WHITE PAPER

Technology Trends and Long-Term Travel Demand

Summary

This white paper discusses three areas of technology – vehicle power systems, intelligent transportation systems and telecommunications – that are likely to affect future transportation behavior and travel demand. Briefly, the major observations are as follows:

- *Vehicle Power Systems:* Hybrid-electric vehicles could constitute nearly one fifth of the U.S. light vehicle market by the end of the decade. Widespread use of hydrogen-powered fuel cell vehicles is still at least several decades away, but other forms of hydrogen power may be commercially viable sooner, and some alternative fuels are nearing cost-competitiveness with petroleum. Future high-efficiency powertrain technologies are likely to increase the initial purchase prices of vehicles, in some cases significantly, while dramatically reducing the vehicle's operating costs. It is conceivable that future vehicles could be extremely expensive to purchase, but essentially free to operate. This type of relationship between initial cost and marginal (pre-mile) cost would eliminate financial disincentives that cause today's drivers to limit their automobile use.
- *Intelligent Transportation Systems:* The application of information technology to vehicles and transportation infrastructure will yield significant benefits in terms of safety and congestion relief. To the extent that intelligent transportation systems increase the effective carrying capacity of highway networks and therefore reduce congestion, they may also reduce the deterrent effect congestion has on some drivers, thereby stimulating more travel. Rapid advances in active vehicle safety technology may enable people to continue driving – and doing so safely – later in life than would otherwise be possible.
- *Telecommunications:* Ongoing advances in the quality and flexibility of teleconferencing systems, along with continued reductions in the prices of these systems, are making them an increasingly attractive alternative to some kinds of business travel.

Vehicle Power Systems

Although it is impossible to predict the exact characteristics of vehicle technologies 25 years hence, we can identify the fundamental forces that are, and will be driving the evolution of vehicle technology. In the U.S. vehicle market, the primary driving forces are the following:

- Global climate change, caused in large part by vehicular $C0_2$ emissions
- Depletion of non-renewable petroleum stocks

- Changing driver characteristics, particularly the increasing average age of U.S. drivers
- The strong and growing consumer demand for advanced, "active" safety features in cars and light trucks

The nation's vehicle fleet currently comprises 136 million passenger cars, 85 million light trucks, and some 8 million heavy (commercial) trucks. In 2002 (the most recent data), these vehicles logged just under 3 billion vehicle miles. Vehicle registrations and vehicle use have increased dramatically over the past 30 years, reflecting the unrivaled utility cars and trucks provide people and businesses. Light trucks have been growing steadily in popularity. Today, light trucks (pickups, SUVs and minivans) account for more than half of light vehicle sales.[1] This has exacerbated problems related to petroleum consumption.

Despite the striking growth in the number of vehicles and miles driven, there have been comparatively few dramatic breakthroughs in vehicle technology over the last half-century. Instead, the last five decades have seen steady maturing and refinement of existing vehicle technologies. The petroleum-powered, internal combustion engine is still, by far, the dominant powertrain technology, although today's engines are much more efficient, cleaner, and "smarter" than their ancestors. The automotive technology-development trajectory may, however, be at an inflection point. Over the past several years, a range of new automotive power systems have entered the market, and others have advanced to the point where their widespread market adoption within the next decade is likely.

Hybrid-Electric Powertrains

Hybrid-electric powertrains couple a gasoline or diesel internal combustion engine with one or more battery-powered electric motors, to provide several important features that conventional vehicles lack, including:

- Smaller, more fuel-efficient engines, because the hybrid's electric motor(s) augment the engine power when needed.
- The ability to use excess engine output during highway driving to charge the batteries, effectively storing for later use energy that would otherwise be wasted (and ensuring that hybrid vehicles need never be "plugged in" for charging).
- The ability to capture braking energy that would otherwise be dissipated as heat, and use it to charge the batteries, thus storing the energy for future use.
- The ability (of certain hybrids) to operate exclusively on battery power during low-speed urban driving, and (in virtually all hybrid systems) to shut off the engine when the vehicle is not moving, thereby conserving fuel and reducing emissions.

Hybrid vehicles provide significant fuel efficiency and operating cost advantages over comparable conventional vehicles. For example, the Toyota Prius, a 5-passenger mid-sized car, has an EPA rating of 55 MPG (combined city and highway), while conventional vehicles in this size category have EPA ratings ranging from 25 to 30 MPG. For the Prius owner, this difference equates to fuel costs savings of $410 to $592 annually, or roughly $.03 to $.04 per mile. Hybrids' operating cost advantages currently are offset, however, by the vehicles' $3,000 to $6,000 purchase price premium (compared with similar conventional vehicles).

