's most fuel-efficient line-up of conventional vehicles.

Other automakers are likely to suffer market share and/or profitability losses in the near term because they do not have competitive hybrid offerings. They will probably have to invest in developing the technology or pay relatively large license fees to Toyota to deploy Toyota's system. Some of Toyota's licensees, however, are only able to obtain technology a generation behind Toyota's current hybrid offerings, which puts the licensees at a technical and economic disadvantage.

To a large extent, the degree to which the laggards will be hurt will depend on the regional mix of their global sales (*Display 37*). Those with the greatest share in North America—General Motors, Ford and DaimlerChrysler—are likely to suffer the greatest share losses, since Toyota and Honda are first targeting North America and Japan for hybrid penetration. The North American automakers may respond to this threat in the near term by offering discounts on their conventional models and accelerating the development of any fuel-saving and performance-enhancing technologies they do have; the result may be more efficient gasoline, biofuel and diesel vehicles. But the North American firms should be wary of pursuing such a strategy: Their declining market shares and profit outlooks are likely to limit their marketing and research budgets, increasing the need to focus their resources on the technology most likely to win in the long term: hybrid technology.

Display 37

Most Vulnerable Automakers: Hybrid Laggards with Sales Focused in North America and Europe

Top 10 Automakers Global Vehicles Sales Regional Mix in 2005

	Unit Sales	North America (%)	Europe (%)	Asia (%)	Other (%)
General Motors	8,814,475	59	21	12	8
Ford Motor	7,484,014	52	30	12	6
Toyota Motor	7,380,807	33	13	50	4
Renault-Nissan Group	5,735,697	25	44	26	5
Volkswagen	4,884,415	11	67	11	11
DaimlerChrylser	4,135,593	69	27	3	2
Hyundai	3,424,693	25	21	43	11
PSA	3,338,327	1	76	5	19
Honda	3,246,237	51	9	38	2
Fiat	1,948,433	0	70	4	25

Sales data includes light- and heavy-duty vehicles made by parent company, majority-owned affiliates and minority-owned group alliances (e.g., Mazda is included with Ford, Nissan with Renault, and Kia with Hyundai).
Source: Citigroup, JD Powers and Merrill Lynch

With respect to hybrid development, automakers are pursuing different strategies. General Motors and DaimlerChrysler have formed a research and development partnership together with BMW; Ford has chosen to license Toyota's system in the near term and pursue its own technology longer term. Four European automakers—Audi, Peugeot, Porsche and Volkswagen—have also elected to cooperate to bridge the technology gap. Partnerships offer numerous benefits: shared development costs; reduced development times (if each partner focuses on a different core technology); and more rapid attainment of economies of scale. The GM/DaimlerChrysler/BMW partnership appears to be centered on joint research and development and shared components. The Audi/Peugeot/Porche/Volkswagen partnership appears to be focused on developing a supplier network that can deliver hybrids on a turnkey basis.

If, as we expect, hybrid costs decline and diesel costs rise due to more stringent regulatory requirements, the hybrid premium to consumers may become equal to or smaller than the diesel premium, and the recent surge in global diesel sales may end. This would be particularly negative for automakers with the largest share of their global sales in Europe, due to the large share of diesel vehicles in that region.

Japan is also an attractive market for hybrids. Toyota and Honda's leadership in hybrids is supplemented by established dealer networks, greater market awareness and more efficient vehicles. Some of the other Japanese automakers, most notably Nissan and Fuji Heavy Industries, the maker of Subaru vehicles, license or plan to license technology from Toyota. Others, such as Mitsubishi and Suzuki, have been seeking to develop their own hybrid technologies. However, they appear to be significantly behind: Their continued efforts have yet to result in a successful hybrid vehicle product launch.

In the rest of Asia, Toyota and Honda are likely to introduce hybrids more aggressively when hybrid component costs are lower, in order to take share from local automobile manufacturers. In a somewhat defensive move, several Chinese, Korean and Indian manufacturers have indicated they will either seek to license Toyota's hybrid technology or develop their own. These new entrants, along with some European automakers, may also pursue mild hybrids first and then seek to progress to full hybrids.

