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HYDROGEN AND FUEL CELL RESEARCH

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

OF THE

COMMITTEE ON
ENERGY AND NATURAL RESOURCES
UNITED STATES SENATE

ONE HUNDRED NINTH CONGRESS

FIRST SESSION

TO

RECEIVE TESTIMONY ON RECENT PROGRESS IN HYDROGEN AND FUEL CELL RESEARCH SPONSORED BY THE DEPARTMENT OF ENERGY AND BY PRIVATE INDUSTRY

JULY 27, 2005

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HYDROGEN AND FUEL CELL RESEARCH

WEDNESDAY, JULY 27, 2005

U.S. SENATE,
SUBCOMMITTEE ON ENERGY,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The subcommittee met, pursuant to notice, at 3 p.m. in room SD–366, Dirksen Senate Office Building, Hon. Lamar Alexander presiding.

OPENING STATEMENT OF HON. LAMAR ALEXANDER, U.S. SENATOR FROM TENNESSEE

Senator ALEXANDER. Good afternoon, the Subcommittee on Energy will come to order. The purpose of this hearing today is to receive testimony on the progress that has been made recently in hydrogen and fuel cell research sponsored by the Department of Energy and by private industry.

We have four excellent witnesses. This is a subject that Senator Byron Dorgan has championed for a number of years in the U.S. Senate, and which I and many other Senators, are greatly interested.

I think what we'll do is I'll introduce our witnesses, and then we'll ask Mr. Faulkner to go first. And then Senator Dorgan and I will ask questions. Mr. Faulkner, will you be able to stay for a few minutes?

Mr. FAULKNER. Sure, whatever you want.

Senator ALEXANDER. Well, then, I think we may invite the other three, if they're here, to come up. Are the other three witnesses here? I believe they are. Then we'll ask questions of the four of you all at once. That might be a better use of our, of everyone's, time.

The genesis for this hearing came out of a conversation Senator Dorgan and I had a few weeks ago when we were talking about the energy bill. Let me put it this way, we stayed up late this week, the Senators on the Energy Committee, completing legislation that we hope the full Congress will enact this week, that sets an energy policy for the United States for the next several years. Congress has worked on that for 5 or 6 years. There are many different opinions on it, it wasn't easy to do, but it's fundamentally important to our country's future.

The way I look at the energy bill, there are really two main directions that it seems to go. One is to transform the way we produce electricity. We do that by largely shifting our emphasis over the long term toward low carbon and no carbon electricity, conservation and efficiency, through support for advanced nuclear

technology, through coal gasification and carbon sequestration, new supplies of natural gas and other new technologies. And we hope that that will, among other things, help stabilize the high price of natural gas in the United States, and eventually bring it down, which is very important for homeowners, and blue-collar workers and farmers in our country.

The second thing that we seek to do is transform our dependence on oil, especially overseas oil. And we make a few short-term steps in the legislation that we're able to agree on—support for alternative fuels helps to do that. The Senate passed a provision requiring reduction of a million barrels of oil a day, but the House didn't agree to that, so that's not in there.

We also have support for hybrid and advanced diesel vehicles, which are at least an interim step, and we'll see how promising they may be in helping us conserve oil. There is a significant provision for a long-term fix for the oil addiction—to borrow some of Senator Dorgan's words—and that is hydrogen fuel cells. There's support for about a $3.7 billion program over 5 years for research and development and for demonstration.

I was in Yokohama, Japan about a year ago, and I visited a hydrogen fuel cell vehicle filling station. I saw seven SUVs parked there. There was a Nissan, a Toyota, a General Motors, a Chrysler—all the major car manufacturers had their hydrogen fuel cell vehicles at this hydrogen filling station in Yokohama. And I filled one up, and in my conversation with the chief executive of Nissan, he said they're spending $700 million a year of their own money on hydrogen fuel cells. The chief executive of Toyota indicated that they're investing a lot of money in hydrogen fuel cells. The president of General Motors just last week made it clear to me that General Motors considers it to be the transforming technology for vehicles, hydrogen fuel cells. So, we know very well that U.S. Senators and other politicians, and even bureaucrats in the Government can't create the technology to solve the myriad of issues that have to do with hydrogen fuel cell vehicles that emits only water vapor, instead of the various pollutants that gasoline does. But we do know that the Government can help to create an environment in which the private sector can succeed.

So, our purpose today is to get an update both from the Government, itself—and the programs we have in the Federal Government—and from industry and outsiders on how we are doing in helping to create an environment in which we are likely to succeed in the United States in terms of production of hydrogen fuel cell vehicles.

Our witnesses today are Mr. Doug Faulkner, who's the acting Assistant Secretary of the Office of Energy Efficiency and Renewable Energy in the Department of Energy—and we'll hear from Mr. Faulkner in just a moment—and then we have three other witnesses: Mr. Jeremy Bentham, the chief executive officer of Shell Hydrogen B.V., Dr. Larry Burns, the vice president of General Motors, and Mr. Dennis Campbell, president and chief executive officer of Ballard Power Systems. I'm going to ask each of the witnesses to summarize their testimony, in about 5 minutes. That would give Senator Dorgan and me—and any of the other Senators who came—more time to ask questions. Mr. Faulkner, if you need

to take a little bit longer than that to give us your update, you're welcome to do that.

So now I'll call on Senator Dorgan for whatever comments he'd like to make, then we'll go to Mr. Faulkner for his testimony. Thank you.

STATEMENT OF HON. BYRON L. DORGAN, U.S. SENATOR FROM NORTH DAKOTA

Senator DORGAN. Thank you very much, Senator. I appreciate the work that we've done together, and the work of the entire Energy Committee on an energy bill. I share with you my hope that by the end of this week, we will have passed a Conference Committee Report through the House and the Senate, and that it's on the President's desk for signature.

One of my former colleagues said, "The future will be better tomorrow." I won't identify the colleague, but you know, the reaction to that is, "One would hope so." But, with respect to energy, it's not all that certain, unless we start making some good decisions. And my colleagues have heard me say that we are hopelessly addicted to foreign oil to run this American economy. With 60 percent of our oil coming from off our shores, it means that our economy is held hostage to the ability to find that oil, and import that oil into our country.

Now, with respect to energy policy, I think there are two approaches that we use. The first, every 25 years when we debate energy policy, that approach is staring at your shoes. You still stand erect, but you're not doing much more than staring at your shoes. And the other approach is looking ahead, to look ahead and search for new alternatives and new opportunities. I'm really pleased to say that in this energy bill—as my colleague, Senator Alexander, just described—we have $3.73 billion in both the hydrogen title and the vehicle title, that attempts to move us in a different direction, move us ahead. We've been putting gasoline through carburetors, and now fuel injectors, for 100 years, in our vehicles. And unless we decide we want to change that, we will continue to do that for the next 100 years. It makes a lot of sense to me because the line on increased usage of energy goes up like this on transportation.

It makes sense to me that we would look for alternatives, look for sources of energy that are ubiquitous, that are everywhere, that we can develop and use, and so I have been pushing hard in recent years, working on this issue of hydrogen in fuel cells. It's not just in our country, the Europeans and others are moving in the same direction, in an attempt to pole vault to the future. It's my fervent hope that my grandchildren and their grandchildren will be driving vehicles that aren't dependent on someone digging oil out of the sand halfway around the world. We can do that, but you've got to decide where you're going. If you're going to get someplace, you've got to figure out what your destination is, and what the route is to get there, and that's the purpose of what we have done in this energy bill.

There's plenty to criticize in this energy bill, and there's plenty that's good. But the one really bright spot, the spot that glows in this energy bill, in my judgment, is the hydrogen title. And I say that not just because I had a significant part of the work with my

colleagues to help write that title, but because we also did a lot of work, as my colleague knows, with the U.S. Fuel Cell Council, the National Hydrogen Association, and a lot of interests involved in looking ahead, looking to the future, to new technologies, and how we might produce, store and transport hydrogen. And I'm really excited about all that.

The other night I said, "There's an old saying, if you don't care where you're going, you're never ever going to be lost." Well, that's true. If you just meander around, you'll always be where you intend to go, if you don't care. But if we can set benchmarks, and waypoints, and decide, "Here's where we want to be as a country," down the road with new technology by the year 2010 and 2020, then we can make things happen. John F. Kennedy said, "We're going to go to the moon in a decade," and we did. And that's exactly what we ought to do to try to escape this addiction we have, for our economy to be held hostage to foreign oil. We can do this, we will do this, as a country.

This hearing, Mr. Chairman, is a refreshing opportunity to review with Mr. Faulkner, with the Department of Energy and three very well-respected folks from the industry who are working on these new technologies—I really appreciate this hearing and think it will, once again, advance the ball—but also augment and supplement that which we did late the other night, or early in the morning I should say, in this energy bill. We have a lot to celebrate today, those of us who think about hydrogen and fuel cells as part of the constructive future of this country's energy supply. So, Mr. Chairman, thank you. I look forward to hearing the witnesses.

Senator ALEXANDER. Thank you, Senator Dorgan.

Mr. Faulkner, why don't you begin? And then we'll invite the other witnesses to come to the table.

STATEMENT OF DOUGLAS L. FAULKNER, ACTING ASSISTANT SECRETARY FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY, DEPARTMENT OF ENERGY

Mr. FAULKNER. Yes, sir. Thank you. I thank you for your offer of more time for my remarks, but I believe that they'll come in 5 minutes or less.

Mr. Chairman, and Senator Dorgan, I appreciate the opportunity to testify on the Department of Energy's hydrogen program. Since President Bush launched the Hydrogen Fuel Initiative over 2 years ago, we've made tremendous progress. We implemented valuable feedback from the National Academy of Sciences, and we're already seeing results. In fact, the Academy is currently completing its biannual review of the Program, and I think we'll see the results of that next week.

The Academy called for us to improve integration and balance of activities within the relevant offices of the Department of Energy, establishing milestones and go/no-go decisions. We have done this. The DOE Hydrogen Posture Plan identifies strategies and milestones to enable a 2015 industry commercialization decision, and each office at DOE has developed a detailed research plan.

We are now implementing those research plans, and making tangible progress. The Department competitively awarded over $510 million in Federal funding, subject to appropriations, for projects to

address critical challenges. The DOE Office of Science announced 70 new projects addressing basic science issues in hydrogen. We've created a national hydrogen storage project, including three Centers of Excellence, with universities, industries, and Federal laboratories focusing on hydrogen storage materials, a critical technology for the hydrogen economy.

These activities address the Academy's recommendation to shift toward more exploratory work. We have identified materials with higher hydrogen storage capacities; however, we still need both fundamental understanding and engineering solutions to address issues like charging and discharging hydrogen and the practical temperatures and pressures. We initiated 65 projects on hydrogen production and delivery, and the results are already promising.

We believe we can meet our goal of $2 to $3 a gallon of gasoline equivalent. Our ultimate goal is carbon-neutral hydrogen production that emphasizes resource diversity. To address fuel cell costs and durability, we will have a new $75 million solicitation, complementing existing materials research efforts, and results are already being achieved here, too.

As highlighted by Secretary Bodman in earlier testimony, the high-volume cost of automotive fuel cells was reduced from $275 to $200 per kilowatt. Through new materials and fabrication technologies to further reduce fuel cell costs and improve durability, we believe we can meet our targets.

We must keep sight of the ultimate goal, the transfer of research to the real world, and we've complemented our research with what we call a "learning demonstration." This 50/50 cost-shared activity, bringing auto and energy companies together to validate infrastructure technologies, will enable us to test laboratory concepts, major systems-level progress, collect data and provide valuable feedback for our research. In May, President Bush participated in the refueling of a GM hydrogen fuel cell vehicle at DC's Benning Road station; that's a part of our learning demonstration effort.

We also conduct research on safety codes and standards, working with the Department of Transportation, and globally, through the International Partnership for the Hydrogen Economy. And we're working with the Department of Commerce and other Federal agencies to create a roadmap for research and development for manufacturing technologies, to bridge that continuum from basic research to commercialization. This effort will help to track new business investment, create new high-technology jobs, and build a competitive U.S. supply base.

The Department is working with partners on all fronts to address the challenges to a hydrogen economy. Under the FreedomCAR and Fuel Partnership, DOE is collaborating with the U.S. Council for Automotive Research (DaimlerChrysler, Ford and GM) and five major energy companies (BP, Chevron, ConocoPhillips, ExxonMobil and Shell). The program's technical targets—created using input from teams of DOE, automotive and energy company experts—represent customer requirements and the business case necessary for widespread commercial success.

Ultimately, it is industry that will build the automotive and energy infrastructure for the country. However, developing hydrogen technologies that are economically competitive with marketplace al-

ternatives entails significant risk. Therefore, Federal investment and high-risk R&D is necessary to overcome technology barriers and to reduce this risk.

Mr. Chairman, Senator Dorgan, the DOE Hydrogen Program is committed to a balanced portfolio which integrates basic and applied research, engineering development and learning demonstrations. This committee has provided valuable guidance.

