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Chairman Stevens, Senator Inouye and other members of the Committee, I appreciate the opportunity to testify on this crucial subject of finding alternatives and supplements to our current petroleum-based automotive fuel system. Although I have my Laboratory's permission to testify today, let me stress that the views I will give you are my own, based on my own analysis and my interpretation of the analyses of my colleagues in industry, government, and academia; they should not be interpreted as the views of Argonne or of the Department of Energy, the primary sponsor of my work for the past 10 years.

I'll begin by discussing what I believe will happen to automotive fuels over the next few decades if we take no strong action. I believe there is the *possibility* – and this is a much debated possibility, with lots of disagreement in the energy community – that the production of conventional oil will peak sometime during the next 20 to 30 years. This is partly a function of geology, which is inherently uncertain, and partly a function of the market. To keep on increasing oil production by nearly 2 percent per year, to match the forecasts of world oil demand of most major forecasting organizations, will require enormous capital expenditures, much of it in countries that are not allowing the free entry of outside capital into their oil production sector. If conventional oil production does peak, the most likely "gap fillers" will be some combination of "demand destruction" – lower demand for oil caused by very large price increases and some combination of lower economic activity and increased efficiency – and the increased production of "unconventional oil" – from tar sands, oil shale, natural gas ("Gas to Liquids, GTL"), coal liquids (as South Africa has been doing for decades), and other sources. These unconventional sources are attractive in the sense that they require no large changes in the major part of the world's transportation infrastructure – vehicles, refueling stations, fuel distribution network, and refineries. Because the production plants are immensely expensive, however, and will appear risky to investors if they believe oil prices may not remain high, there is quite a strong possibility that there may be a substantial period of time when investments in these plants do not come fast enough to prevent significant disruptions in the supply of transportation fuel. Further, these unconventional sources may have significant adverse impacts on emissions of greenhouse gases and have other negative environmental impacts as well, though potentially there are means of mitigating these impacts.

An alternative to this future is that geology turns out to be more favorable than analysts like Colin Campbell and his colleagues believe it to be, *and* OPEC creates a more friendly climate towards outside capital, allowing world oil production to match increasing demand. This scenario will lead us back to lower oil prices (though probably not for several years and perhaps never back to $25 oil) and back to a future of periods of stable prices interwoven with periods of price spikes because of natural and man-caused disruptions. Such a future may be preferable to its alternative, but it will still leave the U.S. economy at the mercy of events in the Middle East.

There are no quick fixes to reducing our gasoline use and substituting alternatives. There are many available vehicle efficiency technologies that are cost-effective in the narrow sense of trading off lifetime fuel savings versus increased vehicle cost, as discussed at length in the 2002 National Academy of Sciences report on fuel economy standards and literally hundreds of other reports and papers, but these cannot play a significant role for several years because of the time it takes to redesign vehicles and roll them into the total fleet. Keeping tires properly inflated, improving vehicle maintenance, and driving a bit more slowly and gently can all play a role essentially instantaneously, but a modest role only. And in terms of new fuels, building new plants for those fuels whose technology is well developed will still take a few years, and few investors will be clamoring to invest in those fuels not being heavily subsidized by (or required by) the government. Finally, a switch to fuels that are not now commercially ready, like hydrogen, will require several decades to make a large dent in oil dependence – assuming that existing R&D roadblocks can be overcome.

Before talking about alternative fuel technologies, let me point out that the most straightforward way to reduce dependence on gasoline is to increase vehicle efficiency, and in fact increasing vehicle efficiency is an important component in allowing alternatives to gasoline to play an important role in our fuel infrastructure (and a significant fraction of DOE's R&D funding in transport technology does go towards vehicle efficiency programs). This latter point is the case because some of the alternatives to gasoline have low energy density, and adequate fuel storage onboard the vehicle is made much easier if vehicle efficiency is improved. Hydrogen is the most extreme case – a 75 MPG hydrogen-fueled midsize car that attains the Department of Energy's year 2010 goal for hydrogen storage volume (.045 kilograms of hydrogen/liter of storage volume) will require nearly 28 gallons of storage volume to achieve a 300 mile range (and 35 gallons at the DOE year 2007 goal). Reducing the weight of its "glider" – its structure and everything else not associated with its drivetrain – by half reduces its fuel storage requirement to 21.5 gallons at the 2010 goal. Because reducing vehicle weight, improving the vehicle's aerodynamics and tires, and increasing the efficiency of its accessories reduce the power needed to run the vehicle, every component of its drivetrain can be smaller and cheaper. Also, many alternatives to gasoline are limited in their ultimate production capacity – the obvious example is biomass fuels – and these alternatives can play a much larger role in a fleet of ultra-efficient vehicles than they can in a more conventional fleet. And, of course, even if gasoline remains the dominant fuel, a 50 mpg fleet will use a lot less gasoline than will a 25 mpg fleet (more than half as much, though, due to the lower "per mile" fuel cost). The policy problem, of course, is that achieving large improvements in fuel economy has proven extremely difficult in the past without relying on government arm-twisting. The technology has been available and has been used – the technical efficiency of today's cars and light trucks is startlingly higher than that of 15 years ago – but their *fuel economy* is the same. All that technology has been used to allow larger, heavier vehicles that reach 60 miles per hour in much less time than their ancestors. The Environmental Protection Agency, in its excellent annual reports on "Light-Duty Automotive Technology and Fuel Economy Trends," notes that the year 2005 light-duty vehicle fleet would have been 24% more efficient than it now is, had it kept the same weight and performance distribution that it had in 1987.