Automotive Suppliers (Electronic)

The automotive-electronics market has been growing rapidly for more than five years and is attractive for its relative stability. Most of the innovation in the automotive sector in recent years has come from electronic components that have made cars more sophisticated and efficient. Electronic components have moved from simple starting and lighting functions to parts regulating complex engine and emissions controls, sensors, and safety and entertainment features. This trend generally benefits suppliers of various electronic systems.

Obviously, the companies with the most to gain are those that specialize in hybrid-specific electronic components (such as electric motors and generators, magnets, power-split devices, and electronic control units/microcontrollers, sensors and battery management systems). These companies are well situated to capitalize on market growth, especially if they can help lagging automakers close the gap between themselves and the leaders in hybrid vehicles. However, suppliers of other electronic parts outside of the power train are also likely to benefit considerably from hybrid market growth, because hybrids should accelerate the trend to increased electronic content per vehicle. Thus, many consumer electronics firms are starting to enter the electronic automotive supplies market.

Automotive Suppliers (Mechanical)

In the near term, the suppliers of conventional mechanical systems, such as brakes, engines, steering and transmissions, are likely to see their sales volumes and profits decline as an increasing number of these systems are either downscaled and/or replaced by new electronic systems made possible by the higher voltage in hybrid vehicles.

Over the mid and long term, this trend should accelerate, making the outlook for traditional mechanical automotive suppliers bleak. To some degree, the intensity of this trend has been masked to date because the leading hybrid manufacturers are to a large extent vertically integrated. Therefore, the shift from mechanical to electronic has largely occurred among their partially owned internal suppliers. As other automakers begin to offer hybrid vehicles, the repercussions for their traditional suppliers could be severe. Many suppliers of traditional mechanical parts are trying to shift their business to the faster-growth electronics arena.

Suppliers of engine technology and materials will be largely unscathed by the trend to hybrid vehicles. As long as the internal combustion engine survives, there will be an advantage to developing smaller, lighter and hence more efficient engines capable of delivering the same or more power as their larger equivalents. Additionally, lighter-weight materials for vehicle bodies or parts with equal performance and safety will also see great demand, since they boost fuel efficiency. Suppliers of these components should do well even over the long term.

Electric Utilities

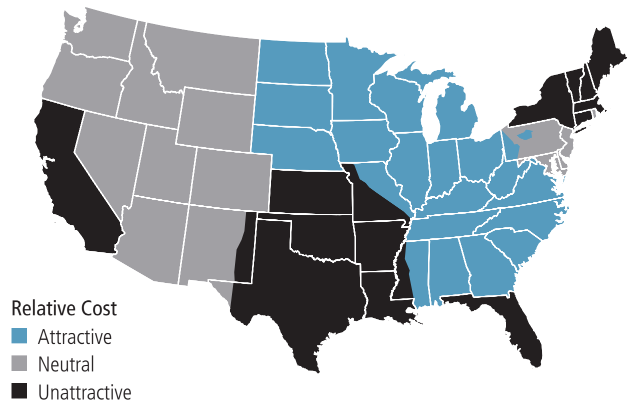
In the near term, hybrid adoption is unlikely to affect the investment prospects of electric utilities. In the long term, however, commercialization of plug-in hybrids could significantly increase utility revenues. Our analysis suggests that there is now sufficient electric capacity in the US and several other industrialized countries to accommodate large numbers of plug-in vehicles, regardless of the time of day charged; more vehicles can be supplied if most are charged during the off-peak (late night/early morning hours) because the gap between baseload and off-peak capacity is generally fairly wide.

Cost, not capacity, is the key issue. In examining the major electric distribution regions in the US, we found that the marginal cost of potential electric supply for plug-ins could vary from less than $40 per megawatt to more than $240 per megawatt, depending on the type of baseload and peak generating capacity and anticipated demand in a given region. To the consumer, this translates into a price of less than $0.04 per kilowatt hour to more than $0.24 per kilowatt hour. Certain regions of the US, such as the central and southeast states, are highly advantaged for plug-ins today, given their excess baseload capacity (*Display 38*). Others, such as California, Florida, New York and Texas, are not. Unfortunately, nearly 40% of the US population lives in those states.

