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The Future of the Automobile: Technological Transformation

by

Fred Webber, Keith Cole and Edward J. Wall

George C. Marshall Institute
Washington, D.C.

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The Future of the Automobile: Technological Transformation in the Transportation Sector

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September 19, 2006

William O'Keefe: Good morning and welcome to this Marshall Institute Roundtable. My name is Bill O'Keefe and I am the CEO of the George Marshall Institute. Normally these are run by Marshall's President Jeff Kueter, but he engaged in a little bit of delegating up yesterday, ostensibly because I have had a long association with the auto industry. As I thought about this program, I thought about how much automotive technology has changed in the past several decades. Today's cars are tremendously advanced compared to those of ten or fifteen years ago. When we were thinking about this, we were motivated by the fact that there is a continuing concern about greenhouse gas emissions and their potential effect on the climate and concerns about high gasoline prices and the dependence on foreign oil. We thought these might be the drivers for another transformation in automotive technology.

We have three very knowledgeable people whom we have asked to address three topics. The first is the technologies that could be introduced over the next ten or fifteen years to increase fuel efficiency and manage greenhouse gas emissions. I stress technology for fuel efficiency and not that four-letter word CAFE (Corporate Average Fuel Economy), which is beyond their control. The second is the technological, economic and perhaps other obstacles to bringing new technology and innovations to market, and we would like their thoughts on what could be done to overcome them. The third is an overview of the process that companies go through in deciding to bring innovation to the marketplace and what factors drive those decisions, and in that context what can be done to accelerate innovation in automotive technology. The order that we will follow is Fred Webber, who is the President of the Alliance of Automobile Manufacturers, Keith Cole of General Motors, and Ed Wall who is the Program Manager for FreedomCar at the Department of Energy. Fred, you can begin and we look forward to your comments.

Fred Webber: Good morning and thank you, Bill; it is a pleasure to be here. I am going to paint an overview of what the industry is up to. I would like to say for the record that we in the automobile industry think that the climate issue is a global one that has to be addressed as a shared responsibility of individuals, government and certainly industry. The Alliance and our nine member companies support the develop-

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[1] The views expressed by the authors are solely those of the authors and may not represent those of any institution with which they affiliated.

ment of new technologies and the deployment of cost-effective energy strategies in all sectors to improve energy efficiency and reduce greenhouse gases. That is the track that we are on and we take that mission seriously. There is no turning back and I will now paint a broad picture of how we are approaching the problem through advanced technology and alternative fuels.

Today there are about 800 million vehicles on the road worldwide. By some estimates, this number is going to grow to about 1.2 billion vehicles by 2020. Along with this growth in the size of the vehicle fleet, there is a substantial growth in the demand for fuel, because people want to go more places and they will be driving more vehicles. Anybody who thinks that there isn't going to be that demand or that we are not going to need oil is kidding himself. But there are alternatives and the more we reach out and develop those alternatives, the more we can take pressure off the oil market and many improvements in many other areas will follow.

As a result, though, of this growth, the worldwide oil demand is expected to increase – and I think my oil company colleagues will agree with this number – by about 3 percent per year. So with this in mind, if by some miracle it were possible to increase the fuel economy of the entire worldwide fleet of vehicles by 25 percent overnight – guess what? It would take only six or seven years for fuel consumption to return to or surpass current levels. This suggests that we have a domino effect, not just in terms of U.S. gasoline consumption, but worldwide gasoline consumption as well.

So is this a hopeless situation? We don't think so, but any attempt to address these concerns about, for example, U.S. dependence on oil, especially foreign oil, can't succeed by focusing only on one component of gasoline demand. Vehicle fuel economy has increased. If you look at the average per auto, it is almost up to 30 mpg, if you really peg it carefully. This fuel economy improvement is going to continue as new and improved technologies find their way into the marketplace. But that factor alone will not help slow the demand for gasoline in the transportation sector and I just explained why. We are going to have a lot more vehicles on the road, the population will increase, and people will want to drive. It is not hard to figure out.

The Alliance supported strongly the Energy Policy Act of 2005. It wasn't perfect, but we supported it because it created an effective energy policy based on broad market-oriented principles. It also promoted policy that would help foster research and development and accelerate the deployment of advanced technology vehicles by providing customer tax incentives and extending manufacturing incentives for the production of dual-fuel vehicles. It was a good idea; we need those incentives. That is why I said that we need this partnership of industry, government and individuals.

Since 1966, automobile manufacturers have been producing vehicles capable of using high-concentration blends of ethanol. I filled up my car yesterday; I was down at a Marine Corps event at Quantico and there was big sign there, which for some reason I hadn't recognized before. It said that this gasoline was 10 percent ethanol, and that has been the case, especially as they have phased out MTBE. Believe it or not, there are 5 million plus vehicles on the road that are E-85 capable. (That means 85 percent of the fuel which you fill up with is ethanol and the other 15 percent is gasoline.) We are going to add another million E85 vehicles in the next few months. If all the E-85 capable vehicles were able to refuel using only E-85, the U.S. would be able to reduce its gasoline consumption by a healthy 3 billion gallons per year. That's a lot and that's progress.

I am driving a hybrid electric vehicle and I love it; it is an SUV and I get about 30 miles to the gallon. It is on loan because it is a Lexus and Toyota occupies the chair of the Alliance, so they let me borrow this car for a year. It has been a real treat and I will hate to give it up. But we have a lot of hybrids on the road. They are going to increase substantially in numbers over the next several years. They offer significant improvements in fuel economy and I know you have read all the publicity about whether they really get fifty miles to the gallon, do they really get forty, etc. Look, its great technology. There is nothing that I like better than sitting in traffic and all of a sudden the engine shuts off and I am running on a battery that is quiet with zero emissions. As you cruise along slowly through the city you are primarily running on the battery. This is great technology and it is going to get better and better. Maybe some of our manufacturing people can explain that in greater detail. But you know when you get 50 percent increase in fuel economy, that's not bad. The industry is also working to introduce technologies that will allow diesel-powered vehicles to meet EPA's latest emission standards.

In Europe, every time I get into a cab or a car, it is diesel; 50 percent of the vehicles being sold now in Europe are what they call "clean diesel." Some are bio-diesel. They are providing fuel economy gains in excess of 25 percent compared to conventional vehicles. This is exciting technology. A friend of mine drove a diesel-powered Mercedes to New York from Washington this past summer and claims that he got forty-nine miles to the gallon. I want to drive that car too to see if I get the same mileage. That is not bad, if that is really the case, and I hope his calculations are correct. But what we do say is that when you drive a diesel-powered vehicle, a new "clean diesel" for example, you are going to get a 10 or 25 percent increase at a minimum. If you couple that with what we are experiencing with hybrid technology, what we can experience with ethanol – again, we will have 6 million vehicles capable of running E-85 by the end of the year – that is progress. That is what we mean by alternative fuels and advanced technology.