This completes my prepared statement, I'll be happy to answer any questions.

[The statement of Mr. Faulkner follows:]

PREPARED STATEMENT OF DOUGLAS L. FAULKNER, ACTING ASSISTANT SECRETARY FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY

Mr. Chairman and Members of the Subcommittee, I appreciate the opportunity to testify on the Department of Energy's (DOE or Department) Hydrogen Program. Today, I will provide an overview of the program, summarize progress in implementing the recommendations of the National Academies' hydrogen report, discuss support for state initiatives and demonstration projects, as well as provide a status of the Hydrogen Program's accomplishments and plans.

Over two years ago, in his 2003 State of the Union address, President Bush announced the Hydrogen Fuel Initiative to reverse America's growing dependence on foreign oil by developing the hydrogen technologies needed for commercially-viable fuel cells—a way to power cars, trucks, homes, and businesses that could also significantly reduce criteria pollutants and greenhouse gas emissions. Since the launch of the five-year, $1.2-billion research initiative, we have had many accomplishments on the path to taking hydrogen and fuel cell technologies from the laboratory to the showroom in 2020, following an industry commercialization decision in 2015.

Our Hydrogen Program emphasizes the research and development (R&D) activities necessary to achieve the President's vision of a hydrogen economy and to address foreign oil dependence and greenhouse gas emissions. Our R&D efforts address the critical path barriers to the hydrogen economy. As an extension of these research activities, we have also established a 50-50 cost-shared partnership with industry to create a "learning" demonstration. These demonstration projects ensure that the automotive and energy industries will work together to integrate vehicle and infrastructure technologies prior to market introduction.

DRIVERS FOR HYDROGEN RESEARCH: ENERGY AND ENVIRONMENT

As a Nation, we must work to ensure that we have access to energy that does not require us to compromise our economic security or our environment. Hydrogen offers the opportunity to end petroleum dependence and virtually eliminate transportation-related criteria and greenhouse gas emissions by addressing the root causes of these issues. Imported petroleum already supplies more than 55 percent of U.S. domestic needs and those imports are projected to increase to more than 68 percent by 2025 with business-as-usual. Transportation accounts for two-thirds of the oil use in the United States and vehicles contribute to the Nation's air quality problems and greenhouse gas emissions because they release criteria pollutants and carbon dioxide.

At the G8 Summit earlier this month, President Bush reiterated his policy of promoting technological innovation, like the development of hydrogen and fuel cell technologies, to address climate change, reduce air pollution and improve energy security in the United States and throughout the world. The Department's R&D in high-efficiency vehicle technologies, such as gasoline hybrid-electric vehicles, will help improve energy efficiency and reduce the growth of petroleum consumption in the nearer term. Under DOE's FreedomCAR Program, the President's FY 2006 budget request is $100.4 million. This funding will make hybrid-vehicle components, like batteries, power electronics, electric motors and advanced materials, more affordable. But, in the longer term, higher efficiency alone will not reduce our petroleum consumption; we ultimately need a substitute to replace petroleum. Hydrogen and fuel cells, when combined, have the potential to provide domestically-based, virtually carbon-and pollution-free power for transportation.

Hydrogen can be produced from diverse domestic energy resources, which include fossil fuels, nuclear energy, biomass, solar, wind and other renewables. We have planned and are executing a balanced research portfolio for developing hydrogen production and delivery technologies. Hydrogen from coal will be produced directly

by gasification—not coal-based electricity. For hydrogen from coal to be viable, research in carbon capture and sequestration technologies must also be successful. The ultimate outcome we are seeking is hydrogen from carbon-neutral fossil, nuclear and renewable energy resources.

In the transition to the hydrogen economy, the Department recognizes that hydrogen will be produced by technologies that do not require a large, up-front investment in hydrogen delivery infrastructure. Instead, hydrogen can be produced at the refueling station by reforming natural gas and renewable fuels like ethanol utilizing existing delivery infrastructure. A fuel cell vehicle running on hydrogen produced from natural gas would produce 25 percent less net carbon emissions than a gasoline hybrid electric vehicle and 50 percent less than conventional internal combustion engine vehicles on a well-to-wheels basis. However, natural gas is not a long-term strategy because of concerns of limited supply and the demands of other sectors. As vehicle market penetration increases and research targets for the diverse hydrogen production and delivery technologies are met, these will help establish the business case for industry investment in large-scale hydrogen production and delivery infrastructure.

MAJOR CHALLENGES TO THE HYDROGEN ECONOMY

The President's FY 2006 request to Congress for the Hydrogen Fuel Initiative is $259.5 million. This funding is necessary to conduct the research to overcome the barriers to the hydrogen economy:

- The technology must be developed to store enough hydrogen on-board a vehicle to enable greater than 300-mile driving range without reducing cargo or passenger space.
- The high-volume cost of the fuel cell system must be reduced by a factor of seven in order to be competitive with today's internal combustion engines, and durability needs to be improved by a factor of five.
- The cost of producing hydrogen must be reduced to be competitive with the cost of gasoline. Hydrogen from natural gas reforming is currently about two times as costly as gasoline (untaxed) and hydrogen from other sources (renewables, nuclear energy and coal combined with sequestration) is even more costly.
- Improved materials and system designs must be developed to ensure the safe use of hydrogen. Codes and standards need to be developed to enable implementation of hydrogen technologies, and international standards are needed to eliminate trade barriers.
- Educational materials must be developed and available for key target audiences (e.g. first responders, etc.) to understand hydrogen and fuel cell technologies and their uses.

PROGRESS AND ACCOMPLISHMENTS

Mr. Chairman, the Department has made significant progress in planning and setting the stage to achieve the research breakthroughs necessary for a future hydrogen economy. The Department has competitively selected over $510 million in projects to address critical challenges such as hydrogen storage, fuel cell cost and durability, and hydrogen production and delivery cost. In addition, we have established a national "learning" demonstration and new projects in safety, codes and standards, and education. All of the multi-year projects discussed below were competitively selected and are subject to congressional appropriations. The continuum of research, from basic science to technology demonstration, will be closely coordinated.

- In May 2005, 70 new projects were selected at $64 million over three years to focus on fundamental science and to enable revolutionary breakthroughs in hydrogen production, storage and fuel cells. Topics of this basic research include novel materials for hydrogen storage, membranes for hydrogen separation and purification, designs of catalysts at the nanoscale, solar hydrogen production, and bio-inspired materials and processes.
- Three Centers of Excellence and 15 independent projects were initiated in Hydrogen Storage at $150 million over five years to develop the most promising low-pressure storage approaches. The Centers include 20 universities, 9 federal laboratories and eight industry partners, representing a concerted, multi-disciplinary effort to address on-board vehicular hydrogen storage.
- To address fuel cell cost and durability, five new projects were initiated at $13 million over three years. A $17.5 million solicitation is currently open to research new membrane materials in fuel cells. And, a new $75 million solicitation will be released this fall to address cost and durability of fuel cell systems.

- A total of 65 projects were awarded for applied research in hydrogen production and delivery, funded at $107 million over four years. These include hydrogen production from renewables, distributed natural gas, coal and nuclear energy.
- A national vehicle and infrastructure "learning demonstration" project, a six-year effort with $170 million in DOE funding, was launched to take research from the laboratory to the real world, critically measuring progress and providing feedback to our R&D efforts.
- Approximately $7 million over four years for hydrogen education development was awarded to serve the needs of multiple target audiences, including state and local government officials, safety and code officials and local communities where hydrogen demonstrations are located.

With these new competitively selected awards, the best scientists and engineers from around the Nation are actively engaged. The stage is now set for results.

Our ongoing research has already led to important technical progress.

- As highlighted by Secretary Bodman in earlier Congressional testimony, the high-volume cost of automotive fuel cells was reduced from $275 per kilowatt to $200 per kilowatt in two years. This cost reduction was the result of increased power density; advancements in membrane materials; reductions in both membrane material cost as well as amount of membrane material required in the fuel cell; enhancement of specific activity of platinum catalysts; and innovative processes for depositing platinum and reducing the overall amount of catalysts.
- In hydrogen production, we have demonstrated our ability to produce hydrogen at a cost of $3.60 per gallon of gasoline equivalent at an integrated fueling station that generates both electricity and hydrogen. This is down from about $5.00 per gallon of gasoline equivalent prior to the Initiative.

IMPLEMENTATION OF NATIONAL ACADEMIES' RECOMMENDATIONS

We have implemented the valuable feedback from the National Academy of Sciences (NAS) review in March 2004 and are already seeing results. The NAS called for us "to improve integration and balance of activities" within the relevant DOE Offices (which include Energy Efficiency and Renewable Energy; Fossil Energy; Nuclear Energy, Science and Technology; and Science). We have done this by developing and publishing an integrated research, development and demonstration plan, called the "Hydrogen Posture Plan," which covers all Department hydrogen activities. The Plan identifies the major milestones which need to be achieved to enable industry to make a 2015 commercialization decision. Each of the four offices has, in turn developed a detailed research plan which outlines how the high-level milestones will be supported. Lower-level, time-phased, performance-based milestones form the basis for measuring research progress.

In response to another National Academies' recommendation, we established a systems analysis activity to examine the impact of different components or subsystems of hydrogen technology on the complete system, as well as establish the time frames needed for transition to a hydrogen economy. "Well-to-wheels" analyses assessing the energy, economic and environmental impacts of various hydrogen production and delivery pathways, as well as other systems analysis activities, will be valuable in technology decision-making and planning for a transition to the hydrogen economy.

The Hydrogen Program has increased emphasis on exploratory research in response to the NAS recommendation that "there should be a shift . . . away from some development areas towards exploratory work" and that "the probability of success [will be] greatly increased by partnering with a broader range of academic and industrial organizations." In accordance with this recommendation, we have moved away from subsystem hardware development, such as fuel cell stack systems and conventional high-pressure storage tanks, to put greater emphasis on materials research.

Starting in FY 2005, DOE's Office of Science has been included in the Hydrogen Fuel Initiative in order to focus basic research on overcoming key technology hurdles in hydrogen production, storage and conversion. The Office of Science-funded research seeks fundamental understanding in areas such as novel materials for hydrogen storage with an emphasis on nanoscale structures and new storage concepts, non-precious-metal catalysts, membranes for fuel cells and hydrogen separation, multifunctional nanoscale structures, photocatalytic (including biological and bio-inspired approaches) and photoelectrochemical hydrogen production, and modeling and analytical tools. The three Centers of Excellence established through the Department's "Grand Challenge" solicitation are utilizing recent progress in materials discovery and technology which allows hydrogen to be stored at low pressures and

modest temperatures. Rather than "stand alone" test tube research, we have an integrated effort to address basic, applied, and engineering sciences to develop materials and systems for storing hydrogen.

Through the hydrogen production solicitations, we have increased emphasis on long-term research. Last October, DOE announced industry and university grants of $25 million over three years, contingent upon appropriations, for solar-driven photoelectrochemical, thermochemical and photobiological technology. The NAS also recommended changes in other hydrogen production technology areas and advised DOE to "increase development of breakthrough approaches for small-scale reformers[,] . . . research novel renewable liquid distributed reforming [and] . . . emphasize electrolyzer development." Our transition strategy emphasizes small-scale reformers and electrolyzers for refueling stations and distributed electricity generation sites. Through our solicitation, we have added new projects totaling $30 million over 3 years, contingent upon appropriations, in these areas. We have worked with our energy industry partners to develop technology roadmaps that emphasize distributed technologies.

COLLABORATION THROUGH PARTNERSHIPS

We are working with partners on all fronts to address the challenges to a hydrogen economy. Under the FreedomCAR and Fuel Partnership, DOE is collaborating with the U.S. Council for Automotive Research (DaimlerChrysler, Ford and General Motors) and five major energy companies (BP, Chevron, ConocoPhillips, ExxonMobil and Shell) to help identify and evaluate technologies that will meet customer requirements and establish the business case. Technical teams of research managers from the automotive and energy industries and DOE are meeting regularly to establish and update technology roadmaps in each technology area.

An Interagency Hydrogen R&D Task Force has been established by the White House Office of Science and Technology Policy (OSTP) to leverage resources and coordinate interrelated and complementary research across the entire Federal Government. This year, the Task Force initiated a plan to coordinate a number of key research activities among the eight major agencies that fund hydrogen and fuel cell research. Coordination topics include novel materials for fuel cells and hydrogen storage, inexpensive and durable catalysts, hydrogen production from alternative sources, stationary fuel cells, and fuel-cell vehicle demonstrations. The Task Force has launched a website, *Hydrogen.gov*, and in the coming year plans to sponsor an expert panel on contributions that nanoscale research can make to realizing a hydrogen economy.

Last year, we announced the establishment of the International Partnership for the Hydrogen Economy (IPHE). The IPHE, which now includes 16 nations and the European Commission, establishes world-wide collaboration on hydrogen technology. The members have agreed to work cooperatively toward a unifying goal: practical, affordable, competitively-priced hydrogen vehicles and refueling by 2020. Projects involving collaboration between different countries are being proposed and reviewed for selection.