Baseload plants, such as coal-fired and nuclear plants, are typically large, capital-intensive facilities with low variable cost. They are difficult to bring on line and put off line; as a result, they operate continuously to serve the minimum load requirements in a given system. Additional demand is met by bringing on additional capacity that is less efficient or has higher variable costs. Mass adoption of plug-ins would allow electric utilities in aggregate to use baseload capacity more effectively. Moreover, new off-peak demand would allow generating plants to operate at a steadier load, which would improve their profit structure. This benefit will become increasingly important as rising demand for electricity unrelated to plug-in vehicles forces utilities to increase capacity; it will give them an additional incentive to add baseload, rather than peakload capacity.

Display 38

US Plug-In Capacity: Ample, but Not Always Low Cost



Attractive reflects likely availability of surplus low cost, baseload capacity and marginal costs of under $40 per megawatt hour. Unattractive reflects likely unavailability of low cost, baseload capacity and marginal costs of more than $90 per megawatt hour. Neutral reflects neither attractive or unattractive. Analysis assumes natural gas prices remain at currently high levels.

Source: Energy Velocity, GlobalView, North American Electric Reliability Council, Prudential Securities and AllianceBernstein

Electric utility providers that now have greater baseload capacity than required to meet anticipated demand are likely to benefit more from a trend toward plug-ins. These utilities are typically more reliant on nuclear power or super-critical coal plants; widespread adoption of plug-ins would likely push other utilities to build such plants. In France, Japan and other countries that are largely reliant on nuclear power, plug-ins would be even more attractive, benefiting both plug-in vehicle makers and electric utilities in those countries.

When natural gas prices were low, gas-fired plants were also used for baseload capacity; today's higher natural gas prices have relegated these facilities to providing intermediate backup supply. Should natural gas prices fall, additional areas around the world could become baseload heavy, which would make plug-ins even more attractive there.

Electric-Power Equipment Makers

As plug-in hybrids gain share, electric utilities are likely to augment their generating capacity. In order to meet immediate short-term demand, they will probably first bring on any flexible and intermediate capacity, as well as inefficient capacity in their existing asset portfolios. Over the longer term, depending on the amount of their excess baseload capacity and anticipated demand from their customers, utilities will either build new peak capacity plants, which are cheaper and quicker to build and may be sufficient to meet demand at reasonable cost to consumers. Or, they may build additional baseload plants, which are more expensive and take longer to build, but are capable of satisfying greater demand at lower cost. Some utilities, of course, may build both.

Peak capacity plants with 50 megawatts of output typically take two years to install at a cost of $20 million. Baseload plants with 500 megawatts of output take about six years to install and cost about $825 million. Over time, the additional revenue stream provided by serving transportation needs could help electric-utility providers modernize the power grid in terms of greater efficiency, reliability and emission controls. As a result, electric-power equipment manufacturers are likely to see significant benefits over the long term.

There are two additional potential sources of spending by electrical utilities that would also benefit makers of electric-power equipment. The plug-ins envisioned today would use standard hardware for home charging (e.g., 120 volts in the US). If battery manufacturers can achieve rapid charging in next-generation hybrid batteries, utilities would have to create the necessary infrastructure to allow consumers to charge quickly. In addition, if utilities seeking level loading decide to adopt variable price schedules that give consumers an incentive to charge at night, the utilities would need to install new meters and related equipment.

Fuel-Cell Providers

Fuel-cells providers have targeted a wide range of markets, from portable applications such as cell phones and laptops, to stationary applications such as back-up or primary power generation, and transportation uses. The emergence of hybrid vehicles raises the cost, efficiency, performance and convenience thresholds that fuel cells will have to cross to become a mainstream transportation technology. This is likely to hurt providers of fuel cells for passenger and military vehicles in the near and long term.

While a fuel-cell vehicle may materialize, it appears likely that it will be a fuel-cell hybrid, which would extend the driving range between hydrogen refuelings and enhance performance. In the long term, commercialization of plug-in hybrids would pose an even greater threat to commercialization of fuel cells, since it would reduce the benefit of switching to a fuel-cell hybrid. Furthermore, governments and energy companies would need to underwrite the massive infrastructure development required to make fuel-cell vehicles a viable consumer option.