Another promising enabling technology is the hydrogen-powered internal combustion engine. BMW calls it the hydrogenized CE. The concept of using hydrogen in internal combustion engines offers a lot of advantages. It has zero emissions. Maintaining the utility, flexibility and driving dynamics of today's automobile, assisting in the development of hydrogen storage technology, developing hydrogen distribution channels and helping to promote hydrogen refueling infrastructure: these are the challenges. But as we move along with hydrogen fuel cell development, hydrogenised CE, we are going to meet those challenges head on. Some people think those challenges are insurmountable. I suspect Keith Cole will talk about that, because General Motors is doing exciting things in the hydrogen field. It is technology that will come to fruition, I suspect, on a large scale in ten years; I have met with GM's Larry Burns and several people in Detroit who are working on this technology, which is very exciting. Early next year I will test-drive a hydrogenised CE made by BMW, the 7 series, which has a dual-fuel capability. You can drive on hydrogen; you have one fueling station out on Benning Road where you can add hydrogen and the computer tells you how to do it. It is all automatic and the computer technology is fantastic and I can't wait to drive that vehicle. I have driven hydrogen-fueled vehicles on test drives; they are very smooth, very quiet and run very clean. The tank takes up most of the trunk, but we are going to solve that problem. For the future, I am one of those who think about hydrogen. I don't want to get into the hydrogen too much because I don't want to steal Keith Cole's thunder, but hydrogen-powered fuel cells, we think, offer the biggest improvement in efficiency and emissions and the greatest opportunity to dramatically reduce the environmental energy footprints of U.S. vehicles.

But the economic, technological and infrastructure challenges are, as I mentioned earlier, very substantial. But you know, when John Kennedy said we were going to go to the moon, the challenges were substantial. A lot of people thought he was daydreaming and yet we got a man on the moon. There is no reason why we can't successfully develop a hydrogen technology. In addition, the introduction of fuel cells into America's light vehicle, passenger and truck fleet is going to require a demonstration of durability and overcoming, as I mentioned earlier, the packaging restrictions of size and weight. I have to put my golf clubs in the trunk; I can't have that hydrogen fuel tank sitting there. Keith may talk about the "skateboard" concept that his folks have developed and I find that very exciting too. I made reference to the new energy law; the hydrogen title in the new energy law will prove, we think, to be a major assist to the automobile industry as we attempt to overcome these hurdles and develop this great technology.

So we are transitioning to some degree away from gasoline-powered internal combustion engines, but this is going to require a lot of people getting together to figure out how to accelerate advanced technology and to help us get into alternative fuels and advanced technologies so that we can take the pressure off the gasoline market. A market-driven focus and incentives for consumers will play a critical role in all of this. So with that, I hope I have set the stage for Ed and Keith to follow through and then later on I will be happy to answer questions.

Keith Cole: Good morning. Figure 1 shows our advanced technology portfolio strategy as we move through time towards the right. We continue to make advancements in the internal combustion engine. Next, you see biofuels coming in and hybrids. Finally we see hydrogen and fuel cells. What is happening in the automobile technology area is something like what happened in telecommunications twenty years ago. If you think back, we had three networks and a couple of independents. When we turned on our TVs, we pretty much knew what we were going to see; the choices weren't that great. What is happening in the automobile industry mirrors, on a smaller scale, what happened in the telecommunications world, where now we have 500 channels.

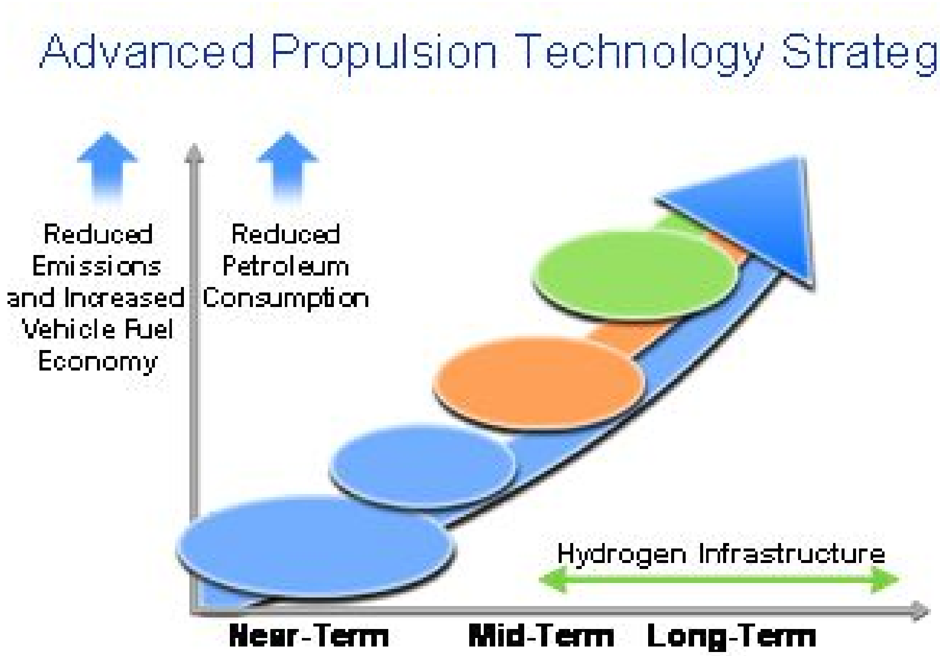


Figure 1

In the automotive world, we have a proliferation of technologies that have suddenly come to the fore. In one sense, the rising price of gasoline allows us to go out on the limb a little further to push technology; concerns about future supply justify the business case for looking at different technologies. But we have a number of factors coming together - regardless of whether it is the price of gas, people who say we are going to have difficulty finding new supplies, or concerns about climate change. Whatever it is, we have a proliferation of new advanced vehicle technologies. Fred has given a very good synopsis of what those technologies are, so let me talk a little bit about what we are doing at General Motors.

On biofuels, you may have seen our "Live Green Go Yellow" campaign. We have over 2 million GM flex-fuel vehicles on the road today. We have announced, along with Ford and Daimler, that we are doubling our production by 2010 to over 2 million flex-fuel and biodiesel-capable vehicles a year from the three companies. We see this as something that you can do right away.

We are taking advantage of the technological capability of diesel and flex-fuel vehicles to use biofuels today. This is something that has a tremendous ability to displace oil almost gallon for gallon. As I said, we foresee 2 million vehicles a year by 2010. But we know that the other half of the equation is biofuels pumps. We have been working state by state with about a dozen state partnerships to partner with ethanol providers that will sell ethanol as E-85 at a price that is cost-competitive on a sense-per-mile basis with the cost of gasoline, and retailers that want to take advantage of filling the demand that's there. Those dozen or so partnerships will result this year in about 150 new E-85 stations.

We just announced in August an improved Duramax diesel engine that will go into production in 2007 and a new light-duty V8 turbo-diesel that will be sometime after 2009. This will be fifty-state compatible, so it meets Tier 2 Bin 5 emissions standards and LEV-2 in California. It has NOx after treatment and a particulate filter. This is certainly cleaner than anything that is on the road today. So we are investing in flex-fuel vehicles and we are investing in diesels.

We are also investing in hybrids. The Saturn VUE Green Line is on sale now; it is a very inexpensive hybrid, and has the best SUV mileage of anything out there today, at 27 mpg in the city and 32 mpg on the highway. We are coming out with a Chevy Malibu Hybrid, which is the same hybrid system as the VUE. The Malibu will be out in 2007 and then late in 2007, our "two-mode" hybrid, what people call a full hybrid, will be on our Chevy Tahoe and GMC Yukon and then the following year on our pickup trucks. This would give about a 25 percent boost in mileage. The new Tahoes are getting about twenty or twenty-one miles a gallon combined, so you are looking in the range of twenty-five miles a gallon for a full-sized SUV. This is a downsized version of the hybrid system in the new diesel-hybrid Metrobuses here in DC, our Allison diesel-electric hybrid transmission system for transit buses.