STATE INITIATIVES AND DEMONSTRATION PROJECTS

The Department supports the growing number of state hydrogen initiatives by providing accurate and objective information about hydrogen and fuel cell technologies. Hydrogen initiatives exist in more than ten states, including California. The Department is a member of the California Fuel Cell Partnership and has participated on planning committees for the California Hydrogen Highway Network. Today, 21 full members and ten associate members representing eight automakers, four fuel providers, the supplier industry, as well as state and Federal Government agencies (including DOE, DOT, and EPA), are working together through the Partnership to share their experiences operating first-of-their-kind research vehicles throughout California. The objective of the new Hydrogen Highway Network initiative, championed by Governor Schwarzenegger, is to ensure that hydrogen fuel availability will match fuel cell vehicle demand.

As mentioned earlier, the Department's partnership with the automotive and energy industries to conduct a national "learning" demonstration project will expand the Program's research while leveraging industry investments in hydrogen and fuel cell technologies; subject to appropriations, the first phase of the project will total over $350 million, with more than 50 percent coming from industry. The project includes four automotive and energy teams made up of General Motors and Shell; Ford and BP; DaimlerChrysler and BP; and Chevron and Hyundai-Kia.

The goals of the project are:

- to obtain detailed component and performance data to guide the Department's hydrogen and fuel cell research, and
- to validate industry's progress toward meeting the milestones leading up to the 2015 commercialization decision.

Three major milestones for 2009, when phase one ends, are: 2,000-hours fuel cell durability; 250-mile vehicle range; and $3.00 per gallon gasoline equivalent hydrogen fuel.

While hydrogen fuel infrastructure and fuel cell vehicle technologies are not ready for widespread deployment or commercialization, DOE believes there is tremendous benefit in energy and auto companies working together before the market introduction phase to ensure that there is seamless integration. Transitioning to a hydrogen-based infrastructure from today's petroleum infrastructure will require coordination between stakeholders. For example, standards for hydrogen purity must be addressed before commercialization can happen. Fuel cell manufacturers would like the purest hydrogen available to ensure the best performance and longest durability; however, it will not be cost-effective for energy suppliers to produce and deliver perfectly pure, laboratory-grade hydrogen. Therefore, some compromise must occur and the demonstration program will provide the data necessary to facilitate development of hydrogen fuel quality standards prior to commercialization and infrastructure investment.

TOWARD THE HYDROGEN FUTURE

DOE is looking to the future as well. Just as we have already made progress, we plan to have significant progress next year. The progress will be tracked using performance-based technical and cost milestones that provide clear and quantifiable measures. We will report this progress annually to Congress and to the Office of Management and Budget.

For our critical targets, it is important that we verify our progress in a way that is independent and transparent. In Fiscal Year 2006, three major technical milestones will be assessed using independent review:

- In hydrogen storage, we will determine the potential of cryogenic-compressed hydrogen tanks to meet DOE's 2010 targets.
- In fuel cells, we will evaluate high-volume fuel cell cost per kilowatt against our 2006 target of $110 per kilowatt and towards meeting the 2010 target of $45 per kilowatt.
- In hydrogen production, we will determine if the laboratory research is complete for $3.00 per gallon gasoline equivalent with distributed natural gas reforming technology. This technology will need to be validated later at full-scale.

In addition, high-volume manufacturing processes must be developed to lower the costs of hydrogen and fuel cells. Manufacturing R&D challenges for a hydrogen economy include developing innovative, low-cost fabrication processes for new materials and applications as well as adapting laboratory fabrication techniques to enable high-volume manufacturing. The Hydrogen Program is working with the Department of Commerce and other Federal agencies to create a roadmap for developing manufacturing technologies for hydrogen and fuel cell systems as part of the President's Manufacturing Initiative. The roadmap will help to guide budget requests in Fiscal Year 2007 and beyond. This work is part of the Interagency Working Group on Manufacturing R&D, which is chaired by the Department of Commerce and includes 14 Federal agencies. The Working Group has identified three focus areas for the future: nano-manufacturing, manufacturing R&D for the hydrogen economy, and intelligent and integrated manufacturing systems. Manufacturing R&D for the hydrogen economy will be critical in formulating a strategy to transfer technology successes in the laboratory to new jobs, new investments and a competitive U.S. supplier base in a global economy.

Successful commercialization of hydrogen technologies requires a comprehensive database on component reliability and safety, published performance-based domestic standards, and international standards or regulations that will allow the technologies to compete in a global market. Initial codes and standards for the commercial use of hydrogen are only now starting to be published. Research will be conducted in Fiscal Year 2006 to determine flammability limits under real-world conditions and the dispersion properties of hydrogen under various conditions and also to quantify risk. Through such efforts, critical data will be generated to help write and adopt standards and to develop improved safety systems and criteria. DOE is also working closely with the Department of Transportation in hydrogen codes and standards.

CONCLUSION

Mr. Chairman, the Department of Energy welcomes the challenge and opportunity to play a vital role in this Nation's energy future and to help address our energy security challenges in such a fundamental way. This completes my prepared statement. I would be happy to answer any questions you may have.

Senator ALEXANDER. Thanks, Mr. Faulkner. How long does your schedule permits you to stay?

Mr. FAULKNER. As long as you want.

Senator ALEXANDER. That's terrific. Well, why don't I invite the other three witnesses to come forward, and we'll ask them to present their testimony. Mr. Bentham, why don't you go first, and then Dr. Burns, and then Mr. Campbell. Thank you very much for being here today.

STATEMENT OF JEREMY BENTHAM, VICE PRESIDENT, ROYAL DUTCH SHELL, AND CHIEF EXECUTIVE, SHELL HYDROGEN

Mr. BENTHAM. Thank you very much, indeed, Mr. Chairman and Senator Dorgan. I really appreciate the invitation to testify before this committee.

My name is Jeremy Bentham. I'm the vice president of Royal Dutch Shell responsible for the hydrogen business and the chief executive of Shell Hydrogen. I'll provide the oral summation here, and ask that my written testimony be submitted for the record.

Senator ALEXANDER. It will be.

Mr. BENTHAM. I thoroughly agree with you that what we're discussing here is a real opportunity to take action today that will have a significant impact on building the kind of future that we want for our children, for our grandchildren. Clearly, we mustn't underestimate the scale or the durability or the seriousness of the commitment that's required to face challenges that are related across the fields of energy, security, environment, and the economy. However, alongside the efficient use of ever-cleaner and advanced familiar fuels, we are convinced that a national portfolio that includes a significant use of hydrogen-powered fuel cell applications will make an important contribution to addressing the fundamental issues we collectively face. Hence, we do believe that the U.S. Senate is showing responsible leadership in helping to develop the hydrogen as a transportation fuel, as we've seen in the Senate's version of the energy bill.

We must recognize that the goal of introducing hydrogen on a significant scale requires an unprecedented joint undertaking by government, by the automotive industry, and by energy companies. My remarks will cover three areas: First, the technical and operational challenges that we face; second, the importance of public/private partnership; and third, what I believe it will take to accelerate the commercialization of hydrogen-powered fuel cell technology.

First of all, the technical and the operational challenges. The real key to this undertaking is the promise of attractive, affordable and commercially successful fuel cell vehicles. While there are other areas of interest, such as station re-power, we believe that the transport market must be the primary focus of attention. It's the vehicles themselves that are currently the furthest away from commercial readiness. So substantial R&D attention must be directed

to inexpensive, on-board hydrogen storage solutions, to the fuel cell power plant itself, and to low-cost manufacturing systems. However, while we know that technological challenges remain in all these areas, we believe there is increasing confidence that vehicles with the necessary operational performance will be introduced within the next few years.

The core challenge to making these affordable will be achieving sufficient levels of mass production to drive down the costs. That will require a period of market-based government incentives to build up vehicle demand and supply, to build up the necessary component-supply businesses, and we need to start building these supply chains and the frameworks for these incentives right now.

Moving to a fuel supply perspective, it shouldn't be forgotten that there already is, and has been, a hydrogen economy and hydrogen infrastructure in place for decades. Currently, 50 million tons of hydrogen are produced and consumed globally every year, mainly in industrial settings, such as in our own refineries, for producing clean traditional fuels.

Now, just to put that number in perspective, that amount of hydrogen could power all of the family cars in the United States, if they were fuel cell vehicles. Also, most areas of significant population are close to significant hydrogen production. I hope you can see back here a beautiful satellite photograph of the United States, showing the areas of population as the light areas, and it's overlaid with the areas within 60 miles of current production sites. Most areas of high population are already close to hydrogen production, so really, the only new factor is to bring hydrogen out of its industrial setting and into the everyday life of customers, in convenient locations.

This can be done in an attractive way, as has already been demonstrated, for example, with a combined hydrogen and gasoline station at Benning Road, here in Washington, DC. As you may know, and has been mentioned, President Bush and a number of people from congressional and regulatory staffs have visited Benning Road, and we are pleased to host any and all of you, if you would like to visit that as well.

We're also confident that we already understand how to supply hydrogen fuel at an attractive price, in a commercially sustainable way, into a reasonably established market. That's an important statement to make. The main challenge to fuel suppliers will come during the earliest phases of market growth, when the utilization rate of individual facilities will be low. To get the ball rolling will take both ingenuity from companies like my own, and some time-limited, market-based incentives from governments.

Looking to the public policy standpoint, one of the attractions of hydrogen fuel is that it can be produced from a wide range of primary energy sources, whether that's natural gas, coal, or renewable sources such as wind and solar energy.

We anticipate that the bulk of hydrogen will initially be produced, as it is now, from natural gas, with increasing use of coal over the course of time, and eventually renewable resources as they become abundant in themselves. We also believe that there must be a goal over the longer term of not adding to the carbon-loading of the atmosphere as we produce hydrogen. Whether that will be

through carbon dioxide geological sequestration, and in the longer term, through the use of the renewable energies, we believe that none of these challenges are unsolvable.

Second, if I can move to some comments on public/private partnership and Federal Government programs. Strong government support and structures are required to shape what I would call a coordinated and geographically-concentrated introduction of vehicles and infrastructure. Government action can be very helpful in orchestrating the dance that needs to take place among the different partners. Government action is also critical in addressing potential roadblocks on the way, such as consistent codes and standards, insurance and liability, and intellectual property rights.

Now, there's clearly a definite need, as you are doing, to continue to promote public awareness and understanding. That's an educational effort that can be effectively fostered by government. As you've recognized, it's also critical that we begin to establish the framework of economic incentives that will give all parties the confidence to invest in the new technologies, establish the supply chains whilst those economies of scale, large-scale production, and reasonable facility utilization are building up.

The current Department of Energy Vehicle and Fuel Validation program, and the other Department of Energy programs, are a useful platform for the future. We support them as far as they go. However, we do believe that to take the next steps in moving from research to reality requires further attention to the bridge that needs to be built over the next 10 years from small-scale demonstration units toward commercialization and commercial operation.

Finally, a few views on what it will take to accelerate commercialization.

Senator ALEXANDER. Mr. Bentham, what we were trying to do is keep each of the testimonies to about 5 minutes so we could have more back and forth. So if you could go ahead and summarize your remaining remarks, we'll come back.

Mr. BENTHAM. I'll summarize in 1 minute, if I may. Less than a minute.

We believe that the establishment of some large-scale, integrated projects that we call "Lighthouse Projects", because they light the way to the future, will be critical. And we believe that these will require the use of many vehicles so that we get operational validation not only of the vehicles, but also a mini-network that shows supply and refueling operations in considerable loading.

So, for us, the next question is which public authorities and which governments will provide the environment to enable these to take place? We think that where there are these conditions and where these Lighthouse Projects are first established will determine whether North America, Europe or Asia will take the lead in building these industries, and through that lead, generate the greatest benefits to the economies and the environments.

In summary, therefore, I think the final, the primary challenges we face in the area are the vehicle technology and mass production, with the effective utilization of facilities being an important secondary consideration, and that the public/private lighthouse projects will be an important bridge toward commercialization.

I'll conclude with my comments there and, of course, will respond to any questions that you have.

[The statement of Mr. Bentham follows:]

PREPARED STATEMENT OF JEREMY BENTHAM, VICE PRESIDENT, ROYAL DUTCH SHELL, AND CHIEF EXECUTIVE, SHELL HYDROGEN

Good afternoon, Senators. My name is Jeremy Bentham. I am the Vice President of Royal Dutch Shell responsible for the hydrogen business and the chief executive of Shell Hydrogen. Thank you for the invitation to testify before this committee and share my views on how the hydrogen & fuel cell industry could—and should—develop over the coming years.