[1] Davis and Diegel, 2004

Hybrid Market Trends

Nearly 88,000 hybrid vehicles (eight models in all) were sold in the U.S. in 2004.[2] Three more hybrid models are expected to enter the market in 2005, and automotive analysts forecast that sales will grow to 200,000 units, or about 1.2 percent of the market.

The rate at which hybrid vehicles' price premiums decline will largely determine hybrid market penetration over the next decade. According to some analysts, if hybrid powertrains remain significantly more expensive than conventional ones (which are themselves becoming steadily more fuel efficient), their share of the U.S. vehicle market is likely to peak at around 3 percent by the end of the decade.[3] Other researchers believe that if manufacturers are able reduce the hybrid cost premium by about half (a reduction consistent with current trends), hybrids could capture 7-10% of the U.S. light-duty vehicle market by 2008, and 15-20% by 2012[4]. The most recent market projections from the United States Department of Energy's Energy Information Agency (EIA) give gasoline and diesel light-duty hybrids (car and truck) roughly 3% of the new light-duty vehicle sales in 2008, and just under 4.5% by 2012. The EIA projects that in 2025 hybrids will account for 5.5% of total light-duty vehicle sales. At that point, there will be approximately 14 million hybrids in operation.

Bio-Fuels

Resent research suggests that even dramatic improvements in vehicle fuel efficiency will be offset by continued VMT growth and increasing demand for larger, more powerful vehicles.[5] Moreover, historical evidence of consumers' sensitivity to gasoline prices suggests that the levels of fuel taxation needed to induce meaningful reductions in consumption would almost certainly be politically impossible to implement.[6] Many researchers believe that plant-based "bio-fuels" offer the best short-term solution for issues of energy supply and greenhouse gas emissions. The two principle bio-fuels are ethanol and bio-diesel, both of which have been under development for several decades, and both of which are commercially available today.

Ethanol

Ethanol is alcohol fuel derived from plants. Ethanol accounts for about 1% of the total North American motor vehicle fuel market. Currently, virtually all ethanol is blended in low concentrations with gasoline, but gasoline engines require no modifications to run on pure ethanol. Corn is the dominant feedstock crop used for ethanol fuel production. Growing corn requires the production of fertilizers and pesticides, irrigation, and the operation of farm equipment. In addition, the ethanol production process itself requires energy. Researchers have calculated that 83% of the energy needed to produce ethanol from corn comes from petroleum[7], making corn ethanol, at present, a non-renewable energy source and a contributor to greenhouse gas emissions.

Ethanol produced from so-called cellulosic biomass, the fibrous bulk of plant matter, represents a potentially attractive alternative to corn ethanol. Ethanol can be produced using grasses, forestry

---

[2] JD Power 2005
[3] JD Power 2005
[4] Greene, et. al, 2004
[5] MacLean, et al, 2004
[6] Some analyses have suggested that fuel prices of $12-$14 per gallon would be needed to induce consumers to choose a vehicle fleet mix that averaged 50 MPG.
[7] Shapouri, cited in MacLean, et al, 2004

residues, even refuse like cardboard. Waste materials from ethanol production (plant lignin) can be burned for energy to run the process and possibly to generate electricity. In theory, cellulosic ethanol production could exceed 80% energy efficiency, and some estimates put its net greenhouse gas contribution at nearly zero because a portion of the $C0_2$ emissions from production and use are re-absorbed by the growing ethanol feedstock crops.

Significant technical challenges remain to be solved before cellulosic ethanol is commercially viable. In addition, meeting the nation's light-duty vehicle fuel needs via ethanol (whether corn-based or cellulosic) would require enormous amounts of land for the feedstock crops.[8] Nevertheless, cellulosic ethanol remains a potentially important energy source.

Because of ethanol's production costs, and due to ethanol's lower energy-density than gasoline, cellulosic ethanol is not currently cost-competitive with gasoline. Recent estimates put the at-the-pump price of cellulosic ethanol at roughly $2.70 per gallon gasoline equivalent.[9] Advances in production processes are expected to bring the cost of cellulosic ethanol down over time, but subsidies and/or policy changes may be required to induce widespread adoption of this renewable fuel source.

Ethanol Market Trends

Energy analysts do not forecast significant growth in the use of ethanol fuel. Although modest growth is forecast in the number of flex-fuel vehicles (capable of burning either ethanol or gasoline), the vast majority of these cars and trucks are run exclusively on gasoline; they occasionally use ethanol-gasoline blends when available, and are almost never run on pure ethanol. EIA estimates that even by 2025 ethanol will account for far less than one percent of total motor vehicle energy use.