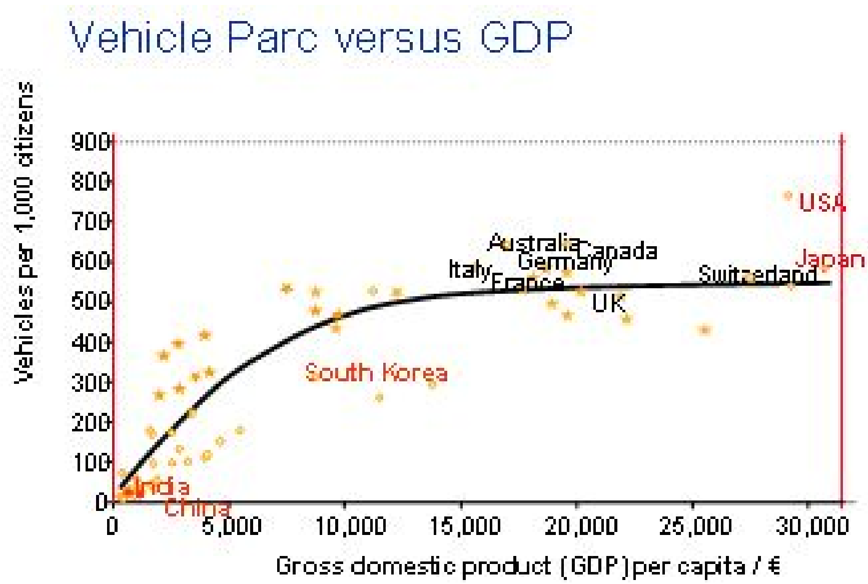


Figure 2

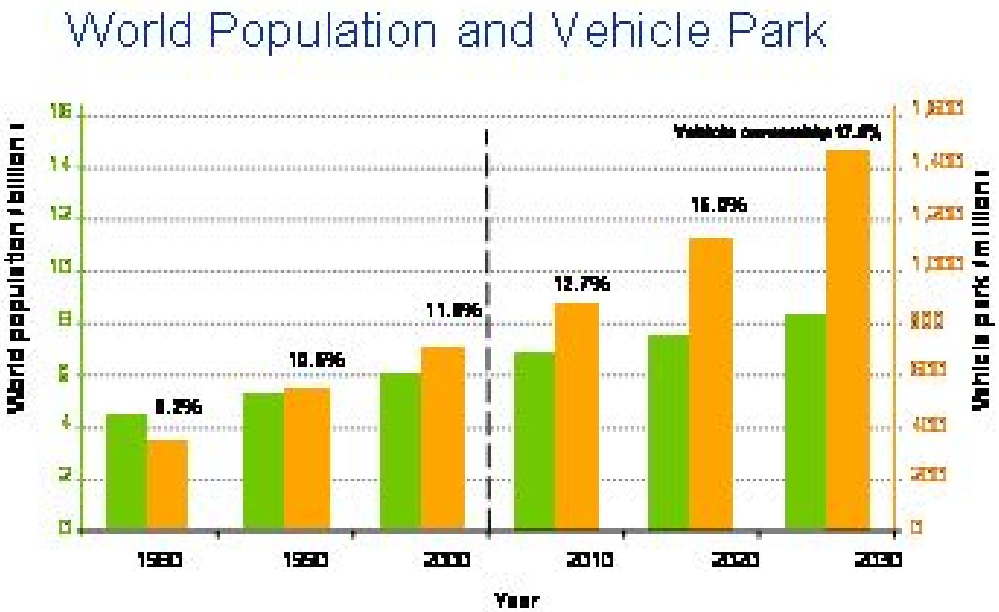


Figure 3

I want to talk a little bit about the factors that relate to fuel cells coming to market and why we see fuel cells as the ultimate answer for the automobile. Figure 2 shows what happens as countries get wealthier. As the gross domestic product goes up, there is a very well defined relationship to vehicle ownership; it is almost a universal aspiration. The striking thing about this chart is that you have huge populations, India, China (Russia isn't called out on that chart, but it is at the lower left), that are getting wealthier and aspiring to more vehicles. So we see a huge growth in demand worldwide for vehicles, even though the North American market isn't growing as much. On Figure 3, the lower progression of bars (the green ones) is population, which is going up to about 8 billion by 2030. But the vehicle population is going up much faster, from 12 to 17 percent ownership, by 2030. That is over one billion vehicles by 2020 and two billion vehicles by 2050. If we are going to have that many vehicles, they have to be close to zero emissions, if we are going to have a sustainable business of selling automobiles.

It is because of that tremendous growth in vehicles that we are looking beyond biofuels and beyond hybrids to hydrogen. One of the interesting things about hydrogen is the diversity of feedstocks that can be used. That is very attractive to us. Today, we are 97 percent dependent on petroleum in the automotive sector, and dependent on one fuel (gasoline) that is subject a significant amount of price volatility. And that price volatility can play havoc with our business plan. We would like to get to a situation where we have a diversity of fuels that can power our vehicles.

Our objective is to design a competitive fuel-cell propulsion system by 2010. What that means for us is to do the engineering to come up with a system that, in terms of performance, durability and cost (assuming automotive scale volumes) would be competitive with today's internal combustion engines. Now the assumption about volumes means that in the early phases, it would probably be more expensive to build, because we wouldn't have the supplier base tooled up for large-scale volumes. But at least we would have a design that we think will last long enough and perform the way we want, and we would know how to build it at volume in a way that can compete with the internal combustion engine. This does not necessarily mean cars in a showroom in 2010; it means this is a challenge to our engineering staff: give us the goods by 2010.

Figure 4

So we have been very active in this area. We showed the AUTOnomy (Figure 4, left) back in 2002 as a concept where the fuel-cell propulsion system would be in a "skateboard" at the bottom of the car and the body would be almost "plug and play." Maybe every couple of years you could swap bodies out. We then came up with a drivable version of that concept, the Hy-Wire (Figure 4, right) the next year. This was an engineering project; if you look under the skin, it took a lot of custom fabrication to assemble this vehicle.

Figure 5

A year and a half ago, we unveiled the Chevy Sequel (Figure 5, left), which was our latest embodiment of the AUTOnomy-HyWire progression. Last week, we unveiled the drivable version of the Sequel in California. It has a 300-mile range and has very good acceleration. It is about the size of a Cadillac SRX. It has wheel-hub motors in the front wheels and a transaxle-mounted motor in the rear. It is true to the skateboard concept; the fuel cell and the fuel cell tanks are underneath the driver's compartment, providing a tremendous degree of design freedom for the overall vehicle.

Sequel represents where we would like go in the future with vehicles specifically built for fuel cells. But we want to get real world experience with fuel cells and we are not waiting around for this technology to fully mature to put vehicles on the road. We are putting fuel cells on the road today with a vehicle that people are more accustomed to. We have been using an Opel Zafira minivan as the base of our hydrogen-3, perhaps some of you have ridden in it.

Just recently, we announced our newest platform, the Chevy Equinox Fuel Cell Vehicle (Figure 5 on the right). It's a beautiful car. Instead of an exhaust port in the back, you have little vertical bars that emit water vapor. There is no intrusion into the passenger cockpit. The fuel cell is in the engine compartment and the hydrogen storage tank is under the rear seat, so you can still carry your golf clubs. At the front end you can see a lot more openings into the vehicle for radiator space. Fuel cells don't run as hot as an internal combustion engine, but they do produce heat, so you actually need more radiator-type space to drive off that heat because the operating system isn't as hot. So there is a custom-designed front end, and a number of other custom features in the Equinox FC. We are going to have about one hundred of these. There will be fifty in the DOE demo program, and another fifty (approximately) outside of that.