Hybrid-Battery Manufacturers

Since the energy-storage system is the single most expensive component of a hybrid vehicle, manufacturers of hybrid-battery systems are well positioned to benefit from the increased penetration of hybrids over the short and long term. We estimate today's market for hybrid batteries is $1 billion to $2 billion annually. Over the long term, the hybrid-battery market could be five to 15 times larger, depending on both hybrids' share of new vehicle sales and prices of hybrid batteries.

Almost all hybrid batteries sold today are nickel metal hydride units. The major players for nickel batteries are Panasonic EV (now majority-owned by Toyota), Sanyo, Cobasys (a joint venture between Energy Conversion Devices and ChevronTexaco) and possibly JCI/Saft. To the extent these companies persuade automakers to accept battery designs that use their existing technology, the companies will benefit for several years: Automakers do not typically change battery suppliers during the product life of a given model. Design acceptance by the automakers, however, is difficult to gain. It requires a strong relationship with the automaker, a solid understanding of battery chemistries, manufacturing prowess, and the ability to produce highly reliable and durable batteries at reasonable cost.

We expect a transition to lithium batteries to begin in the next few years, possibly as early as 2008, with the release of the next generation of today's proven hybrids. Lithium batteries are likely to decrease the cost and improve the performance of hybrids. They would also facilitate greater competition, because major consumer electronics firms (such as Hitachi and Toshiba) are likely to enter the market.

Given the likely transition to lithium batteries, automakers and battery manufacturers may limit their investments in new nickel-battery capacity, which could constrain near-term supply and help existing nickel battery manufacturers. But the introduction of lithium batteries should accelerate adoption of hybrids, and nickel-battery manufacturers not able to develop a lithium technology will likely be hurt.

Natural Resource/Commodity Suppliers

In the near term, commodity producers may benefit modestly from the transition to hybrids, since today's hybrid vehicles are estimated to each require an incremental 30 to 60 pounds of nickel and 50 pounds of copper.[94]

Most of the additional nickel resides in the battery pack; the copper is mostly in electric wiring. In the near term, increased hybrid sales could lead to higher nickel prices, since supply has been tight. However, new supply is scheduled to come on line over the next five years, and many applications using nickel (such as tableware) have potential substitutes that would limit the impact of higher prices. Over the long term, nickel is likely to be displaced by lithium in the hybrid battery.

The amount of lithium required for hybrid batteries—regardless of the configuration that is ultimately adopted—will be a small fraction of the amount of nickel now used in hybrid batteries. There are few lithium producers, but an ample supply of the base materials.

The impact to copper producers should be more muted since the copper market is 11 times larger than the nickel market, and high prices are inducing a shift to cheaper substitutes for such applications as brass ornaments in home and commercial buildings.[95] Also, automakers are seeking to use lighter-weight materials in hybrids, which may reduce the copper content per vehicle in the long run.

Oil and Gas Producers (Integrated)
For integrated oil companies, which make up the lion's share of the market capitalization of the energy industry, the trend to hybrids will be negative because it is likely to disrupt their refining and distribution business. Although their exploration and development business may be relatively unaffected, hybridization will not be a benefit.

For the sake of clarity, we separately assess refining and distribution, and exploration and development. A key issue in assessing the prospects for integrated players is the relative weight of these two business lines.

Oil and Gas Exploration and Production Firms
The profitability of these firms is likely to decline from the current peak, but the industry may still be attractive for many years. The relative attractiveness of exploration and production over the longer term will depend on the precise supply and demand situation.

In recent years, many oil and gas exploration and production companies have found it difficult to find oil. Exploration costs are rising, as geo-political factors limit access and harsher, more remote areas have to be drilled. Thus, more advanced technologies need to be deployed. As a result, continued buoyant demand growth in the face of supply constraints could lead to higher prices in the near term. Over the medium and longer term, however, the mass adoption of hybrids and plug-ins would cause demand to decline, perhaps bringing it in line with future supply.

Of course, unlike hydrogen-powered fuel-cell vehicles, hybrid vehicles do not completely displace oil; they only reduce its consumption. As long as oil remains in use as a fuel source for transport and other applications such as petrochemicals and plastics, oil exploration and production operations will be necessary.