I think it makes more sense to focus on a longer time frame for new fuels – perhaps a decade or more. In reviewing the Department of Energy's hydrogen program in 2005, the National Research Council suggested to the Department that it look to a wider portfolio of fuels, given the substantial technical and economic risks associated with hydrogen *and all other potential fuel pathways:*

"The program should perform high-level systems analyses that identify the potential, the challenges, and the specific research breakthroughs for alternatives that could achieve the program vision without requiring a hydrogen infrastructure, and it should use these results to help define R&D efforts and allocate funds within DOE."

Planning for the suggested systems analyses is underway at DOE, and I am confident that these analyses will begin soon. There are many dozens of different pathways to achieving large amounts of alternatives to conventional gasoline, and it makes sense to take a hard look at most of them. In advance of this effort, however, let me share some of my preliminary views about a few pathways.

Using hydrogen in fuel cell vehicles is the most prominent fuel pathway being examined and developed in this country and worldwide. Vehicle manufacturers and suppliers in the U.S. and worldwide are spending billions of dollars on this research, and national governments and the EU are spending substantial sums as well. Although the Department of Energy spending on hydrogen is well below what the private sector is spending, hydrogen is the key focus of its vehicles and fuels R&D programs. The reasons for the focus on hydrogen include:

- Zero vehicle tailpipe emissions
- Ability to use multiple feedstocks, including electricity, to produce hydrogen (though it's worth noting that gasoline and diesel fuel can also be made from multiple feedstocks using Fischer-Tropsch and other synthesis processes)
- High vehicle efficiency with fuel cells
- Potentially excellent well-to-wheels emissions of greenhouse gases, with some hydrogen pathways

There has been excellent progress on all fronts of the hydrogen R&D effort, but there remain formidable challenges in such areas as hydrogen production costs, fuel cell stack costs, onboard fuel storage, and a host of other key areas. My *opinion* is that we will probably have to wait for at least a few decades before we see a significant impact on light-duty vehicle fuel use from hydrogen. It is also my opinion that we have no guarantees that the hydrogen R&D program will be fully successful, despite our best efforts. Consequently, I fully agree with the National Academy's desire to see DOE expand its focus to encompass other fuel pathways. However, I am concerned that this expansion not rob the hydrogen program of needed resources, and I will discuss this issue a bit later.

DOE is also pursuing various biomass fuels, for example ethanol from cellulosic sources (e.g., wood, waste, fast growing grasses), though at a level well below the hydrogen programs. The advantage of this pathway is that it produces far fewer greenhouse gases than today's fuels because of the carbon recapture in the regrowth of the feedstock biomass. However, substituting for a significant share of U.S. light-duty vehicle fuel use would entail growing plantation-style crops (e.g., fast-growing grasses or trees) on a large percentage of U.S. cropland; on the other hand, biomass crops can be successfully grown on land that is of lower quality than that required for most food crops. The biggest R&D hurdle for this pathway is to drastically reduce the cost of the cellulose-to-ethanol production process. There are some tantalizing possibilities here, including efforts by Craig Venter (of human genome research) and others to discover and/or "design" microorganisms that can accelerate the process. Venter also is pursing the production of hydrogen using genetically-engineered microorganisms, with some DOE support.