Figure 6

The other piece of the hydrogen fuel cell equation is infrastructure. We are learning a lot about the infrastructure challenge in the ethanol debates at the moment and our efforts in trying to get E-85 infrastructure. If anything, hydrogen is more difficult because these aren't dual-fuel vehicles. Figure 6 shows our previous generation, HydroGen3 fuel cell vehicles at the Shell hydrogen station on Benning Road here in DC. We are well aware of the challenges involved in new refueling infrastructure. However, we think it is doable if we focus on infrastructure in a local area, and not so much on long corridors. People drive 90 percent of the time within a fairly localized area, and we believe the better approach is to focus on saturating a local market with enough hydrogen stations that people feel that they can find a station when they need one.

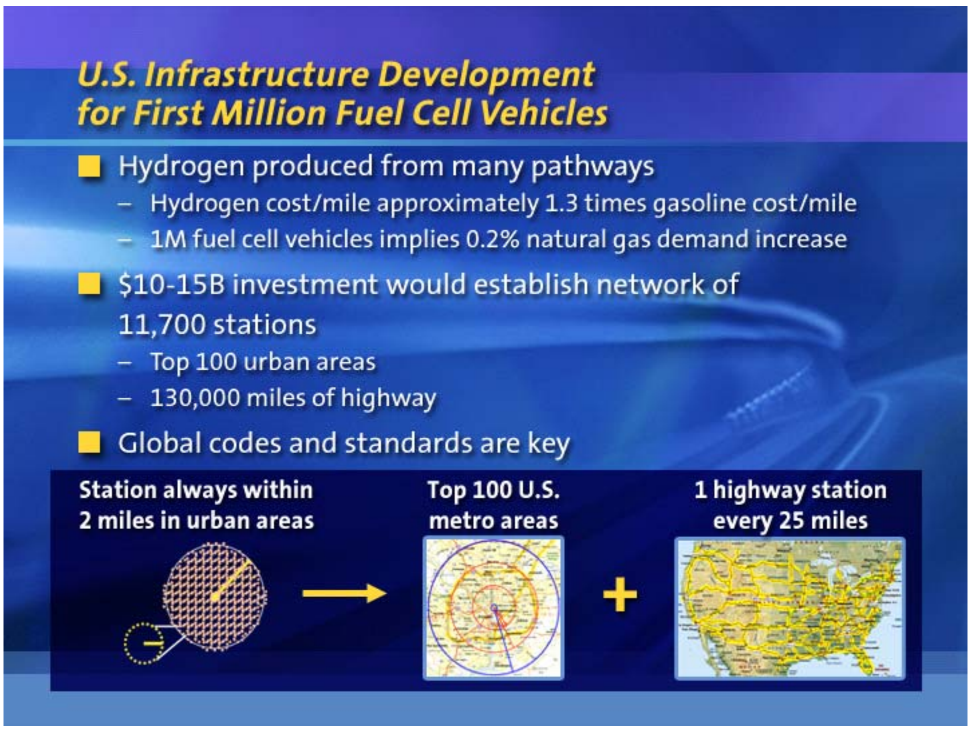


Figure 7

We have looked at what it would take to give reasonable access to hydrogen in the top hundred urban areas (which account for about 70 percent of the population) plus the interconnecting 130,000 miles of highway (Figure 7). You are looking at about $10 billion if infrastructure costs are at $1 million a station. We think you can do a lot better than that, and we are seeing good evidence that the cost will ultimately be less. So the scale of getting started is not an insurmountable hurdle. But this early part of the infrastructure development curve is the most difficult, where it is hardest to see the business case being made. It is where we have the greatest need of policy incentives, but it is something that, should the country decide to go in this direction, we feel is doable.

What is it going to take to go to market? The biggest thing is customers, and we have been focusing on early customers and developing those relationships: the Post Office, the Army, FedEx. We see possibilities in the stationary market as well. In addition to announcing our new vehicle, the Equinox FC, we now have something called Project Driveway. We are going to do a market test of this technology to take it out of the demo world and use it to test and quantify the market. This is an important step, as General Motors gets closer to commercialization. Project Driveway involves one hundred fuel cell vehicles focused in three locations, California, New York City and Washington, D.C. where we have hydrogen infrastructure. The vehicles are designed to last for 50,000 miles, start and stop and operate in sub-freezing temperatures and to meet all 2007 federal motor vehicle safety standards.

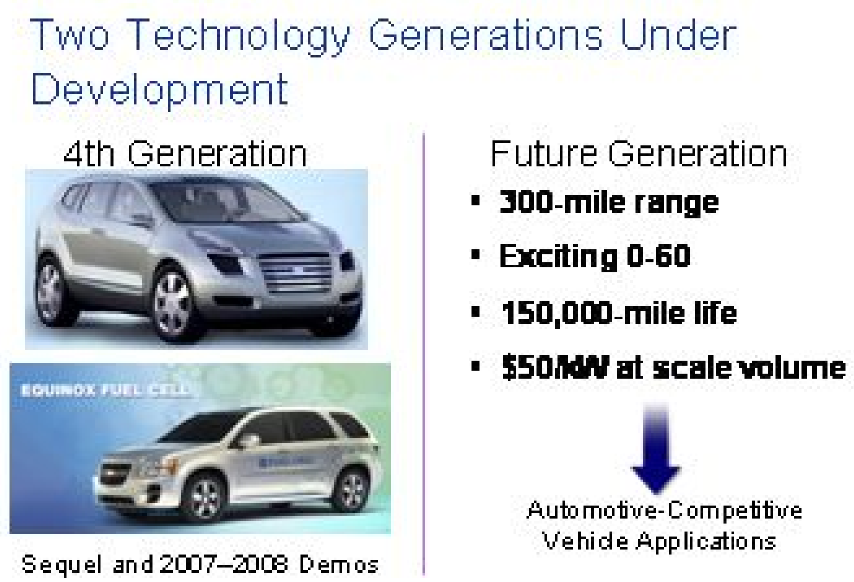


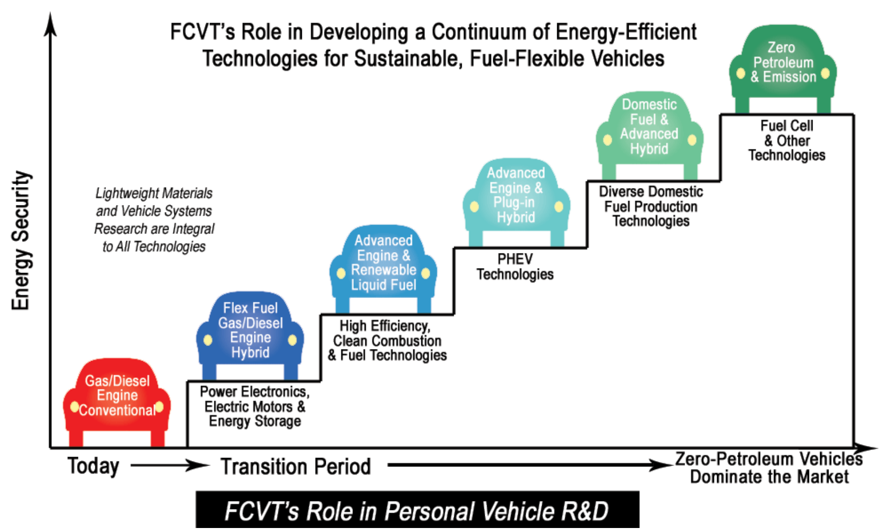
Figure 8

The left side of Figure 8 shows where our fourth generation fuel cell is in use - in the Sequel, our forward-looking design, and then the Equinox, our "how do you get cars on the road today" design. But this technology in a sense is already obsolete; by the time we get it up and designed and engineered into the vehicles, we have already moved on beyond that. So while our fourth generation is in the process of being placed in vehicles, we are really focusing on the next generation. In this next generation, which we call Auto-Competitive, we plan to have a 300-mile range, exciting performance, a 150,000 mile life (which is really our benchmark for commercially viable vehicle), and a cost at volume of $50 a kilowatt. If we meet those targets, we have an automotive-competitive product. We don't have a timeline for that, but our goal for coming up with this design is 2010.