Biodiesel

Biodiesel – fuel oil derived from plants – is another important alternative fuel. Biodiesel has been in development for more than 10 years and is available nationally (albeit at nowhere near the scale of conventional diesel fuel). Biodiesel fuel can be used in existing diesel engines.[10] Therefore, like ethanol, biodiesel provides a direct replacement for conventional fuels. Also, biodiesel vehicles emit significantly lower levels of several key pollutants than do conventional diesel vehicles. Moreover, biodiesel production and use generates only about 20% the $C0_2$ emissions of conventional diesel.[11]

Most biodiesel is currently made from soybean oil, which, like corn, is a relatively expensive and resource-intensive crop. The wholesale price for 100% biodiesel fuel (B100) is currently about $2.60 per gallon, as compared with approximately $1.50 for conventional diesel fuel.[12] New tax credits for biodiesel producers, however, bring the wholesale price of B100 down to $1.60 per

[8] Some estimates put the number as high as 80-240 million hectares, or between 1/9 and 1/3 of the land area of the lower 48 states, to fuel the light-duty vehicle fleet.
[9] MacLean, et al, 2004
[10] Biodiesel is often blended at 20% with conventional diesel fuel, primarily to prevent fuel gelling at low temperatures. Heated fuel tanks and/or fuel lines on diesel vehicles enable the use of 100% biodiesel (B100) at any temperature.
[11] US Dept. of Energy, Alternative Fuels Data Center, 2005
[12] Interview with a leading bio-diesel producer, February, 2005

gallon, making it almost cost-competitive.[13] Indeed, some biodiesel producers predict that, thanks to the tax credits, within about five years biodiesel fuel will be cheaper than conventional diesel. As a result, biodiesel consumption is projected to grow strongly over the next decade.

Because of its cost-competitiveness with conventional fuels, and its ability to be used with existing vehicles, bio-diesel may represent the next wave in transportation fuel. Factors moderating its market penetration include consumer acceptance of diesel vehicles, and land requirements for feedstock crops.

Hydrogen

Hydrogen frequently is touted as the fuel of the future. Hydrogen can be used to power internal combustion engines, or fuel cells that generate electricity.

Hydrogen Fuel Cells

A fuel cell uses hydrogen to generate energy through an electro-chemical process, the only byproducts of which are water and heat.[14] Several types of fuel cells exist, all using essentially the same process: electrons are stripped of hydrogen molecules, and forced to flow through an electrical circuit, producing current.[15]

Fuel Cell Market Trends

All credible market forecasts indicate that commercially-viable vehicle fuel cells – and the hydrogen supply infrastructure to support them – are a decade away at the earliest. The EIA, for example, forecasts that by 2010, just over 2,000 fuel cell vehicles will be in operation in the U.S. By 2025, that number will have increased to about 77,000 vehicles, or just .02% of the total U.S. light-duty vehicle fleet. Because widespread hydrogen refueling infrastructure most likely will take decades to develop, fleet applications (e.g., municipal vehicles, transit buses, motor pools) are likely to lead the way, since these can more easily use centralized fueling depots.

Hydrogen Internal Combustion

While most hydrogen research and development work focuses on fuel cells, several car makers – including Ford and BMW – have developed modified internal combustion engines (I.C.E.) that burn hydrogen gas. Advances in certain engine technologies[16] have made it possible for hydrogen-powered engines to equal the performance of gasoline engines, while producing virtually no pollution and zero $C0_2$ emissions (hydrogen contains no carbon atoms). Furthermore, the technologies that make hydrogen I.C.E possible were developed originally for gasoline engines, and are in use today on many vehicles.

---

[13] The tax credits, signed into law in 2004, allow a 1-cent per percent blend discount. So, for example, 20-percent biodiesel blends (B20) receive a 20-cent per gallon tax credit, and B100 fuel gets a $1 per gallon credit

[14] Although the supply of hydrogen is theoretically limitless, hydrogen does not occur freely in nature, and extracting it (from natural gas or water, for example) requires significant amounts of energy. If that energy is derived from conventional sources, then the hydrogen fuel cycle does, in fact, produce pollution, even if the hydrogen is ultimately used in a fuel cell. In the future, solar-powered electrolysis of water may provide abundant, and pollution-free hydrogen.

[15] This is a highly simplified description. Detailed information on fuel cells, is available at: http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/basics.html

[16] E.g., supercharging, coil-on-plug ignition and computerized engine-management.