Clearly, we must not underestimate the scale, durability and seriousness of commitment required to grasp the related energy, security, environmental, and economic challenges we collectively face. Alongside the efficient use of ever-cleaner and more advanced familiar fuels, we are convinced that a national energy portfolio that includes significant use of hydrogen fuel and fuel-cell applications will make important contributions to addressing these fundamental issues. The U.S. Senate has shown leadership in helping develop hydrogen as a transportation fuel as we've seen in the Senate's version of the energy bill, but we should not underestimate the scale of developments required.

First of all, I think we should all acknowledge that the goal' of moving to hydrogen is an *unprecedented* undertaking by government, auto industry, and energy companies and just importantly, such an effort is needed to address the long term energy needs of the U.S. and the world.

Even a brief look at a simplified overview of the current energy picture of the United States highlights key features such as the almost complete dependence of transport on a single, primary, imported energy source—oil, and also the high amount of energy which goes to waste rather than useful service, which is an environmental as well as an economic burden.

Hydrogen fuel and fuel-cell applications can make important contributions to addressing these fundamental issues, such as providing a transport fuel that can be derived from a wide range of present and future primary energy sources, to be used in vehicles with high efficiency, low emissions, and high customer attractiveness. Also, this technology enables electricity generation in widely distributed locations where much of the currently wasted heat generation can be usefully applied. Such a portfolio can provide much-needed options for national policy-makers, and attractive choices for customers.

That's a positive outlook. But we have to be realistic. It comes at a cost. It requires long-term investment, and it requires long-term commitment from both industry and government. Everyday incremental developments and ongoing market influences will bring everyday incremental changes, but I think most people are looking for more than this. Governments want those bigger challenges to be met as quickly as possible.

As businessmen and industrialists we need to get down to the practicalities of how to invest private and public resources wisely to making this happen. And to begin with, that means looking at what we've achieved so far; what we've learnt from it; and what we need to do next to make that positive outlook a reality.

SHELL: A WEALTH OF EXPERIENCE IN HYDROGEN

For an energy company like Shell, dealing with hydrogen is, of course, nothing new. We have many decades of experience using hydrogen in our refineries, where we handle over 7,000 tons a day as part of the production of ever-cleaner and better traditional fuels.

From a fuel supply perspective, it should not be forgotten that there is already a hydrogen economy and hydrogen infrastructure. Globally, 50 million tonnes are produced and consumed every year. Just to put this number into perspective, this amount of hydrogen could power all the family cars in the U.S.A. if they were fuel cell vehicles. Also, most areas of significant population are already close to significant hydrogen production (as shown in this satellite photograph of the U.S.A. at night overlaid with the areas within 100km of current production sites). Industrial hydrogen production is already widespread and close to those who would want to use it. We only have to compare the locations of major cities with those of facilities where hydrogen is produced to see how significant these nodes are. Indeed, in the U.S., and throughout the industrialized world, few people are more than 60 miles away from major hydrogen production site. This deserves exclamation points because I'm sure many us had not come to realize this until recently.

So we already have an initial hydrogen platform. The challenge now is to bring it out of its industrial setting and into convenient, consumer-friendly locations. That this can be done in an attractive way has already been demonstrated, for example, with our Benning Road station here in Washington DC.

We are also confident that we already understand how to supply hydrogen fuel at an attractive price in a commercially sustainable way into a reasonably established market. The main challenge to fuel suppliers will come during the earliest phases of demand growth when the utilisation rate of individual facilities will be low. To get the ball rolling will take both ingenuity from companies such as my own and some limited market-based incentives from governments.

From a public policy standpoint, one of the attractions of hydrogen fuel is that it can be produced from a wide range of primary energy sources, including natural gas, coal and renewable sources such as solar and wind energy. We anticipate that the bulk of hydrogen will initially be produced, as now, from natural gas, with increasing use of coal over the course of time. We also believe that there *must* be a goal over the longer term of not adding to the carbon loading of the atmosphere; whether through CO_2 geological sequestration or through the use of renewable energies such as wind and solar—but we believe that none of these are challenges are unsolvable.

Shell Hydrogen was established six years ago to bring a focus on hydrogen as an ordinary fuel in itself, in transport and distributed power applications. And from what we have learned since, we believe that it can indeed become an important element in the future energy mix, along with the cleaner, traditional fuels, and important advances such as modern bio-fuels and gas-to-liquids components.

To get there, however, a number of factors need to be in place, such as inexpensive and compact hydrogen storage and purification, and cheap large-scale production. Hence our active role in a range of technology ventures in these areas. For example, Shell is proactively involved in unconventional solutions to the storage issues. If more familiar methods—such as ultra high pressure storage—remain too expensive, then we already have an advanced role in seeking alternatives.

We've also established Venture Capital enterprises and partnerships within and across industries; and worked with government organizations at local, regional and national levels worldwide. And finally—and most conspicuously—we've been involved in demonstration projects that span Europe, North America and Asia.

My main message for today is that we now need to move beyond the small isolated demonstration projects we've seen so far, but before addressing this central topic let's remind ourselves how far we have come with the demonstrations.to date.

DEMONSTRATING IN ALL THE MAJOR HYDROGEN MARKETS

An important step for us, of course, was opening the very first publicly accessible Shell-branded hydrogen refuelling station in the world in Reykjavik, just 2 years ago. In Europe, since then, we've helped set up hydrogen stations for fuel cell buses in Amsterdam and Luxembourg, as part of the Clean Urban Transport for Europe initiative

On another continent, the Japan Hydrogen and Fuel Cell Demonstration Project—or JHFC—is progressing well, with 10 refuelling stations around the Tokyo metropolitan area serving more than 50 FCVs. The Ariake station that Shell operates is the most highly used of these stations, which means it's probably the most utilised hydrogen station in the world. Indeed, when I last visited Japan, I actually saw a queue of FCVs waiting to be refuelled! And these from as many as eight different auto manufacturers.

In North America, we are active in California and we have launched our plans to build an 'East Coast Corridor'—starting with our station on Benning Road here in Washington DC, to be extended with a station in New York and a station connecting these important cities in 2006. These form part of our infrastructure validation project with our partners General Motors and the Department of Energy. I would like to emphasise the importance of our station here in Washington. This station showcases the first hydrogen dispenser fully integrated at a regular retail gasoline station in the United States, servicing a fleet of six FCVs from General Motors. It's well worth a visit to sample the customer experience of the future.

MAKING THE MOST OF LESSONS LEARNT AND TECHNICAL CHALLENGES

So . . . we've been very busy and we've learnt a great deal; and, I'm pleased to say, the results continue to be positive. True, we see the technological hurdles still to be overcome—in particular, the development of inexpensive, on-board hydrogen storage systems; and affordable, mass-produced fuel cell systems. But we believe that none of these are unsolvable.

The real key to this undertaking is the promise of attractive, affordable, and commercially successful hydrogen-powered *fuel cell vehicles.* This must be the primary focus of attention, and *it is the vehicles themselves that are the farthest from commercial readiness.* R&D attention should be directed to inexpensive on-board hydrogen storage solutions, to the fuel cell powerplant itself, and to low-cost manufacturing systems. While technological challenges remain in these areas, however, there is increasing confidence that vehicles with the necessary performance will be introduced in the next few years. The core challenge to making these affordable will be achieving sufficient levels of mass production to drive down costs. This will require a period of market-based government incentives to build up vehicle demand and supply and the necessary component supply businesses, in a rapid and timely fashion. We need to start building these supply chains and designing these incentives now.

Our experience indicates that there is every likelihood that our industries will be able to bring hydrogen-powered FCVs to the point where both vehicle *and* fuel are attractive and affordable. The trick will be achieving mass production to drive down costs, as indicated in this estimate of the impact of production volume on drive-train affordability. We also believe that the public benefits resulting from this justify the considerable government interest and investment required to reach this point.

And, of course, we see that public response to the introduction of hydrogen-powered technology developments still varies enormously—from enthusiastic to fearful, depending on how effectively public engagement has been conducted locally, or how politicised the subject has become. We've certainly noticed a difference between working in communities like Iceland—where support and desire have really been built up over several years—and here in Washington DC, where our project was initially greeted with both community *and* regulatory suspicion.

Building public confidence as early as possible is important, so that we have the fertile ground of public support and regulatory experience when take-off does, eventually, becomes possible. Otherwise, progress will suffer long and unnecessary delays. There is a most definite need to promote public awareness and understanding—an educational effort that can be effectively fostered by government.

So where do we go from here? Let me return to the central theme I mentioned earlier. While we have made tremendous progress, it's clear we can't rest on our laurels. And instructive though our demonstration projects have been, continuing to serve a handful of vehicles from single sites doesn't move us forwards.

So our thoughts on the next move are very clear—we need to replicate more realistic scenarios. Hence Shell's proposal last year for the establishment of a small number of large-scale, integrated demonstration activities, which we call Lighthouse Projects.

LIGHTHOUSE PROJECTS BRIDGE THE GAP

Strong government support and structures are required to shape a coordinated and geographically concentrated introduction of vehicles and deployment of fueling infrastructure.

Government action is also critical in addressing potential early roadblocks such as codes and standards, insurance and liability, and intellectual property rights.

It is also critical that we begin to establish a framework of economic incentives that will give all parties the confidence to invest in these new technologies, and establish supply chains, while the economies of large-scale production and reasonable facility utilisation build up

The current Department of Energy vehicle and fuel validation programme, and other DOE programmes, are a useful platform for the future, as far as they go. However, to move from Research to Reality, now requires further attention to the bridge that needs to be built in the next ten years from small-scale demonstrations towards commercial operation.

As mini-networks of consumer-friendly retail sites, we believe that Lighthouse Projects will play a crucial role in bridging the gap between the current demonstration projects and commercialisation. In our view, they will act as the stepping stone to a commercial infrastructure roll-out.

We recommend focusing on a limited number of large-scale projects, mainly focused on transport applications involving hundreds of vehicles and several combined hydrogen and gasoline refuelling stations operating on a semi-commercial basis. Other relevant applications may also be included to maximise synergy.

Involving several different companies—in partnership with government authorities—Lighthouse Projects will not only significantly increase coverage and mobility, they will provide us with the real-world operational and economic data we des-

perately need. As such, they will enable us to address the biggest barriers that face the development of this industry.

Why so many vehicles? Well one reason is that an effective component supply chain is going to be essential for vehicles and other applications to move down the cost curve towards mass production. And this means giving component suppliers a realistic outlook on activity and investment levels over the next few years, while applications achieve the necessary performance and attractiveness criteria.

And from a fuel provider's position, we need to build experience in conditions where facilities are utilised at levels much closer to future realities. And last, but certainly not least, we need to demonstrate these facilities on a scale that will really inform and interest the public—our future customers.

In short, we believe that if we don't take the step to full Lighthouse Projects, we cannot build and test the strategies, disciplines and incentive mechanisms we need to coordinate our activities for the next phase of development and allow the industry to grow.

While the current United States Department of Energy infrastructure validation projects and other U.S. initiatives are very positive and valuable developments, the JHFC project in Japan is probably the closest current example to our proposal, and we're watching it closely to see how it develops; and particularly the growth in the number of vehicles involved.

We believe that *failure* to take the next step to full Lighthouse Projects could have serious consequences.

KEEPING THE FOCUS

First, there is a real danger that we *don't* focus our efforts, government funding and industry attention will become hopelessly fragmented; with valuable time being lost through duplication and re-inventing the wheel.

This is entirely possible—we've already experienced the issue of infrastructure "earmarks" in the U.S.; and in Europe, there will be a strong push from all 25 individual member states to site activities in their own country. But if our next move sees five or six vehicles scattered in each of 100 places throughout the world, we'll end up going nowhere fast.

UTILISATION HURDLES

The second danger is that even if we get over the technology and mass production hurdles for fuel cell vehicles, we will run into a huge infrastructure 'utilisation hurdle' that significantly increases hydrogen supply costs.

For example, we have results from a series of scenarios from a study of the roll-out of vehicles and fuel infrastructure in a major metropolitan area. In one set of scenarios retail stations are located in areas and sites where they do not stimulate good additional demand for fuel cell vehicles, and experience low facility utilisation. In other scenarios, however, there is closer coordination with vehicle manufacturers on their anticipated customer needs, and with local authorities on effective site development, and this is built on better experience with effective utilisation of facilities through realistic Lighthouse Projects. This leads to much better alignment of capacity with anticipated demand, and more cost-effective matching of customer interests.

From our analysis of these scenarios, it is clear that a coordinated infrastructure roll-out, making good use of existing manufacturing and retail assets, realises much lower full supply costs—up to a factor of two lower! The alternative is higher hydrogen fuel prices, but that will simply discourage vehicle purchase.

Looking forwards, therefore, there is a great need for mechanisms like larger scale Lighthouse Projects that encourage coordination between vehicle and fuel suppliers—with suitable investment incentives—to enable the industry to grow from its pre-commercial beginnings, to the next phase of early commercial development.

This means having fiscal and other economic incentives that give manufacturers, infrastructure providers and users the confidence to invest in these new technologies and establish supply chains while the economies of large-scale production build up. It also means having more flexible, dynamic financial instruments aimed at fostering industry growth.