Tom Friedman and a few other journalists recently embraced the concept of the "plug-in hybrid," or PHEV, a hybrid electric vehicle with a larger motor and battery that can be recharged overnight and thus substitute electricity for gasoline for some of the vehicle's miles. Although journalistic embraces should be treated with some skepticism, I too like the concept and believe it is worth pursuing. The key here is that most drivers put on most of their mileage in short trips. A PHEV20, a plug in with 20 miles of battery range, can replace about 31-39 percent of annual miles driven for the average driver if the vehicle is recharged every night; a PHEV 60 can replace 63-74 percent of these miles. Coupled with the vehicle's high fuel economy, a fleet of PHEV60s would use less than 20% of the gasoline used by a similar fleet of current vehicles. Also, having the fuel used by that fleet be cellulosic ethanol is a tantalizing prospect – because it raises the possibility that biomass fuels could play a dominant role in the U.S. light-duty vehicle fleet sometime in the future, despite their supply limitations. Another thing I like about PHEVs is that, in the face of a severe disruption in liquid fuel supply, a PHEV owner will have the capability of traveling at least limited distances without using such fuels – and for considerable distances if fast chargers are available at a decent percentage of gas stations. However, I should be quick to note that PHEVs are like hydrogen fuel cell vehicles in one important regard – they have significant R&D hurdles to jump before they can be seen as fully practical. Substantial improvements in battery life and reductions in cost are the key hurdles, and I should note that lack of sufficient progress in batteries basically killed the electric vehicle "revolution" that California hoped to jump start a while ago. However, I do believe that the high degree of optimism that one *must have* to be confident that the hydrogen economy can succeed the oil economy, if applied to PHEVs, would make one a supporter of this pathway as well. At the least, this pathway deserves a very careful examination.

The group of pathways I mentioned before, those of "unconventional oil," are being pursued vigorously by industry, and some are now fully commercialized. Canada is well on its way to become a major world supplier of oil from tar sands, and several gas-to-liquids plants have been built or are under construction. As I noted, I'm concerned that these pathways may not be built up quickly enough in the face of a peaking in conventional oil production (if it occurs), leading to a period (probably of several years) of severe supply disruptions. If the federal government is not willing to take the very strong initiatives that will be necessary to move hydrogen, biomass, or other true alternatives to gasoline into the marketplace, I would hope that it would at least pay strong attention to evaluating what policies could pave the way to a very rapid buildup of unconventional oil production should this become necessary.

Thus far, federal and State attempts to move alternatives to gasoline into the marketplace have failed. California tried vigorously to promote methanol and then electric vehicles, and could not make much progress with either (although the push for methanol led to the introduction of reformulated gasoline, and the electric vehicle effort played an important role in improving electric drivetrains, the key to hybrid electric drivetrains and crucial to any hope for successful hydrogen fuel cell vehicles). The federal government's efforts, embodied in EPACT, achieved only a small fraction of its market penetration goals. The lesson here is that a limited or half-hearted attempt to move alternative fuels into the marketplace will almost certainly fail in the face of a firmly entrenched gasoline infrastructure and a vehicle/fuels system that delivers exceedingly good performance. And if we wait for the oil supply emergency that would ease the way for a fuels transition, we have many years of disruption before enough of the transition has occurred to support a stable transportation system.

In other words, we have the following choices:

1. Remain relatively passive and hope that geology and OPEC's willingness to support huge investments in expansion of oil supplies allows a reasonably stable future for worldwide supplies of transportation fuels.
2. Take whatever measures we can to smooth the way to a future transition to unconventional oil as a major part of world oil supplies.
3. Move strongly to reduce U.S. dependence on oil as the overwhelming source of our transportation fuels. Improving vehicle efficiency as well as taking a host of measures to reduce automobile dependence (better land use planning, improved transit services, etc.) should be an important part of the choice. The studies I am familiar with show, however, that moving to new fuels must be part of this choice if we also care about emissions of greenhouse gases.

I don't know how long oil prices will remain at today's high levels, and I don't think anyone else does, either. However, at today's prices, during the next year we will spend about $300 billion on gasoline for our fleet of cars and light trucks, and the fleet will drive more miles each following year for the foreseeable future. The federal government is now spending on the order of one tenth of one percent of this amount on research and development into improved vehicle efficiency and new fuels for this fleet, with a robust share going to hydrogen programs. I wonder if this is enough, especially for fuels pathways other than hydrogen (although the hydrogen program would also benefit from more resources) and especially for a world in which our oil security appears to be so fragile.

Thank you for giving me this opportunity to discuss my thoughts on this most important topic.