Because they rely on existing technologies, hydrogen I.C.E vehicles offer a fast way to make hydrogen-powered transportation available. Nevertheless, the future path of hydrogen I.C.E is not clear. Hydrogen I.C.E may serve as a "bridge" technology: it may enable quick market entry of hydrogen vehicles while ultimately giving way to fuel cell systems in a decade or more. Alternatively, automakers may choose not to pursue hydrogen I.C.E. past their existing initial efforts, and instead focus on longer-term fuel cell research and development. Or, hydrogen I.C.E may indeed become the dominant hydrogen transportation technology.

Intelligent Transportation

The application of information technology to vehicles and transportation infrastructure is yielding significant benefits in terms of safety and congestion relief. Future advancements promise to extend and increase these benefits.

Active Safety Systems

A variety of onboard systems on the market today augment the driver's abilities, to make driving safer and easier. These systems benefit all drivers, but may be especially helpful to older drivers, whose reaction time, vision, and manual dexterity often are reduced. Onboard systems may enable people to continue driving - and doing so safely – later in life than would otherwise be possible. As the driving population in the U.S. continues to age, this extension of people's "driving years" could have important implications for total VMT, energy use, congestion, and other issues related to the number of people on the road.

The first electronic automotive anti-lock braking system (ABS) became commercially available in 1978. Since then, as CPUs, sensors and hydraulic and electrical control systems have become faster, more capable and less expensive, a steady evolution has occurred in the variety and effectiveness of onboard safety systems. The main onboard systems on or entering the market today include:

- *Electronic Stability Control* – monitors wheel slippage, driver steering inputs and vehicle yaw, and selectively applies brakes to individual wheels and reduces engine power to keep the vehicle on course and reduce or eliminate skidding. This system can help compensate for driver error (e.g., misjudging curve) and inability to compensate for skidding.
- *Adaptive Cruise Control* – uses a radar sensor to monitor the distance to the vehicle ahead, and reduces engine throttle and applies the brakes as needed to maintain a safe following distance. This system can help compensate for slow driver reaction time and inattentiveness.
- *Lane-Departure Warning* – uses a forward-looking digital camera to monitor visible lane markings, combined with image-recognition software, and sensors that determine vehicle speed, yaw and steering angles. If the vehicle begins to wander out of its lane, the driver is alerted with an audible alarm and, typically, a physical warning like a seat vibration. Lane departure warning systems can help compensate for driver distraction and drowsiness.

- *Night Vision* – uses infra-red thermal imaging technology originally invented for military use, to “see” in the dark beyond the reach of the car’s headlight beams. Camera images are displayed for the driver on a monitor, or projected onto the base of the windshield for a “heads-up” display.
- *Heads-up Display* – another technology originally developed for military use. Projects key information (e.g., speedometer, fuel gauge, night-vision images) onto the windshield below, but in line with, the driver’s line of sight. This allows the driver to monitor the vehicle without taking his eyes off the road.
- *Rear-View Camera* – uses a small digital video camera mounted on the rear of the vehicle, and an LCD monitor in the vehicle to show the view behind the vehicle. This system can assist drivers who have trouble turning around to look out their cars’ rear windows.

Future Active Safety Systems

The next generation of onboard safety technology will include video cameras that monitor traffic signals to prevent red-light running, or that scan for pedestrians approaching the road, and radar or laser sensors that will detect vehicles in the driver’s blind spots. These technologies will improve safety for all drivers, and may have a significant impact on the ability of elderly people to continue driving.

Intelligent Infrastructure

Intelligent infrastructure installations monitor transportation network conditions, and use information on congestion, incidents, road work, weather conditions and other factors to provide information on alternate routes, advise travelers of delays, adjust control devices (traffic lights, ramp meters) and take other actions. These systems can help maximize highway carrying capacity, reduce delays and improve system efficiency and safety. Current ITS applications include variable message signs that provide congestion, incident, alternate route and emergency information; real-time traffic information (now available on mobile telephones in many areas); and transponder-based electronic toll-payment systems that allow drivers to pay on the fly, dramatically reducing queuing at toll plazas.

Future Technology

The next generation of ITS will replace infrastructure-based applications (e.g., message signs, traffic-control centers) with vehicle-based systems. Onboard transmitter/receivers will allow individual vehicles to exchange information, turning the myriad cars on the road into giant mobile ITS networks. When coupled with global positioning system (GPS) technology, this will allow location-specific information sharing among vehicles. For example, if congestion builds on a stretch of roadway, the cars in traffic will broadcast their situation to those “upstream” giving the drivers time to take alternate routes and avoid adding to the traffic jam (onboard navigation systems, now fairly common, will automatically select the best routes around the congestion).