It means establishing regulations, codes and standards, and intellectual property rights, to encourage new technology and protect investment in R&D. It also means building up human capital—trained scientists and engineers. And it most definitely means promoting public awareness and education.

And to achieve *all* of this requires very substantial public-private partnerships.

CONCLUSION

Lighthouse Projects as we have defined them are the catalyst to fulfilling all these conditions, for overcoming fragmentation, and for realising the next step towards commercialisation of the industry.

Building on our experience and valuable lessons so far, the next question is simply which governments and public authorities will provide the environment for this step, and which businesses will respond. Where these lighthouse projects are established will determine whether North America, Europe or Asia will build a lead in these industries and, through that lead, secure the greatest benefits to their economies and environments. I look to our current industry and government partners, and other serious parties, to join with us in developing innovative partnerships to realise these lighthouse projects.

In summary, therefore, I believe the primary challenges to developing the hydrogen opportunity are fuel cell vehicle technology and mass production, with the effective utilisation of refuelling facilities being an important secondary consideration, and that public-private Lighthouse Projects will be an important bridge towards commercialisation.

Thank you.

Senator ALEXANDER. Thank you very much.

Dr. Burns.

STATEMENT OF LAWRENCE D. BURNS, PH.D., VICE PRESIDENT, RESEARCH & DEVELOPMENT AND STRATEGIC PLANNING, GENERAL MOTORS CORPORATION

Dr. BURNS. Mr. Chairman and Senator Dorgan, I'm responsible for leading General Motors' fuel cell program. We place very high priority on fuel cells and hydrogen as the long-term power and energy carrier for automobiles. We see this combination as the best way to ensure energy independence, remove the automobile from the environmental debate, to grow our economy, to grow jobs, and very importantly, the best way to allow automakers to create better vehicles for our customers and the kinds of vehicles that they really want to buy in high volume. Now, high volume is absolutely critical. It's the only way we could meet the growing global demand for automobiles while at the same time realize the energy and environmental benefits that we're all seeking.

Our fuel cell program is focused in three areas. First, we're developing a fuel cell propulsion system that can compete head-to-head with an internal combustion engine system. Second, we're demonstrating our progress publicly to let key stakeholders know the potential of this technology. And finally, we're collaborating with energy companies and with governments to ensure the safe, convenient and affordable availability of hydrogen in a way that can lead to rapid transformation of the industry.

We're targeting to design and validate a fuel cell propulsion system by 2010 that has the cost, durability and performance of an internal combustion engine system. Now that's at an assumed volume on the cost side, consistent with the scale of our industry. This is an aggressive timetable, and it's clear that it's being industry-led. It's also clear that we believe these technologies have matured to the point where such a timetable is possible. We've made significant progress on the technology—in the last 6 years, we've improved fuel cell power density by a factor of seven. This helps us enhance the efficiency and reduce the size of the components for the car. We significantly increased the durability, reliability and cold start performance of our fuel cells. We are developing safe hydrogen storage systems that are beginning to approach the capa-

bility to deliver the range that our customers will expect between fill-ups. And we've made significant progress on cost reduction through technology improvements and systems simplification.

Our progress has convinced us that fuel cell vehicles have the potential to be fundamentally better automobiles on nearly all attributes that are important to our customers. This is a key to enabling high-volume sales. And with just one-tenth as many moving parts as internal combustion engine systems, we're confident that our vision to make this technology cost-competitive and durability-competitive is indeed possible.

We've made excellent progress with respect to demonstrations. We have a fleet of six hydrogen vehicles here in Washington, DC. It's now in its third year. We've had nearly 3,000 people take a ride or drive our hydrogen fuel cell vehicle. The FC vehicle fleet is actually fueled at the fuel station that Jeremy mentioned earlier, on Benning Road. This is a very important, albeit small, step toward demonstrating the infrastructure. We've collaborated with the U.S. Army in building the first fuel cell-powered military truck, and it's being evaluated now at Fort Belvoir. We also will field 40 fuel cell vehicles as part of the Department of Energy program, and these vehicles will span two generations of technology. And finally, we've made visible the vision for a totally re-invented automobile around fuel cells and advanced electronics, they go by the names of AUTOnomy, Hy-wire, and most recently, Sequel. Sequel was revealed at this year's North American International Auto Show in Detroit, and it will have a capability of a range of 300 miles between fill-ups. It's a sport utility vehicle aimed right at the sweet spot of our market, with acceleration from zero to 60 miles per hour in less than 10 seconds. And by the way, it was designed to meet Federal Motor Vehicle Safety Standards.

Now, with respect to collaboration, we're working closely with Shell, with Sandia, with Dow, with Hydrogenics, with QUANTUM, with the Department of Energy, and then part of the FreedomCAR fuel cell partnership with other auto companies and energy companies. We see the biggest challenge to vast industry transformation to hydrogen and fuel cells as being the fueling infrastructure. A major advantage of hydrogen is that it can be obtained from numerous pathways, including renewable sources. We think it's the key to relieving our 98 percent dependence on petroleum as energy for our cars and trucks.

Building a new infrastructure is a formidable task, but as Jeremy mentioned, 50 million tons per year of hydrogen are already being used globally, and that equates to 200 million vehicles worth of hydrogen, if it was used for those purposes. I think the important point here is that the world has a lot of experience producing hydrogen in large volumes, doing it safely, and doing it at commercially competitive costs for those applications. We also do not have to build the infrastructure overnight. The entire U.S. fleet would turn over in about 20 years, and as such, we would be able to pace the infrastructure with the growth of that fleet.

Now, we applaud the Department of Energy and Federal Government initiatives on hydrogen infrastructure; however we believe more needs to be done if we're going to be ready for large-scale demonstrations, and ultimately mark our growth in the next dec-

ade. We'd like to see the Federal Government articulate a clear and broadly sanctioned vision that requires more than just the Department of Energy and Department of Transportation to make hydrogen and fuel cell technology development and application a high priority. Clear, consistent communication to the American people of this vision and the underlying rationale for hydrogen and fuel cells are also vitally important to building public acceptance of fuel cell vehicles.

The energy bill is directionally quite good, in our judgment, but if we are really serious about transforming to a hydrogen economy, we're going to have to do more in the coming years. The auto industry alone is spending about a billion dollars a year to develop this technology, so if the Government sees a need to accelerate progress, we believe that government funding at greater levels is warranted.

We welcome, in particular, the energy bill's increased R&D funding. Now, as I mentioned, we're targeting a first-generation system by 2010 that can compete with the internal combustion engine system, but the real volume—and the real benefits—will come from second-generation technology and beyond. So, continued R&D on advanced materials for fuel cell components and for hydrogen storage is very much welcome. Market demand for fuel cell vehicles must also be encouraged. The price of hydrogen will be a critical factor in doing that, so one consideration would be, perhaps, to not tax hydrogen with fuel taxes, maybe, perhaps until we have up to 5 million vehicles on the road. And since availability will also be an issue, a generous tax credit would ensure the investments necessary for developing hydrogen filling stations and mitigating the risks of these investments.

Looking past 2010, we must start thinking about moving beyond today's small scale demonstrations. We welcome the Federal fleet purchase program of the energy bill, and believe Congress should consider doing more in this area. This would be an important bridge to commercially competitive vehicles and high-volume production.

To summarize, General Motors sees hydrogen as the long-term automotive fuel and the fuel cell as the long-term power source. Our fuel cell program seeks to create clean, affordable, full-performance fuel cell vehicles that really excite and delight our customers, and that's really the key to getting to high-volume sales in these vehicles. We believe customers will really want to buy these vehicles in large numbers, and that society will reap the economic energy and environmental benefits. Thank you.

[The statement of Dr. Burns follows:]

PREPARED STATEMENT OF LAWRENCE D. BURNS, PH.D., VICE PRESIDENT, RESEARCH & DEVELOPMENT AND STRATEGIC PLANNING, GENERAL MOTORS CORPORATION

Mr. Chairman and members of the Committee, thank you for the opportunity to testify today on behalf of General Motors. I am Larry Bums, GM's Vice President of Research & Development and Strategic Planning, and I am leading GM's effort to develop hydrogen-powered fuel cell vehicles.

GM has placed very high priority on fuel cells and hydrogen as the long-term power source and energy carrier for automobiles. We see this combination as the best way to simultaneously increase energy independence, remove the automobile from the environmental debate, stimulate economic and jobs growth, and allow automakers to create better vehicles that customers will want to buy in high volumes.

High volume is critical. It is the only way to meet the growing global demand for automobiles while realizing the large-scale energy and environmental benefits we are seeking.

GM's R&D program is focused on three areas:

- Developing a fuel cell propulsion system that can compete head-to-head with internal combustion engine systems.
- Demonstrating our progress publicly to let key stakeholders experience firsthand the promise of this technology.
- Collaborating with energy companies and governments to ensure that safe, convenient, and affordable hydrogen is available to our customers, enabling rapid industry transformation to fuel cell vehicles.

We are targeting to design and validate an automotive-competitive fuel cell propulsion system by 2010. By automotive competitive, we mean a system that has the performance, durability, and cost (at scale volumes) of today's internal combustion engine systems.

This aggressive timetable is a clear indication that fuel cell technology for automotive applications is industry driven (rather than government driven) and that this technology has matured to a point where such timing is indeed possible.

We have made significant progress on the technology:

- In the last six years, we have improved fuel cell power density by a factor of seven, while enhancing the efficiency and reducing the size of our fuel cell stack.
- We have significantly increased fuel cell durability, reliability, and cold start capability.
- We have developed safe hydrogen storage systems that approach the range of today's vehicles, and we have begun to explore very promising concepts for a new generation of storage technology.
- We have made significant progress on cost reduction through technology improvements and system simplification.

Our progress has convinced us that fuel cell vehicles have the potential to be fundamentally better automobiles on nearly all attributes important to our customers, a key to enabling high-volume sales. And with just 1/10th as many moving propulsion parts as conventional systems, our vision design has the potential to meet our cost and durability targets.

We have also made excellent progress with respect to vehicle demonstrations:

- Our six-vehicle fleet demonstration here in Washington, D.C. is now in its third year, with almost 3,000 people participating in a ride or drive. We also have other demonstration programs in California, Japan, Germany, and soon in China.
- The D.C. fleet is fueled at a Shell station equipped with a hydrogen pump. This is the first retail outlet dispensing hydrogen fuel in the U.S. and a significant, albeit small, step toward a hydrogen infrastructure.
- We collaborated with the U.S. Army on the development of the world's first fuel cell-powered military truck; it is currently being evaluated and maintained by military personnel at Fort Belvoir.
- We also will field 40 fuel cell vehicles, spanning two technology generations, as part of the Department of Energy's Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project. We are pleased to see that the Energy Bill affirms this demonstration. This is the right size program at the right time. It is large enough to generate real learnings about operating fuel cell vehicles, without being so large that it diverts the resources of automakers from our central focus on automotive-competitive technology.
- GM has also created the AUTOnomy, Hy-wire, and Sequel concepts, which demonstrate how new automotive DNA can transform our vehicles. Sequel, a five-passenger crossover SUV, is the first fuel cell vehicle capable of driving 300 miles between fill ups.

With respect to collaboration, we are working with key partners on virtually every aspect of fuel cell and infrastructure technology. Among our partners are Shell Hydrogen, Sandia National Lab, Dow Chemical, Hydrogenics, and QUANTUM Technologies as well as the Department of Energy, which includes the FreedomCar and Fuel Partnership involving Ford, Chrysler, and five energy companies.

The biggest challenge to a fast industry transformation to hydrogen and fuel cells is the fueling infrastructure. A major advantage of hydrogen is that it can be obtained from numerous diverse pathways, including renewable sources. As such, it promises to relieve our 98-percent dependence on petroleum as an energy source for cars and trucks.

Building a new fueling infrastructure is a formidable task. Fortunately, we are not starting from scratch. A global hydrogen infrastructure already exists today that produces 50 million tons of hydrogen per year—which equals the amount of hydrogen needed to fuel 200 million fuel cell vehicles! While this hydrogen is currently allocated to industrial uses, it shows that hydrogen can be produced and used economically and safely on a huge scale in commerce.

We also do not have to build the infrastructure overnight. It takes about 20 years to turn over the entire vehicle fleet, so it is possible to evolve infrastructure development in line with vehicle production.

GM has calculated that an infrastructure for the first million fuel cell vehicles could be created in the United States at a cost of $10-15 billion—about half the cost of the Alaskan oil pipeline (when its $8 billion price tag is converted into today's dollars). This infrastructure would make hydrogen available within two miles for 70 percent of the U.S. population and connect the 100 largest U.S. cities with a fueling station every 25 miles.

While this is a somewhat oversimplified calculation, it demonstrates that an initial hydrogen infrastructure would not be cost prohibitive. In fact, the cost is only a small fraction of the capital the oil industry says it will need to keep up with increasing demand for petroleum.