The worst case for these companies is that surging investments lead to massive new discoveries and developed supply just as hybrids and plug-ins dramatically reduce demand. The resulting oil glut would lower prices substantially. This scenario is unlikely, in our view. On the supply side, many industry observers believe future supply additions will be smaller and more gradual than additions have been over the past 50 years. On the demand side, emerging Asia is likely to consume an increasingly large volume of oil for many years, even though fuel efficiency per vehicle is likely to rise. Furthermore, the sizeable shift to hybrids and plug-ins necessary to have a large impact will also take several years.

In the medium term, the adverse impact of plug-ins may also be mitigated if these vehicles lead to increased demand for natural gas by electric utilities as they build additional baseload capacity. The benefit to natural gas suppliers of increased natural gas sales to power plants and shifting exploration and production activities could partly offset the impact from reduced oil demand.

Oil and Gas Refiners and Distributors
Oil and gas refiners and distributors are more likely to be adversely affected by the trend to hybrid vehicles. The impact may be modest in the near term, but severe longer term as hybrid sales increase. Hybrid vehicles will require fewer gallons of gasoline, reducing fuel sales; fewer stops at gas stations will also result in reduced store sales. In addition, the high utilization rates refiners enjoy today may vanish and overcapacity may hurt refining margins. These developments will likely accelerate when plug-in vehicles are commercialized and consumers begin to use the electric drive to propel most of their journeys. To the extent hybrids and plug-ins are concentrated in the industrialized countries of North America, Japan and Europe, refining and distribution companies in these regions will feel the greatest impact.

Retailers with Gasoline Sales

As hybrids and plug-ins are adopted, drivers will need fewer gallons of gasoline and will make fewer stops to refuel, particularly in cities and towns (versus highways), where electric drive trains are most efficient and recharging via the electric grid most feasible. The impact could be quite negative for one often-overlooked segment of the gasoline distribution system: convenience stores, supermarkets and big box discount retailers. These businesses will clearly be hurt by the shift to hybrid vehicles. The magnitude of the impact will likely depend on the extent to which they rely on gasoline sales to generate profits and attract customers to the store.

Semiconductor Suppliers (Power)

Faster and smaller semiconductors for managing the flow of larger amounts of electric power have become available at lower cost in recent years and made inroads into a variety of applications, from elevators to home appliances and, more recently, the automobile. These chips are critical for drive-by-wire technologies such as electric steering, as well as the hybrid power train, because they can handle high voltages and alternating currents with much greater control, reliability and efficiency.

Because they are key to the conversion of electrical energy for driving a motor at variable speeds, these specialized chips are likely to represent a growing share of the semiconductor content of both hybrids and non-hybrid vehicles. Increased penetration of the automotive market may also create a virtuous circle: Greater sales to the automotive market may help drive economies of scale, leading to even greater ubiquity of these components in non-transport applications.

We estimate that the market for power semiconductors is less than $350 million, but could range from $2 billion to $5 billion in the mid term, and even larger in the long term, depending on both the size of the hybrid market and the cost of power semiconductors. Since Toyota is manufacturing these components in-house, many analysts have not focused on the automotive market opportunity for these chips. In our view, these analysts are significantly underestimating even near- and mid-term demand from other automakers that are increasing their hybrid offerings.

Semiconductor Suppliers (Traditional)

Sales to the automotive market only account for 5% of total global semiconductor revenues today, but that is poised to change quickly.[96] Semiconductor manufacturers have recognized the stable growth, reasonable profits and opportunities for product differentiation in the automotive market. As a result, more of them are creating business units that specialize in the automotive market.

The semiconductor content of vehicles has already increased dramatically with demand for more intelligent vehicles capable of controlling the engine for enhanced fuel efficiency and lower emissions, of conveying information via sensors, and of delivering more comfort and responsiveness, with greater safety. Hybrids and further electrification of the vehicle will accelerate sales growth for semiconductor suppliers to the sector over the near and long term. Given the massive size and growth of other semiconductor markets, it is unlikely that the automotive market will become a major subsector in aggregate for quite some time. However, the superior margin prospects in this category could boost the bottom line for some industry participants. ■

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Dokyoung Lee, Senior Portfolio Manager—Style Blend Services
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