Bob Lutz, our head of design, raised an interesting question at the events we held in California to unveil our recent round of vehicles: where will it happen first? We see a tremendous demand to get beyond petroleum in China. They face, if anything, an even worse situation in oil imports and are very focused on looking for alternatives. We sincerely hope that the move to a hydrogen economy happens here first, but the point is, we are a global automotive company. If there is a demand and the right infrastructure and policy mix occurs somewhere else, that is where the development will happen. And that would really be a shame, because we tend to build our cars where we sell them; almost all of our cars that we sell in China today are built in China. But I think the most likely locations for fuel cell vehicle deployment, would either be here or in China. I appreciate your attention and when Ed is done, I will be glad to answer any questions.

Edward J. Wall: Thank you, Fred and Keith. Our vision of the future is not unlike the one that Keith expressed for General Motors. We have a long- range vision in which ultimately the vehicle will require no petroleum and will produce no criteria pollutants. That is at the upper right symbolically on Figure 9 and certainly a fuel cell vehicle operating on hydrogen satisfies that vision.

Strategic Approach to Transportation Energy Security



The FreedomCAR and Fuel Partnership is "… a very effective way to develop technologies that will satisfy all of the requirements for the deployment of radically new systems in the marketplace on a large scale."

NAS/NRC Review of the Research Program of the FreedomCAR and Fuel Partnership, August 2005

Figure 9

We see a continuum of technologies along the way, however. There are many technologies that will be needed to fulfill the vision of the zero-emission, zero-petroleum vehicle: for example, the hybrid power train (advanced batteries, power electronics, and better electric motors). And in general, all these components are going to have to have better performance than today's components, they are going to have to be cheaper and they are going to have to have longer lifetimes. We see the American consumer having been spoiled by the products that the OEMs are delivering today. If you buy a car or light truck in this country, you pretty much expect to get 150,000 miles out of it, and most cars will be on the road approximately fifteen years. So the consumer, having been conditioned, is going to expect the same thing out of the advanced vehicles of the future – at least that, if not better. So we see a number of technologies, the hybrid technologies that will be required by the fuel cell vehicle of the future, but also a combustion hybrid that could contribute to saving petroleum between now and the time that we see fuel cell vehicles in large numbers. So we see these technologies as being along the technology continuum.

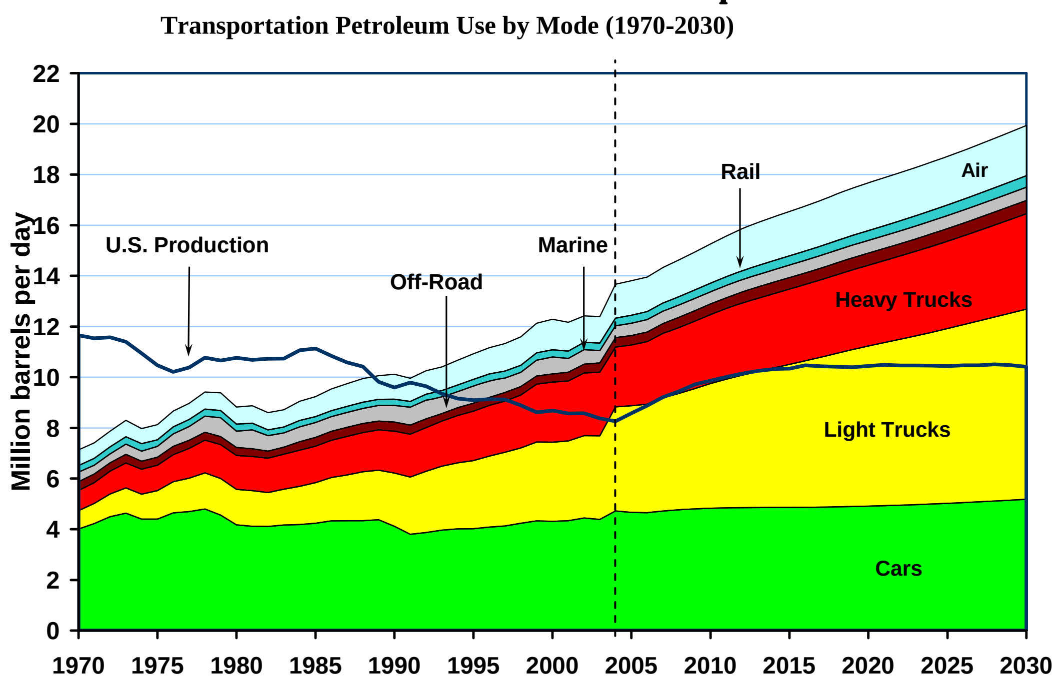
Lightweight materials and vehicle systems research will be integral to all of these. If we can make the vehicle lighter while maintaining the utility and the safety characteristics of today's vehicles, it will take less fuel to move that vehicle around. For example, carbon fiber as well as magnesium, titanium, and aluminum for structural components are being investigated. But once we make a vehicle out of these exotic materials, we have to examine how we recycle the vehicle, so some of our work at the Department of Energy is aimed at recycling. At Argonne National Laboratory, we have a pilot recycling facility where we are looking at recycling the vehicle of the future built with magnesium or titanium, aluminum and steel certainly, and a lot of composite materials. Currently when you recycle a vehicle, you pull the power train frame, send the rest through a shredder and separate it magnetically. But you aren't going to separate these materials magnetically in the future, so this is an area where, with our partners at USCAR, we are devoting some attention.

We are also looking at advanced combustion. Even though combustion vehicles have been here for a hundred years, we do not feel that the ultimate efficiency has been wrung from the combustion engine yet. Our scientists at the labs tell us that theoretically we can approach 60 percent thermal efficiency on a combustion engine. So we are looking at advanced combustion processes, low temperature combustion, and homogeneous charge for compression ignition. The latter offers the opportunity of using the advances in electronic controls of the vehicle to operate in a very narrow range between higher temperatures, where you form nitrogen oxides, and lower temperatures, where you form soot. If we can operate in that narrow zone, we have the opportunity for higher efficiencies and lower emissions from combustion engines.

So we are working in all these areas and we are also looking at a key component, which is the fuel. It's a key enabler for the use of advanced technologies and we are also looking to see where advanced fuels can help diversify our sources of fuel and reduce our over-reliance on petroleum at this time. Our research in ethanol from cellulosic sources offers considerable benefits to this nation looking forward. But ethanol, we recognize, has lower energy content than gasoline and diesel fuel. At the moment, miles per gallon would be lower if cars were running on E-85. We are working with our automotive partners to investigate ways to optimize the engine and take advantage of the characteristics of ethanol (its ability to run at a higher pressure ratio, for example) to see if we can gain back some of what would be given up using the lower-energy-density fuel.

This is the range of technologies at which we are looking. We do see it as a continuum from where we are today to where we hope to be in the future. Figure 10 gives us an idea of the magnitude of the challenge we face. The last year we have full data for is 2003. In 2003, roughly 13.5 million barrels a day were used for transportation, just over 10 million barrels a day for highway transportation alone, and that works out to about 7.5 million for cars and light trucks for passenger use, and about 2.5 million for heavy trucks.

Transportation Petroleum Use by Mode (1970-2030)
2003 Total = 13.42 mbpd



Note: The sharp increase in values between 2003 and 2004 are caused by the data change from historical to projected values.
Source: Transportation Energy Data Book: Edition 25, ORNL-6974 (to be published) and EIA Annual Energy Outlook 2006, February 2006.