GM applauds the Department of Energy and the federal government for its hydrogen infrastructure initiatives. However, in our view, much more needs to be done if we are to be ready for the large-scale fuel cell demonstration programs and market growth that we envision for the next decade.

We would like to see the federal government articulate a clear, concise, broadly sanctioned vision that requires agencies beyond DOE and DOD to make hydrogen and fuel cell technology development and application priority areas of engagement.

Clear, consistent, ongoing communication to the American people of this vision and the underlying rationale for hydrogen and fuels cells is also vitally important to building public acceptance of fuel cell vehicles.

The Energy Bill now under consideration by Congress is directionally quite good, but if we are really serious about transforming to a hydrogen economy, there will be more to do in the coming years. The automotive industry alone is probably spending close to $1 billion per year on fuel cell technology. If government wants to accelerate progress, a greater investment is warranted.

We welcome in particular the Energy Bill's increased funding for R&D. Fuel cells energized by hydrogen fundamentally change the DNA of the automobile. While we have made dramatic progress toward a first-generation automotive-competitive system, like with any new technology, the real volume and benefits will be realized in second-generation designs and beyond. As such, we would like to see a significantly expanded national R&D initiative on breakthrough fuel cell materials, hydrogen storage, and hydrogen generation—leveraging the creative capabilities of our government labs, universities, and industrial research facilities—to help us move quickly to later-generation designs.

Market demand for hydrogen fuel cell vehicles must also be encouraged. The price of hydrogen will be a critical factor and Congress should act now to exempt hydrogen from fuel taxes until, perhaps, at least five million fuel cell vehicles are on the road. Since availability will also be an issue, a generous tax credit would ensure the investments necessary for development of hydrogen filling stations by mitigating the risks of these investments.

Looking past 2010, we must start thinking about moving beyond today's small-scale demonstrations. We welcome the federal fleet purchase program in the Energy Bill and believe Congress should consider doing more in this area. This would be an important bridge to commercially competitive vehicles and high-volume production.

To summarize, General Motors sees hydrogen as the long-term automotive fuel and the fuel cell as the long-term power source. Our fuel cell program seeks to create clean, affordable, full-performance fuel cell vehicles that will excite and delight our customers. We believe customers will buy these vehicles in large numbers and that society will reap the economic, energy, and environmental benefits.

I want to emphasize, however, that this is not just about car companies wanting to sell vehicles. In a very real sense, this is about nation building:

In the 19th century, the construction of the transcontinental railway gave rise to new industries and changed our country's economic destiny. In the 20th century, the development of the interstate highway system achieved similar dramatic results. The creation of a hydrogen-based economy is the 21st century's exercise in nation building. Leadership in hydrogen and fuel cell technology will underscore our preeminence in innovation and is absolutely vital to our future. It will ensure our abil-

ity to compete on a global basis, enable sustainable economic growth, and spur the creation of exciting new job opportunities for future generations of Americans.

GM is ready and eager to work collaboratively with government, energy companies, and suppliers to *drive the hydrogen economy to reality.*

Thank you.

Senator ALEXANDER. Thank you very much, Dr. Burns.

Mr. Campbell.

STATEMENT OF DENNIS CAMPBELL, PRESIDENT AND CEO, BALLARD POWER SYSTEMS

Mr. CAMPBELL. Senator Dorgan, and Senator Salazar.

Senator ALEXANDER. I should welcome Senator Salazar from Colorado, who has joined us. Thank you very much for being here. We're going to—we're finishing the testimony of each of the four witnesses and then we'll turn to questions, if that's all right.

Mr. CAMPBELL. My name is Dennis Campbell, and I'm the president and CEO of Ballard Power Systems. We are the exclusive fuel cell supplier to Ford Motor Company and to DaimlerChrysler, and we also have supplied product to eight of the top ten automotive manufacturers.

Fuel cells offer a game-changing technology that can help us overcome some of the most pressing problems of our time: energy security, global climate change, urban air quality and long-term energy supply. In addition to the obvious benefits, a fuel cell-powered car is also simpler to build, inherently more reliable, with fewer moving parts, and can be more versatile, feature-rich, and more fun to drive.

As with any disruptive technology, though, there are critics, those who prefer the status quo, those for whom the glass is always half empty. Well, today I'd like to respond to the skeptics and the naysayers with a factual update that suggests the hydrogen economy is closer than many people think. I'll discuss three of the major challenges that must be overcome—reducing the cost, increasing the durability and ensuring reliable start-up in freezing temperatures.

Earlier this year, Ballard released a technology road map, as part of our plan to demonstrate commercially viable automotive fuel cells by 2010. Our road map is fully aligned with the Department of Energy's 2010 automotive fuel cell goals.

From 1999 to 2003, we reduced the cost of our fuel cells by 80 percent, while achieving a ten-fold increase in durability. By 2004, we reduced our costs, adjusted for high-volume production, to $103 per kilowatt. Our goal this year is to get that down to $85, and we're confident that by 2010, we can achieve the DOE's target of $30 per kilowatt.

The DOE has also set a commercial durability target of 5,000 hours—roughly the expected life of today's piston engines, or 150,000 miles. We are on track to meet that goal. Last year, we demonstrated automotive technology with a lifetime of 2,200 hours. Our Ballard Power fuel cell buses in Europe have surpassed more than 2,500 hours of operation, and our stationary co-generation fuel cell system for Japan has achieved more than 25,000 hours of lifetime.

A third technical challenge is to improve the ability of our fuel cells to start in freezing temperatures. Last year, we demonstrated

an ability to start at minus 20 degrees Celsius, reaching 50 percent of the rated power within 100 seconds. Our goal for 2010 is to demonstrate start-up from minus 30 degrees Celsius in 30 seconds.

Now, the technical challenges that we face are significant, but our confidence in meeting them is bolstered each day by the tremendous progress that we're making—progress in fundamental understanding, in the development of advanced design tools, simulation models and accelerated test methods, and in our manufacturing process capabilities. A key enabler of this progress is the demonstration of fuel cell vehicles in the hands of everyday customers. Since 2003, Ballard fuel cells have been powering 30 Mercedes-Benz transit buses in daily revenue service in 10 cities throughout Europe. More than 3.5 million passengers have already experienced the advantages of clean, quiet fuel cell transportation.

The Department of Energy's Fleet Validation Program takes our field experience to the next level. Ballard, through its automotive partners—Ford and DaimlerChrysler—as part of the DOE initiative, will be powering approximately 60 vehicles in various locations throughout the United States. Right now, Ballard fuel cells are powering more than 130 vehicles on four different continents.

Now, effective demonstrations are critical, but the single most important determinant of when fuel cells can be introduced to the mass market is the will and commitment of government. There's no better investment for government to make in the health and welfare of its people than an all-out Apollo-like commitment to hydrogen and fuel cells.

The President's hydrogen initiative has galvanized the industry and government in support of the hydrogen economy, and continues to facilitate public/private collaboration. The pending energy bills, R&D and demonstration programs, if fully funded, will strengthen the President's initiative and provide a vital boost to fuel cell commercialization.

It's a great start, and I congratulate the committee for their outstanding leadership in getting the energy bill to this point. But considering the stakes, I urge Congress to do more. An effective national strategy to accelerate the hydrogen economy must also include a transition to market plan. Only government can overcome the classic "chicken and egg" problem and kickstart the transition to fuel cell power. We applaud the proposed $1,000 per kilowatt tax credit for stationary fuel cells. For automotive fuel cells, the framework of an effective transition to market program is present in legislation sponsored earlier this year by Senators Dorgan and Graham, and is also captured in the energy bill's vehicles and fuels provision.

In closing, I strongly recommend that Congress significantly increase funding for this fuel cell vehicle procurement program. A vigorous procurement program targeting fuel cell vehicles for Federal and State fleets must be in place alongside R&D and demonstrations as a third component of a national strategy to accelerate the hydrogen economy. A clear commitment by Congress to make a specific and sizable annual outlay in fiscal years 2010 to 2015 on State and Federal fuel cell fleets would support the volume production necessary to drive costs down, to stimulate the build-out of a hydrogen infrastructure, draw additional private capital into

the sector, and provide the American public with a large-scale introduction to the hydrogen economy. There's no doubt the challenges are real, but they can and will be met.

Thank you for the opportunity to appear before you today, and I look forward to answering any questions you may have.

[The statement of Mr. Campbell follows:]

PREPARED STATEMENT OF DENNIS CAMPBELL, PRESIDENT AND CEO, BALLARD POWER SYSTEMS

Mr. Chairman, Members of the Committee, my name is Dennis Campbell and I am the President and CEO of Ballard Power Systems. Thank you for the opportunity to speak with you today on a subject of central importance to today's pressing energy, economic, and environmental challenges.

Ballard is recognized as the world leader in developing and manufacturing proton exchange membrane or PEM fuel cells. We've been developing PEM fuel cells since 1983 and hold nearly 1,000 patents, granted and pending, on some of the most fundamental fuel cell technologies.

We are the exclusive fuel cell supplier to Ford Motor Company and DaimlerChrysler and to date have supplied eight of the top 10 automotive manufacturers. Today, Ballard fuel cells power more customer demonstration vehicles than all other fuel cell developers combined.

Based on our more than 20 years of research, development and extensive over-the-road experience, we've concluded—and I believe each of the major automotive manufacturers would agree—that hydrogen fuel cells will be the automotive powertrain of the 21st century.

Fuel cells have the power to transform our world because they offer a comprehensive solution to the most pressing problems of our time: energy security, global climate change, urban air quality, and long-term energy supply.

In addition to these obvious benefits, a fuel cell powered automobile is also simpler to build, inherently more reliable with fewer moving parts, and has the potential to be feature rich, more versatile and more fun to drive.

At Ballard our corporate vision statement is "Power to change the world". While that may sound like a lofty statement, there are those who would take it a step further and state that fuel cells in fact, have the power to save the world.

The fact is, the hydrogen economy is not just some Utopian dream, it is an opportunity that is within our reach. The building blocks are here today, and we have clear line of sight to solutions that will meet the remaining technical challenges.

As with any disruptive technology, there are legions of critics, those who prefer the status quo, those for whom the glass is always half empty.

When I was a student at the University of Oklahoma in 1967, the Senator from New York came to our campus for a talk. That night, Bobby Kennedy said something that has stayed with me all these years and continues to inspire me today. He said:

"Some men see things as they are and ask 'Why?' I dream things that never were and ask, 'Why not?'"

At Ballard we are focused on "why not." We're focused on solving problems, on advancing the technology, on meeting the challenges.

We are responding to those who claim that fuel cell technology is, and will remain, prohibitively expensive; that onboard fuel storage is too difficult; that a hydrogen refueling infrastructure is too much trouble; or that it takes too much energy to produce hydrogen.

We're focused on providing evidence, not opinion. Let me offer some data to set the record straight.

Last year, before the House Science Committee, Dr. Joseph Romm, a leading critic of fuel cell technology, claimed that PEM fuel cell costs were about 100 times greater than the cost of a comparable internal combustion engine and that a major technology breakthrough would be needed in transportation fuel cells before they would be practical.[1]

The truth is that from 1999 to 2003, at Ballard we reduced the cost of our fuel cell by 80% while achieving a ten-fold increase in lifetime. By 2004, we reduced the cost of our fuel cell, adjusted for high volume production, to $103 dollars per kilowatt—that's only a bit more than three times higher than the commercial target the

[1] Dr. Joseph Romm before the House Science Committee, March 3, 2004.

Department of Energy has set for 2010. Our goal this year is to get down to $85, and we're confident that by 2010 we can achieve DOE's target of $30 per kilowatt.

This is not unlike developments in the computer industry. In 1956, a gigabyte of memory cost $10 million. By 1980, the cost had been reduced to $193,000 per gigabyte. Today, the cost is about $1.15.

The hydrogen delivery infrastructure, cited by many critics as an insurmountable obstacle, is merely an engineering problem. There are already more than 100 fueling stations in place around the world. The estimated cost for broad deployment of a hydrogen fueling infrastructure in the U.S. is variously estimated at between $10 and $20 billion—not much more than the $11 billion that the industry reportedly spends each year to simply maintain its present gasoline delivery system.

With respect to on-board storage of hydrogen, progress is being made with higher pressure tanks, purpose built vehicles, and the investigation of solid storage media.

Governments are assembling the building blocks of the hydrogen economy in fuel cell vehicle demonstrations throughout the world. Through these demonstrations, citizens are gaining exposure to hydrogen and fuel cell vehicles and the promise of clean, energy independent transportation.

One such demonstration is the Department of Energy's Fleet Validation program. Ballard, through its automotive partners Ford and DaimlerChrysler, will be powering approximately 60 vehicles in this initiative in various locations throughout the U.S., generating important data and experience that will directly advance the technology.

Another highly successful demonstration program is the European Fuel Cell Bus Project. Since 2003, Ballard fuel cells have been powering 30 Mercedes-Benz Citaro buses in daily revenue service in 10 different cities. This program is co-financed by the European Union.