Onboard safety technology could work in concert with car-to-car networks. For example, if a patch of black ice on a bridge triggers one car’s stability control system, that car could send out a slippery-road warning. All networked vehicles in the area would receive the message, but only those cars headed for the bridge would warn their drivers.

Telecommunications

Every advance in communication technology – beginning with Marconi's wireless telegraph transmitter in 1900 and extending to the multimedia web conferencing systems of today – has held the promise of reducing the need for certain kinds of travel. If information can be shared remotely, the travel needed for face-to-face meetings is, in theory, unnecessary. Empirical research indicates, however, that advances in telecommunications technology have not, as yet, led to significant travel reductions.[17]

The failure of telecommunications to substitute more fully for travel is due, in part, to limitations of the technologies involved. In particular, teleconferencing systems – which are supposed to supply real-time voice and video and therefore enable "virtual" meetings – historically have suffered from poor quality video (e.g., picture freeze-ups), and frequent problems synchronizing audio and video feeds. Fortunately, improvements in web-based teleconferencing, and parallel improvements in Internet data carrying capacity ("bandwidth") are addressing these problems, as well as enabling new capabilities.

Chief among the advantages that new web-conferencing systems provide are lower costs, and the ability of users to participate in online conferences from almost anywhere. Traditional teleconferencing required participants to gather at central locations, and required companies to own expensive videoconferencing equipment or rent time at specialized teleconference centers. New web-conferencing technologies allow participants to join in from any location, using self-contained, low-cost video/audio units that plug into the USB port of any PC.[18] In addition, many new systems support not only voice and video, but also document sharing and instant messaging as well. By dramatically reducing the cost of teleconferencing, supporting diverse capabilities, and allowing participants true freedom of location, new web-based teleconferencing technologies may provide a real substitute for face-to-face meeting and may, therefore, supplant some travel.

[17] Mokhtarian
[18] Some web-conference units cost as little as a few hundred dollars.

References and Suggested Reading

Davis, Stacy C. and Susan Diegel, Transportation Energy Data Book: Edition 24, Oak Ridge National Laboratory, December 2004.

Edwards, John, "Don't Hang Up: New Technologies Make Web Teleconferencing Worth Another Look," *CIO.com*.

Green, David L., K.G. Duleep and Walter McManus, "Future Potential of Hybrid and Diesel Powertrains in the U.S. Light-Duty Vehicle Market," Oak Ridge National Laboratory, 2004 ORNL/TM-2004/181

Gresser, Julian and James A. Cusumano, "Hydrogen and the New Economy," The Futurist, March-April 2005, pp. 19-25.

Honnery, Damon and Patrick Moriarty, "Future Vehicles: An Introduction," *International Journal of Vehicle Design*, Volume 35, Numbers, 1 & 2, 2004, pp. 1-7.

Horrell, Paul, "Behold the All-Seeing, Self-Parking, Safety-Enforcing, Networked Automobile," *Popular Science*, September 2004.

Laitner, John A., Donald A. Hanson, Irving Mintzer and J. Amber Leonard, "Adapting for Uncertainty: A Scenario Analysis of U.S. Technology Energy Futures," in *Energy, Environment and Economics in a New Era: Proceedings of the 24th Annual North American Conference of the USAEE/IAEE, Washington, DC, July 8-10, 2004.*

Lovins, Amory B. and David R. Cramer, "Hypercars, Hydrogen and the Automotive Transition, *International Journal of Vehicle Design*, Volume 35, Numbers 1 & 2, 2004, pp 50-85.

MacLean, Heather L., Lester B. Lave and W. Michael Griffin, "Alternative Transport Fuels for the Future," *International Journal of Vehicle Design*, Volume 35, Numbers 1 & 2, 2004, pp 27-49

Mokhtarian, Patricia L., "Telecommunications and Travel," White Paper prepared for Transportation Research Board, 2000. See also www.its.ucdavis.edu/telecom for numerous other publications.

Mudge, Richard, "Using Technology to Manage and Operate 21st Century Transportation Systems," NCHRP Project 20-24(38)B, Declan, Inc., Reston, VA, November 2004.

Shell Oil, Press Release "Hydrogen Future Drives Into the Big Apple," January 27, 2005, www.shell.com.

Sperling, Daniel, Future Drive: Electric Vehicles and Sustainable Transportation, Island Press, 1995.