Figure 10

In Figure 10, to the left of the dotted line is actual fuel use and to the right is what is projected by the Energy Information Agency looking all the way out to 2030. We see there is some elasticity to fuel consumption. As the price for petroleum started to climb in 2003, we saw reduced use, both in cars and in light trucks, and that is seen as the blip on the chart when you go from actual data to the projected data. We expect that in the next set of EIA projections, we will see the higher prices taken into account and there will be some reduced projections. But even so, it is a considerable amount of fuel and in the face of what Keith observed, the growing demand for fuel worldwide, we see the future as a future where there will be continued upward price pressure on petroleum. So more efficient technologies are one key to deal with that.

In regard to the government role, if we look at the obstacles (and that is one of the focuses of this session this morning), we certainly see technology breakthroughs – longer-life technologies, technologies that are cheaper – as being critical obstacles to overcome. The other is the cost of the technology. Certainly we see the federal role is in long-term, high-risk research, and trying to accelerate the deployment of advanced technologies once they have been validated. Our partnerships have been aimed at promoting that sort of research, going out to a point where a company would not be operating solely on its own because of the risky nature of the technologies being investigated.

In the FreedomCar and Vehicle Technologies (FCVT) Program, we are not only conducting the next generation of advanced automotive R&D. We also have a small deployment element in which we are looking at trying to accelerate development of vehicle components that will enhance energy security. We have just completed a solicitation in this area and our emphasis this year is on promotion of E-85, getting more E-85 out there, and trying to stimulate or catalyze the development of local government-supplier-manufacturer partnerships. In the solicitation which we just announced the results a couple weeks back, General Motors, for example, is a partner in four or five of the awards, along with local municipalities and state governments.

Looking at areas where we can help overcome the obstacles, the Energy Policy Act provided not only tax incentives for purchasers of more efficient vehicles, hybrid vehicles and advanced combustion vehicles, but also provided for loan guarantees. This is something we are examining right now. We have a solicitation out looking for opportunities and companies that see the loan guarantees as a method to help overcome the risk of manufacturing deployment of advanced technologies. We are looking for partners in this area and hoping through the loan guarantee section of the Energy Policy Act we can help "buy down" the risk, as it were. We see that as a role for government.

In the deployment area, taking E-85 as an example, it's a complex question. We have to have the vehicles there. As Keith mentioned, there are nearly 6 million on the road today. General Motors, Ford, DaimlerChrysler and Nissan have all committed to make more in the future, so there will be more vehicles available. When I checked last week, there are only about 750 stations that offer E-85 in the country, so we need to expand the station network so that those who have E-85 vehicles could be confident of getting fuel when they need it, a problem not unlike the one that Keith detailed in discussing hydrogen fuel. Finally, we need to be sure that there is adequate supply to those stations that are committed to providing E-85.

We do see our partnerships as critical in this effort. My office is involved in two in particular, the FreedomCar and Fuel Partnership and the 21st Century Truck Partnership. The FreedomCar and Fuel Partnership has three automotive partners (General Motors, Ford, DaimlerChrysler) who participate under the auspices of USCAR and five energy partners (ConocoPhillips, ExxonMobil, Shell, British Petroleum, Chevron). The 21st Century Truck Partnership is even more extensive; aside from DOE, we have three additional federal partners, EPA, DOT and the Department of Defense, along with manufacturers in the areas of engines, system integration and hyper-technologies, including Allison Transmission, Caterpillar, International, BAE Systems, Novabus, Mack, Detroit Diesel, Oshkosh, Honeywell, Volvo, Cummins, Eaton, DaimlerChrysler, PACCAR, and Freightliner.

In these partnerships, we feel our participation helps reduce the risk involved in working with some very risky technologies where success is by no means assured. It helps us on the government side to focus research at our national laboratories on what are really the most pressing challenges. Our industry partners can provide a template to help us focus on where the big barriers are to commercialization, what the most critical technologies are to undertake research on. Ultimately each company will take the results of the cooperative government-industry research and decide what combination they are going to apply, which technologies fit their individual business models, and which ones they would seek to take and combine with their own internal proprietary work to bring the product to the market.

- **Hybrid and Electric Propulsion:** By 2010, Hybrid and Electric Propulsion R&D activities will reduce the production cost of a high power 25 kW battery for use in passenger vehicles from $3,000 in 1998 to $500 (with an intermediate goal of $750 in 2006) enabling cost competitive market entry of hybrid vehicles.

- **Materials Technologies:** By 2010, develop material and manufacturing technologies that if implemented in high volume could cost effectively reduce the weight of passenger vehicle body and chassis systems by 50% with safety, performance, and recyclability comparable to 2002 vehicles.

Figure 11

We do have a number of goals associated with the federal research. These goals were developed in cooperation with our industry partners (Figure 11). We have them in the area of hybrid and electric propulsion. With the President's announcement of the government's desire to investigate the potential of plug-in hybrids, we are currently looking, with our energy partners, at research in the area of hybrid and electric propulsion that would relate solely to a plug-in hybrid vehicle, a vehicle that you could plug in at night. The President really asked a "what if" question: what if we could come up with a vehicle that had forty miles of electric range? The analysis suggests that if that were possible and the cost wasn't prohibitive, that two-thirds of the vehicle miles traveled in this country could be traveled on electricity instead of on gasoline or diesel. This offers a tantalizing option to substitute one energy source for another.

We have goals in materials technology area, aimed at lightening the weight of a vehicle and we also have goals in advanced combustion and vehicle systems integration (Figure 12).

- **Advanced Combustion Engines and Fuels:** Improve the efficiency of internal combustion engines from 30% (2002 baseline) to 45% by 2010 for light-duty passenger and from 40% (2002 baseline) to 55% by 2013 for commercial (heavy-duty) vehicle applications while utilizing an advanced fuel formulation that incorporates a non-petroleum based blending agent to reduce petroleum dependence and enhance combustion efficiency.

- **Vehicle Systems and Materials Technologies:** Reduce heavy truck parasitic losses (e.g. aerodynamics, ancillary systems) from 39% of engine output in 1998 to 24% in 2006 and reduce the weight of an unloaded tractor-trailer from 23,000 lbs in 2003 to 18,000 lbs in 2010 (a 22% reduction), thereby increasing heavy truck fuel efficiency.

Figure 12

If we look at the future, we certainly see that the economy is global. Worldwide R&D is characterized by competition, innovation, and application of strategies across industries. FCVT enables research and partnerships for an energy efficient future where American industry produces competitive goods for consumers around the world. We are going to see more and more worldwide manufacture of technologies and not just by the OEMs but also by the supplier community. In the coming decades, we will see a range of hybrids, HCCI engines, fuel cell vehicles, lightweight materials, flex-fuel vehicles & renewable fuels.

Personally I think we are now at a very exciting time in automotive technology. It is not unlike the first ten years of the 20th century, when we saw many competing technologies in the automotive marketplace. If we go back 100 years ago today, the dominant vehicle on the road was the battery electric vehicle. But eventually the marketplace sorted out between the various competing vehicle technologies and eventually settled on what came to dominate the rest of the 20th century. We are entering a similar time today. We have hybrid technologies; they reached 1 percent of the vehicle market last year. We have advances in combustion, offering new hope for greater efficiency in vehicles. We have gasoline and diesel; in the future, a fuel might have characteristics of both. It might be neither gasoline nor diesel, as we look at advanced combustion. We have the potential of plug-in hybrids and the promise of ultimately zero-emission, zero-consumption of petroleum vehicles, the opportunity offered by fuel cells. I think it is an exciting time to be involved in research in this area and I am looking forward to seeing how things play out over the next ten to fifteen years.