To date, more than 3.5 million passengers have ridden these Ballard powered buses, putting them in direct contact, today, with clean, quiet and efficient hydrogen-fueled transportation. In London, Mayor Ken Livingstone embraces these fuel cell buses as part of his initiative to reduce ambient noise levels in the city.

In addition to the European program, six other Ballard powered transit buses are operating in Perth, Australia and Santa Clara, California with three more scheduled for Beijing later this year.

Through these and other demonstrations, Ballard fuel cells are powering more than 130 vehicles on four different continents, approximately three quarters of all publicly demonstrated fuel cell vehicles on road today.

As we move from demonstrations to a commercially viable fuel cell product for the automotive sector, there are four key technical challenges to be overcome: reducing the cost, increasing the durability, ensuring reliable startup in freezing temperatures, and doing so within the available package space.

Ballard has a plan to overcome each of these challenges . . . what we call our technology "road map", our public commitment to demonstrate commercially-viable automotive fuel cell stack technology by 2010. This "road map" is fully aligned with the DOE's published commercial targets for this technology.

Let me first address fuel cell cost. Meeting DOE's 2010 cost target of $30 per kW will ensure that a fuel cell engine is cost competitive with today's internal combustion engines. There are a number of factors that affect fuel cell cost. Two of the most challenging are the amount of platinum used in the catalyst, and the type of membrane used in the fuel cell construction. Ballard has done significant research and development to reduce the amount of platinum we use. In 2004 we demonstrated a 30% reduction without compromise to performance, efficiency or durability. We are also looking at a number of membrane chemistries and constructions to significantly reduce the cost of this critical component. We believe we are on track to achieve the DOE target of $30 per kilowatt by 2010.

Durability is the second key technical challenge we face. The DOE has set a 2010 commercial target of 5,000 hours—about 150,000 miles which is roughly equivalent to the lifetime of today's internal combustion engines. As with the cost challenge, membrane design and material is a key factor in fuel cell lifetime. Last year, we demonstrated automotive fuel cell technology with a lifetime of 2,200 hours. Many of the Ballard-powered fuel cell buses operating as part of the European Fuel Cell Bus Project have achieved more than 2,500 hours of operation. We have a stationary fuel cell—our cogeneration system for residential usage in Japan—that has achieved more than 25,000 hours of lifetime. We are confident that we can deliver the DOE target of 5,000 hours by 2010.

The third technical challenge is to improve the ability of our fuel cells to start in freezing temperatures. The electrochemical reaction within a fuel cell produces water and heat. Managing that water in sub-freezing temperatures is essential to a successful start-up. Our advanced simulation tools and testing methods have pro-

vided us with insight and a fundamental understanding of how water behaves through the various cycles of fuel cell operation. Last year, we demonstrated technology that was able to start at −20° Celsius, reaching 50% of the rated power within 100 seconds. Our goal for 2010 is to demonstrate start-up from −30° Celsius, reaching 50% of the rated power in 30 seconds. The DOE target for 2010 is −20° Celsius, reaching 50% of the rated power in 30 seconds.

Power density, is an important boundary condition that constrains the previous three goals to ensure that the solutions can be packaged within the limited vehicle space available. Last year, we demonstrated fuel cell technology at 1,200 watts per liter net. The DOE's 2010 commercial target is 2,000 watts per liter net. As in the case of freeze start, we've actually set a more stringent target for ourselves, at 2,200 watts per liter net, based on our customers' requirements, and we're confident that we can achieve that.

To summarize: we know what the technical challenges are, we have multiple technology paths that we are pursuing, and we are confident that we will demonstrate commercially-viable automotive fuel cell stack technology by 2010.

The single most important determinant of when fuel cells will be commercially available for automotive application is the will and commitment of government. If the role of government is to protect and serve its people, there is no better investment for government to make than an all-out, Apollo-like commitment to hydrogen and fuel cells.

The President's Hydrogen Initiative has galvanized industry and government in support of the hydrogen economy, and continues to facilitate public-private sector collaboration.

Though I believe a higher overall funding commitment is appropriate, the pending energy bill's important R&D and Demonstration programs will strengthen the President's initiative and, if fully appropriated, provide a push at a crucial stretch along the commercialization timeline.

Yet I urge Congress to take a further step. A national strategy to accelerate the hydrogen economy must not only have strong R&D and Demonstration programs but also a robust transition to market plan that provides a bridge to commercialization. Only government intervention can overcome the classic chicken and egg problem and kick-start the transition to a hydrogen economy. The proposed $1,000 per kilowatt tax credit for stationary fuel cells is a good beginning—but more must be done to support vehicular fuel cell introduction.

The framework of an effective transition to market program for fuel cell vehicles is present in legislation sponsored earlier this year by Senators Dorgan and Graham, and is also captured in the energy bill's Vehicles and Fuels provision. I strongly recommend that Congress elevate, expand, and significantly increase funding for this procurement program for fuel cell vehicles. A strong procurement program aimed at fuel cell vehicles for federal and state fleets must be in place, along side R&D and Demonstrations, as a third component of the national strategy to accelerate the hydrogen economy.

Broadcast early enough and with sufficiently clear guidelines, a clear commitment by the Congress to make a specific and sizable annual outlay for the fiscal years 2010 to 2015 on federal and state fleet procurement of fuel cell vehicles would: (a) support early volume production by automotive OEMs and suppliers that is necessary to drive cost down; (b) support the build out of hydrogen infrastructure; (c) draw additional private capital into the sector, and (d) provide the American public with a large scale introduction to the hydrogen economy.

In closing, let me say that the challenges are real—but they can and will be met.

I would like to commend the committee on its outstanding leadership with respect to this year's energy bill, and for the forward-thinking hydrogen and fuel cell provisions therein.

Thank you for the opportunity to appear before you today. I look forward to any questions you may have.

Senator ALEXANDER. Thank you, Mr. Campbell, and thanks to each of you for your testimony. Why don't we each take about 5 minute turns, and we'll just keep going for awhile.

Mr. Bentham, you talked about production of hydrogen; most of it's from natural gas today, I believe, and I had two questions related to that. One is, if in the United States we produce hydrogen from natural gas, won't we just be increasing our reliance on overseas natural gas, which is where we're going to have to get a lot of our gas over the next few years, and won't we create the same

problem with natural gas that we have now with overseas dependence on oil? And second, I don't believe you mentioned nuclear power as you listed the variety of ways that we might produce hydrogen; would that not be an obvious way for the United States to produce hydrogen?

Mr. BENTHAM. Thank you for the question.

As you mentioned, indeed, most of the world's hydrogen production currently is culled from natural gas, and I'd like to say that the most efficient ways of producing hydrogen are from chemical conversion. That chemical conversion can be applied to natural gas, or any hydrocarbon that can be gasified. And so, coal gasification is a good route to hydrogen, and we see that to be an increasing possibility going forward. And it really, then, becomes a question of the different policy requirements and the various incentives toward shaping the way forward. It may be, from a system point of view, at any particular time, better to increase the amount of indigenous use of coal to create coal gasification and to use that as electricity into the grid, to back out natural gas and to use natural gas, or a fraction of that natural gas, to produce hydrogen. So, you have to think of it in a systems way, which way is the best way to go forward. And different circumstances will determine which way forward is the most appropriate, but indeed, both of those routes would effectively get efficient production of hydrogen, and can effectively reduce natural gas usage by increasing the use of indigenous coal, for example.

You mentioned nuclear, and there are two routes to using nuclear to produce hydrogen. One of them is using the heat from nuclear—thermochemistry. That is really rather still a fundamental development process, and is many years from practical application. The other one is through electrolysis—effectively, again, using electricity to produce hydrogen, just as you might, with a renewable source, use electricity to produce hydrogen. Overall, it may be more efficient, from an energy systems point of view, from a national point of view, to put that electricity directly into the grid to back out the use of hydrocarbons, to use to produce the hydrogen. So it's really a systems issue. Each of those routes you can use directly to produce the hydrogen, but it may be more efficient to use, indirectly, the hydrocarbon, and to back out the overall use.

Senator ALEXANDER. Thank you very much. Mr. Faulkner, in the 1990's, the Department of Energy sponsored the partnership for the next generation vehicles with the idea, I think, of trying to accelerate the use of the hybrid technologies, and now we are—we have a FreedomCAR initiative to encourage the fuel cell vehicle. A National Research Council Report on the hybrid program in the 1990's was critical, because it was limited to just three manufacturers of cars, headquartered in Detroit, only two of which are headquartered in Detroit today.

I wonder if you have given consideration, in the Department of Energy, to involving all of the companies in the world that are working with fuel cell technology, including especially those who do domestic manufacturing? When I visited the hydrogen fuel cell filling station in Yokohama, there were at least seven—maybe there were nine—SUVs there from manufacturers all over the world. And if we want to make progress in this country on cleaner air, global

warming, energy independence, then we have to think about all of the cars that are produced in the United States and sold in the United States and not just by the two companies that are still headquartered in Detroit.

So, what are your plans for including all automobile companies, at least those that are engaged in domestic manufacturing in the United States, in the hydrogen fuel cell initiative?

Mr. FAULKNER. Senator, could I make a comment, before I get started on that, on the natural gas question that you asked Mr. Bentham at the table?

Senator ALEXANDER. Sure.

Mr. FAULKNER. Natural gas is seen as a transition to other sources of hydrogen production. We would eventually like to get to renewable sources of hydrogen, renewable sources for hydrogen production, and I think the Energy Information Administration has projected that that transition would only increase natural gas demand by less than 3 percent by 2025.

In response to your question about foreign auto makers, we're not averse to working with, to building R&D partnerships with foreign auto makers, those in Asia. I think we're looking to develop relationships with all auto makers, if we can share fully and actively in research and development. We're keeping an open mind on that. Our currently relationship is with the USCAR, that's the Big Three in Detroit now—DaimlerChrysler, GM and Ford.

Senator ALEXANDER. Excuse me, Mr. Faulkner, where is DaimlerChrysler headquartered?

Mr. FAULKNER. It's in Europe, sir. That relationship with USCAR, that entity requires as a condition of its membership that a foreign auto maker do major power train research and development here in the United States, and DaimlerChrysler is foreign, and it does do that.

Meanwhile, foreign auto makers can still participate in the whole range of meetings, helping to develop documents, participate in solicitations, subject to U.S. laws and regulations. Hyundai is in our learning demonstration program, Toyota is doing "work for others"—a technology transfer tool with Savannah River Lab in hydrogen storage. So I think the bottom line is, we're open to that, but we do have this formal relationship with USCAR, sir.

Senator ALEXANDER. Well, thank you, Mr. Faulkner, maybe we'll come back to that. I mean, we're very proud of General Motors, for example, which is why they're here today, and they make cars in Tennessee. We're very proud, also, that Nissan makes cars in Tennessee as well. In the energy bill, we considered this question twice, and decided to support domestic manufacturing, which meant all cars and vehicles that are produced in the United States by members, so I hope you'll consider that.

Senator Dorgan.

Senator DORGAN. Mr. Chairman, thank you very much. Mr. Faulkner, some while ago, I guess 3 or 4 years ago, when the Department of Energy representatives were in front of the committee, I asked them if they were doing some work to look forward 50 years, for example, to evaluate in 50 years what we aspired to have happen with respect to the supply and the type of energy we used. The reason I asked that is that we talk about Social Security 50

years, and 75 years and 100 years, and I was just curious, what is our strategy, and what is our aspiration with respect to the kind of energy in our energy future that leads back to 50 years. The answer, at that point, from the Department of Energy was, "No, we really—we don't have a road map for 50 years from today." So that's what got me kind of interested in the notion of trying to figure out how we move toward alternatives. Because I think, ultimately, retaining this addiction to foreign oil is unhealthy for our country.

Your testimony was well-done and it suggests that the Department now feels like it's committed and really has a significant interest in hydrogen and fuel cell technology—is that a good way to describe where the Department is?

Mr. FAULKNER. Well, sir, the President deserves a lot of credit for his visionary stance in promoting hydrogen fuel cells. Yes, the Department is committed to that, to his vision, and I think we're well on the way to success there.

Senator DORGAN. You're absolutely correct, the President does deserve credit. I did say his initial suggestion was a little more timid than I would be, because about half of it was taken from other funding, and it was about $1.2 billion or so; but nonetheless, it is true that President Bush provided the leadership to say, "Let's step in this direction," and he deserves substantial credit for that, and I think the Congress, and particularly in this conference committee that has now come up with a $3.73 billion authorization, also recognizes that we need to move in this new direction.

Let me ask, Mr. Campbell, Dr. Burns or Mr. Bentham—tell me what you see of the plans in other areas of the world, such as Europe? I've read a lot about what Europe is doing with respect to hydrogen fuel cells, and their aspirations for an energy future; can you contribute some knowledge in that area?