Questions and answers.

Question: Two days ago, I had an experience I haven't had for quite a while: I filled up my tank for less than $2 a gallon of gasoline. This was in Gainesville, evidently the result of a temporary price war. Whatever the case, I found the experience exquisitely pleasurable. I wonder to what extent many of the plans being outlined here would be jeopardized if the occasions for having that experience of relatively cheap gasoline were to multiply. In recent years we have seen politicians becoming irate about high-priced gasoline. To the extent that the Federal government has a stake in many of these technological projects, is there any threat, any possibility of political pressure to keep gasoline high priced, to prevent me from having that exquisite pleasure any more?

Keith Cole: I did see a recent article that talked about the latest conspiracy theory of the oil companies – that they are conspiring to drive the price low to do essentially what you are saying. A gas tax was wildly unpopular in the past, and I don't think that has fundamentally changed. However, it is an idea that comes up periodically. There have been many ideas floated in Congress over the last six months, but I haven't heard that one. You get slight variations on it, like a counter-cyclical push for ethanol subsidies, but nothing directly to your point. What your experience points up is that the reality of gas prices is not as smooth as EIA projections of the future prices. The reality is that we have a very volatile market. The supply for gasoline is the best it has been in some time, partly as a result of people buying it and holding it thinking prices would go up and now having to put it back on the market. What's extremely difficult for us as an auto manufacturer is we have to plan many years in advance for a market that is incredibly volatile. If there was, God forbid, an attack on a Saudi refinery, that would have deep implications for the market. If Chavez goes nuts, or the Nigerians implode into civil war, all those things could drive prices higher. At GM we don't see the "peak oil theory," that we are going to run out of oil happening any time soon. Prices will go up as supply gets constrained and there are other fuels that will come into the market, whether it is tar sands or oil shale or ethanol. The reality we face is that we have to plan for a very volatile market; we can't be caught flat-footed if the price goes up. One of the things that I have seen in the five years that I have been at GM is a growing understanding of how technological leadership can translate into public perception of your product, as interesting and desirable. I think somewhat irrespective of the price of gasoline, we as a company are more interested in pushing the limits of technologies and I don't think we are the only ones doing that.

Fred Webber: I would like to chime in and make two points: when safety became a competitive issue in the automobile industry, all kinds of great things happened. We have never had before safer cars and light trucks than we have today. We can't account for driver behavior, that's the other factor that is hard to control, but our vehicles have never been better from the safety standpoint. Now fuel efficiency, alternative fuels, advanced technology, all these have become competitive issues. I think the global automobile industry is going to continue to produce more fuel-efficient vehicles, and I find that to be very exciting. Keep in mind that the U.S. automobile industry, and if I can all manufacturers who sell and make cars here, these companies in the United States have invested $15 billion a year in R&D, more than the pharmaceutical industry, more than high tech. It is an incredible number and they are going to want to see this investment come to fruition. So I guess the message is, they are going to stop.

Edward J. Wall: To continue the discussion earlier with regard to increasing global demand for vehicles for mobility, it can only continue to put upward price pressure on petroleum. Will the market be more volatile? I think it will, or at least volatility will continue because volatility is the market tightening. We may see some very attractive prices; I would say enjoy them all you can. The growth in demand in the world points upward. We look at the work we are doing at the Department of Energy as an insurance policy. It is not work that can be done overnight. We have to have technology validation which sometimes takes years. We are working now for what might be possible in ten years.

Question: Ed, one of your focuses apparently is on materials technology and apparently involves, among other things, new materials that are lighter weight but still retain the same strength. Are you guys doing anything at all in crash avoidance systems, which are another part of that?

Edward J. Wall: We have done some in the Department of Energy in the past. One of the products, from one of the national laboratories, was radar on a chip that could be used for avoidance of obstacles. We have done some work on proximity systems. But certainly that is something that the worldwide auto community is starting to look at. At the international shows you are seeing more displays of concepts with those types of devices on board. I was at the Tokyo motor show last year and saw a number of concepts with crash avoidance technology. We saw some in Detroit last January and we are looking with great anticipation to the next round of auto shows.

Fred Webber: I drove a Volvo a year ago that told me when I was drifting out of my lane or drifting from the drive lane and crossing over. I also drove a BMW not too long ago and had it on cruise control at 65 mph on the New Jersey Turnpike. As I approached the car that was ahead of me, the cruise control system slowed me down to keep the appropriate interval. That is crash avoidance. I am sure Honda has a lot of technology in this area. As I said, we are getting safer and safer, and crash avoidance systems are very much a part of what you are going to see in the future automobile.

Keith Cole: This is just the first generation. I think the next frontier is vehicle-to-vehicle communication. Larry Burns, our VP of research, is very active in pushing this. If you think about it, we have the technology through GPS to know where every vehicle is every moment and know it to a degree of precision that would allow us to know if it is drifting off to the side of the road. That technology capability exists; it is going to be an issue of how far down that path you want to go.

Question: In the area of fuel cells, is GM or any of the other companies still pursuing the onboard reformer that makes gasoline into hydrogen as an interim stage?

Fred Webber: The DOE is not pursuing that, as far as I know.

Edward J. Wall: No, we had a technology down-select, we call them, two years ago now where we decided that we would not be doing continued research in that area, feeling that it is more likely, looking at the complexity of the system and the cost of the system, it would be more likely to reform, say, at the service station and provide hydrogen there. We would need fewer reformers and the restrictions of size would not be as great at service stations as they would be on-board vehicles.

Keith Cole: We are not pursuing on-board reformation of gasoline.

Question: I am very encouraged by the number of flex-fuel vehicles that are on the road and how many you are planning on putting out there. I am a little concerned, though, that many people don't even know that they own flex-fuel vehicles. The 750 E-85 stations that are out there are great, but out of how many fueling stations are there in the country, do you really see flex-fuel being able to sell well in markets that aren't directly related to ethanol, like the Midwest is? Do you see it as a viable option in California and on the East Coast?

Keith Cole: California and the East Coast are challenging, California, of course, for some regulatory reasons, but also logistics. Because of the Renewable Fuels Standard (RFS), in the last twelve months you now have the establishment of an ethanol distribution infrastructure at the terminals pretty much throughout the country where it has never been before, New Jersey, Virginia, the Southeast, California. So the E85 infrastructure challenge becomes more of a last-mile problem than it was two or three years ago, when you didn't have any ethanol terminal capability in a lot of places. The 2005 energy bill has really provided the conditions to ignite the markets into funding ethanol development, and that is the most powerful tool. We are well above where the RFS requires. I think I saw figures on the web about how soon we are going to hit the 7.5 billion gallons almost four years in advance of the statutory deadline. We have been heartened by the addition of ethanol capability, with additional production volume coming on very quickly. We fully expect that the majority of that will be taken up in the blend stock market. But what we are finding is that ethanol companies that are choosing to forgo some of those profits that they could get in the spot market say, in exchange for establishing the distribution channel for E-85. So in our partnerships with Pacific Ethanol and VeraSun and others, we see entrepreneurs saying, "Yes, I can sell a lot of ethanol in the blend stock market today, but I want to establish and open a beachhead into a much larger market potentially in the future," which would be E-85. So they are willing to sell to the retailer at prices that are attractive to their customers. That is what is going to drive this, customer demand. Customers are excited about having fuel that doesn't have to be imported and that supports our agricultural community. I don't know what the size of that market is, but it is more than we have today. We are finding tremendous support and not only in the Midwest; our partnership in California was a big one. In Texas, we partnered with Kroger. I think we did ten stations, and they are already talking about doing more stations. Michigan is the same. We just did Sheetz up in Pennsylvania; they are very interested in this, and we were down in Florida last week making announcements on some stations. There is a lot of interest because they think they can attract customers with E85. No one is forcing these retailers to do it.

Fred Webber: We have over 180,000 gasoline stations in the country and maybe 800 might provide you with E-85. Therein lies the challenge. But I think Keith is right; the trend is a good one. I was down in North Carolina recently and they are building five ethanol production plants down there. The state is trying to figure out how to partner with private industry to get more pumps. You are right; some people are driving E-85-capable vehicles and don't know it. I think the automobile industry, both the dealers and the manufacturers, are doing a better job in getting that word out. But Chrysler, GM and Ford have made a major public commitment to go forward with ethanol and they are not going to stop. I know that you are thinking cellulosic and you all look at the Brazilian example and that is a great one. The government of Brazil just decided they are going to do this. They have solved the infrastructure problem, I think.

Question: I have read a lot of papers saying that biodiesel is a lot more efficient both to produce and use than ethanol. Why do you think that ethanol is being pushed harder in the markets than biodiesel?

Edward J. Wall: Well, with a light-duty vehicle market, the cars and light trucks accounting for three quarters of the fuel that is used on the highway, certainly something that could substitute for that petroleum use should have a significant emphasis. That notwithstanding, we are doing work in the biodiesel area: we are working with the National Biodiesel Board to address that 25 percent of highway petroleum that goes into diesel use. We are working with them to develop standards for multi-blend levels. Currently there is a standard for 100 percent biodiesel. We are looking at standards for various blend levels in between. Currently most engine manufacturers only warrant their engines for E-85; we are working with engine manufacturers and research to increase that level. I believe that there are only a couple manufacturers that warrant for a higher blend level than E-85.

Keith Cole: You are right; one issue is standards and there is the standard-setting effort, but also the biodiesel production universe is kind of like the Wild West; it's somewhat like what ethanol was some years ago. There is a lot of different quality biodiesel that is coming on the market and that is a challenge for us, especially with the absence of a standard. It's a maturing market; it is not where, on the production side, where we would like to see it, both in terms of the production volume of biodiesel and the quality standards. The second thing is we have more flex-fuel vehicles on the road than we have light-duty diesels on the road, so we have more customers out there that can run their cars on E85 ethanol than we have customers who can change from diesel to biodiesel. We are excited about biodiesel; it's a very clean fuel. We would like to see it come along more. It is tied to the acceptance of diesel in the U.S. market and that is less known than the acceptance of flex-fuel vehicles. One of the reasons for the push for E85 ethanol is that we have had a program under the CAFE program to give credits for the production of flex-fuel vehicles. That has been an incredibly successful program, breaking the "chicken and egg" problem by getting at least 5 to 6 million vehicles on the road. We are going to get more, but we are further along on that side, on E-85-capable vehicles, than we are with biodiesel.

Frederick Webber: I think the important thing is, and this is where government can come into it: let's not pick winners. Let's go on all fronts, whether it's clean diesel, biodiesel, ethanol or hybrids, or hydrogen. Let's more forward on all fronts and develop them as best we can because that is what makes the future very exciting as far as the industry I represent is concerned.

Edward J. Wall: One of the points I would make in terms of the government role, if you look at our website, www.fueleconomy.gov, one of the things we are trying to do is present information so consumers can make informed choices. We feel the more choices consumers have, the better off we all are. I misspoke earlier; the number of ethanol stations out there is actually 850. We feature on our website the locations by state of every station that is open; you can find a listing of all the vehicles currently sold in this country that are flex-fuel, that type of thing.

Frederick Webber: What is the automobile industry, a little over one hundred years old? I think this is one of the more exciting times that the industry has ever gone through. In terms of advanced technology and alternative fuels, it is almost like a revolution. Do you realize that we have, on the car lots today, over a hundred different models that will give you more than 30 miles per gallon? That is progress. As Keith said, we are going to have over 6 million flex-fuel vehicles on the road by the end of the year. We are going to have 9 million vehicles that advanced technology presents. This is very exciting.

Question: Having owned two Tahoes in the last ten years, I am an enthusiastic fan of the new designs and excited to learn about the modifications that will be introduced next year. Could you talk specifically about how the decision was made to put a hybrid capability into that platform as opposed to any others and what kind of thinking is going on inside the company on expanding the use of that technology into the other vehicle lines you have?

Keith Cole: Let me just talk specifically about the hybridization of the Tahoes and the Yukons and then our light pickup trucks and then the Suburbans. We took a little different approach to hybridization than Toyota did. They took a car that was already getting 30-35 mpg and hybridized and drove the numbers up very high. It is a great technological achievement in the Prius. If you look at the amount of gasoline that you would save by going from 30 mpg to 50 mpg, if you were driving 12,000 to 15,000 miles a year, it is fairly limited. If you go to the www.fueleconomy.gov site and look at the fuel economy for the hybrid version and non-hybrid version of vehicles – there is a calculator there on gallons saved – you are hard put to save more than 100 or 200 gallons of gas a year by purchasing the hybrid alternative. If you take a vehicle that is getting now 20 mpg and hybridize it, you are actually saving a lot more gasoline in a 25 percent increase on a vehicle than you would save with even a larger percentage increase on a vehicle that might get 30 miles plus a gallon to begin with. So we looked at this and said the payback for the consumer for a hybrid system is going to occur much faster on a larger vehicle that consumes more fuel to begin with.

So we started with one of the largest class of vehicles, transit buses, that get maybe 3-4 mpg, run on an urban transit cycle usually, and are the ideal platform for hybridization. Our Allison division developed what looks like an automatic transmission, but is actually a diesel-electric hybrid system that increases the fuel economy of those transit buses from 3-4 mpg up to 5-6 mpg. It also reduces NOx by about 50 percent and particulate matter by about 90 percent. More than that, we can downsize the diesel engine in those transit buses so it is about the size of the diesel we have in our large pickup trucks. As a result, the Allison hybrid system is a very popular product with tremendous fuel savings. What we are doing now is taking that philosophy and applying it to the light-duty vehicle fleet: what we did was take the Allison system, downsized it so it fits into the same packaging as an automatic transmission, and by doing that, it becomes exportable across our entire truck fleet. So it is sized to fit into the Yukons and Tahoes. As I said, it will push it from 20 to 25 mpg. Yes, there will be a price premium for that, about similar to what you are paying for some of the other hybrids. But in that vehicle, you will get a payback much quicker. Whether gas is $2 a gallon or $3 a gallon, your payback will be faster for a hybridized Tahoe than for a hybridized smaller car.

But the big thing is that it was designed to fit into an architecture that is nearly half of our production of trucks, large SUVs. And we are working to further bring it down in size and be able to export it across other architectures. Because that was a tough technical challenge and took a long time, longer than we'd like, we came out with the lighter hybrid, which is also cheaper, for the Saturn VUE. The other difference between us and hybrid systems offered by other companies, is that both of these systems are designed for the American drive cycle. They are not optimized so much for city driving as much as balanced between city and highway driving. This is different than many of the hybrids out there that improve your city fuel economy, but essentially do nothing on for highway mileage. The Saturn VUE is normally 22 mpg in the city and 27 mpg highway; with our hybrid system, it gets 27 mpg city and 32 mpg highway. So it increases both the city and the highway mileage. The same thing is true of the Tahoe, especially as we have combined the Hybrid system with our Active Fuel Management technology. With Active Fuel Management, when you are running down the highway, four cylinders can shut and you can get another burst of fuel economy on top that.

William O'Keefe: Thank you very much; these were very interesting and insightful presentations.

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