Mr. CAMPBELL. Well, I can give you some information on what we see in Japan. Prime Minister Koizumi has been very aggressive in support of the transition to hydrogen and fuel cells in that country. I'm proud to say that the Prime Minister has a Ballard fuel cell in his official residence, providing hot water and electricity for his home. But he's been very supportive for hydrogen fuel cells for automobiles, and has set a target in Japan to have 50,000 fuel cell vehicles on the road by 2010, and to have 5 million on the road by 2020. Now that's a very aggressive target, far more aggressive than the numbers that we're looking at in this country—and whether or not it's feasible is a different question—but at least they have set out an ambitious agenda for transition to hydrogen fuel cells in Japan.

Senator DORGAN. Mr. Bentham.

Mr. BENTHAM. Yes, I'll add a little bit on what's happening within Europe. A lot of the activity within Europe has so far been driven at both the level of the member states themselves, but also the European Commission, and there is a European Hydrogen and Fuel Cell Technology Platform, which I have the pleasure of chairing, which is bringing together the various stakeholders around Europe to provide strategic overview. I would say that they are still in the process of catching up in terms of the level of development of activity compared to Japan and the United States, but

they have an awful lot of good science, good engineering there. They also have the kinds of fiscal flexibility in terms of the cost of the taxation on vehicles, and the cost of the taxation on fuel to give flexibility to help encourage the path going forward, and they have a projection or a plan, an aspiration to see approximately 2 million vehicles on the roads in Europe by 2020.

Senator DORGAN. Can I go back to you, Mr. Campbell? Tell me again the targets and timetables in Japan.

Mr. CAMPBELL. The targets that have been articulated by the Prime Minister are to have 50,000 fuel cell vehicles by 2010, and 5 million by 2020.

Senator DORGAN. I would just say, in the energy conference report we just passed, I pushed like the dickens to get targets and timetables. They're a little bit squishy, I must admit, but I tried to get them in, in any event. We do have section 811, 100,000 hydrogen fuel cell vehicles in the United States by 2010, and 2.5 million by the year 2020. So I really feel that if you're going to move in a direction, you need to set some waypoints, or some targets and timetables, and that's the reason I kept pushing for that. And, again, they're not—these are not any mandates, but nonetheless, they give us a roadmap of what we're going to do.

Just one additional question. China has about 20 million automobiles at the moment. They've got 1.3 billion people, I believe, and 20 million automobiles. It's estimated they will have 120 million automobiles by the year 2020, so they'll go from 20 million to 120 million in the next 15 years. They're going to want to fuel those vehicles, so just figure what the demand side does on oil, to run gasoline through the fuel injectors or the carburetors. And that's one of the reasons I feel so strongly about what's going to happen to the price of oil with the limited supply and only so much oil under the sand in such a small part of the world. We need to look at all these alternatives. Do you have any notion of what the Chinese are thinking about—we know a little bit because of their CNOOC's approach to buying Unocal, but what else are they thinking about with respect to an auto industry and how they would power that industry? Do any of you know the answer to that?

Mr. CAMPBELL. Senator, I could offer some insight. We have been meeting for some time with the various technical institutes and the Ministry of Science and Technology in China. They have a very aggressive technology development effort on the way in China. There is no place on earth that has a more compelling case for fuel cell technology than China. There's every reason to believe that China will do what they have done with wireless telephone and skip the wire line; they could easily skip the petrol infrastructure and go right to a hydrogen infrastructure. It makes tremendous good sense for China to do that.

Senator DORGAN. I had not thought about that point, but it's a fascinating point, because they're at such an embryonic stage here that they could just create their own infrastructure that is very different for a new type of energy.

Mr. CAMPBELL. That's absolutely right, and frankly, that's what they're thinking.

Senator DORGAN. Just one aside. You also know that one of our U.S. domestic auto manufacturers is suing the Chinese for—they

alleged—lifting the entire production design for a little car that the Chinese are now producing called the QQ, produced by the Cherry Company. One of our companies says that it's simply from a stolen set of designs for a U.S. vehicle. And the Chinese are also launching and ramping up an auto industry for export, aggressive export at the same time, which is just an aside on this entire Chinese issue.

Mr. CAMPBELL. Well, Senator, if I could add, the issue of intellectual property rights in China is a very important one, and a cautionary tale as we begin to engage with the Chinese on an advanced technology like fuel cells.

Senator DORGAN. It's a big issue. And let me just say that testimony of all four of you today has just been excellent, I think it really adds substantially to our knowledge and to the interest in this hydrogen fuel cell economy. Thank you very much.

Senator ALEXANDER. Thank you, Senator Dorgan.

We welcome Senator George Allen. I will call on him in just a minute.

On your point, Mr. Campbell, and yours, Senator Dorgan, about China skipping a generation, and skipping over a distribution system, in effect, Japan did that with steel after World War II. All of their steel mills were destroyed, so they built a whole new generation of steel mills, creating a lot of problems for us here in the United States because we had old steel mills.

Senator Salazar.

Senator SALAZAR. Thank you very much, Chairman Alexander and Ranking Member Dorgan, for holding this important question.

My question I think refers to you, Mr. Faulkner. We spent a lot of time here over the last 6 months working on this energy bill, and I think it's a good step in the right direction. Perhaps not the perfect bill that any one of us would have wanted, but that's the nature of compromising. But I'm hopeful that we will have a bill that the President will sign here soon.

There's a lot of investment in here with respect to hydrogen, billions of dollars in terms of the fiscal impact coming out of this energy bill. One of my scientist friends wrote me this note with respect to the hydrogen. He says, "I don't like the bill where it speaks specifically with respect to hydrogen. The hydrogen economy is still mostly a theory. There are many technical hurdles to overcome if hydrogen transportation and production is to be used on a large-scale basis. The demonstration of hydrogen-powered vehicles generates press, but the cost of these vehicles is near $1 million, so it's almost hypocritical to say that we're going to get there with regard to the goals that have been articulated by the Department of Energy and by the President." So my friend might go as far here as to tell me that that's what I ought to do is feed opposition to the conference committee report, which I will not do. But will you respond to that? Because I think that with a lot of members of the public, you start talking about the technology of hydrogen fuel cells, and that's sort of their response. It's sort of pie in the sky, when we're talking about the kinds of timelines that DOE has articulated, and Mr. Campbell, the goals that you said you thought were reasonable. How do we go about explaining to the public that this is, in fact, something doable?

Mr. CAMPBELL. That's a good question, sir. Well, first of all, I don't think that anyone—at least I wouldn't sit here and say I'm 100 percent certain we're going to reach all of the targets we've laid out, that's not the nature of research, but we feel confident that we've laid out with our partners a good research plan. The President laid out a 5-year program, and we're already starting to talk internally about going beyond that.

I understand the sentiment. A couple of the sentiments embedded in what you've said, one of them is, "This is so important, the percentage of imported oil that we use is going up, so why can't we go faster?". Well, I think the nature of research is, sir, that unfortunately it may be unpopular to say, but sometimes you can only go so fast. You can't—you know, fundamental research doesn't occur overnight, and breakthroughs are impossible to predict ahead of time. But I think we do have technical hurdles in here, and I think that we're on a good pathway now. This program is, from a government standpoint, one of our—it's reviewed and dissected and overseen by a lot of different people, it's got a good partnership program, and I think the other thing I would probably say is, if you have to get started today to reach long-term goals, what if we had started this 5 or 10 years ago, how much further along would we be? So we have to start sometime, and we are making progress, as I laid out in my testimony. I won't go through any of that right now, but I think we have a good target, we have a good plan and we have a good partnership.

Dr. BURNS. Senator, if appropriate, I'd like to make a comment on that from General Motors' perspective. We've publicly stated that we are designing and validating a fuel cell propulsion system by 2010 that can go head-to-head with the internal combustion engine. I think it's one of these phenomenon—an "if we build it, they will come" kind of a mindset, like a Field of Dreams, in a sense.

I have the honor of leading a team of researchers and scientists in our laboratories working on this technology daily. They're creating the state-of-the-art. I'd be more than happy to invite your friend to our laboratory to show him at least what I can show him without violating our own confidentiality, we're so confident that these targets can be met. Certainly if your friend is spending time in state-of-the-art fuel cells facilities, that's great. He certainly may have reached different conclusions from the science than we're reaching. We don't see anything right now that says it can't be done.

And so we just need to keep moving aggressively toward the goals we've set for ourselves to get this propulsion system validated, show the world that it is, indeed, possible to have a propulsion source that has one-tenth as many moving parts as an internal combustion engine. Keep in mind that an internal combustion engine is a pretty complicated mechanical device. It marries up with a transmission and a mechanical drive train and a fuel system, and controls an emissions system, exhaust systems and all of that. We're talking about, conceptually, a much simpler pile of parts to make the vehicle move, and all we have to do is put one fuel on it—hydrogen. And it's immensely scalable from small applications to large applications.

We're doing this for business reasons, and if we can see that possibility, our competitors can see that possibility. Certainly, we believe we need to do unto ourselves before others do unto us. So I think it's possible, I'd be happy to share some insights with your friend if he or she is interested in doing that.

Senator SALAZAR. Let me just say this comment to both Dr. Burns and Mr. Faulkner: I've appreciated your testimony here, and I think it's compelling that you can make the statement, as you just did, Dr. Burns, that in 5 years from now we're going to be in the position where you, from a General Motors perspective, can say that we can, in fact, replace the internal combustion engine. That's an incredible statement to make, because we're not talking about 50 years out, we're not talking about 25 years out, we're talking about 5 years out.

A question for you, Mr. Faulkner: for someone like me, learning about the hydrogen fuel economy, where is it within the DOE complex that someone like me or my fellow Senators or others might be able to get a good on-the-ground briefing with respect to what you're doing with respect to the R&D and milestones? It probably would not be at the National Fuel and Energy Lab in Golden; or would it be?

Mr. FAULKNER. Well, NREL plays a key role in this issue, sir. You could also probably find quite a bit on the website and we'd be willing to come up and talk to you personally. We have a hydrogen posture plan, we have a hydrogen vision and roadmap. These are developed not just by government, but in a partnership with technical targets, timelines——

[The following was received for the record:]

The following organizations may be visited to provide Senator Salazar with "a good on the ground briefing" of hydrogen and fuel cell technologies related to the Department of Energy's (DOE) Hydrogen Program.

NATIONAL RENEWABLE ENERGY LABORATORY (NREL), GOLDEN, COLORADO

A tour can be arranged to provide an overview of key research activities and milestones related to hydrogen production, storage, fuel cells, and technology validation as well as cross-cutting areas of systems analysis and safety, codes, and standards. NREL is the lead laboratory in the Center of Excellence in carbon-based materials for hydrogen storage. The tour will include laboratory facilities as well as wind turbines, solar photovoltaics, and electrolyzers to produce hydrogen.

Contact: George M. Sverdrup, Ph.D. Technology Manager, Hydrogen, Fuel Cells and Infrastructure Technologies, National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, CO 80401-3393; Tel—(303) 275-4433; Mobile—(303) 919-8762; Email—george__sverdrup@nrel.gov.

GENERAL MOTORS CORPORATION (GM)

Tours may be arranged at GM's facilities in Warren, Michigan, and/or in Honeoye Falls, New York. The Honeoye Falls site is preferred because that is the location where most of the GM fuel cell research takes place. Laboratory facilities related to hydrogen and fuel cell technology development as well as prototype hydrogen fuel cell vehicles may be seen. GM is a partner in DOE's "learning demonstration" effort to develop and demonstrate hydrogen fuel cell vehicles in real world operating conditions and has several fuel cell vehicles in the DC area.

Contact: Keith Cole, Director, Legislative and Regulatory Affairs, General Motors, Suite 401, 1660 L Street, NW, Washington, DC 20036; Tel—(202) 775-5040; Email—keith.cole@gm.com.

SHELL HYDROGEN

Shell Hydrogen, set up in 1999 to develop business opportunities in hydrogen and fuel cells technologies, is a global business of The Shell Group with headquarters

in Amsterdam, the Netherlands, and regional bases in Houston and Tokyo. A tour may be arranged to visit the first hydrogen fueling station in Washington, DC, on Benning Road.

Shell is partnering with GM in DOE's "learning demonstration" activities to develop and demonstrate hydrogen infrastructure technologies for fuel cell vehicles.

Contact: Sara B. Glenn, Washington Counsel, Shell Oil Company, Government Affairs, 1401 Eye St., NW, Suite 1030, Washington DC 20005; Tel—(202) 466-1400; Email—sara.glenn@shell.com.

UTC POWER

A tour may be arranged at UTC Power in South Windsor, Connecticut, to view laboratory facilities as well as stationary fuel cell power plants and prototype fuel cell vehicles. Technology development facilities and test stations may be seen for a range of fuel cell applications, including fuel cells developed for NASA's space program (Apollo, space shuttle, etc.). UTC is a leader in fuel cell technology, with more than 40 years of experience, and provides on-site power systems for commercial and industrial markets, with fuel cell power plants in 19 countries.

Contact: Judith Bayer, Director, Government Business Development, UTC Power, 1401 Eye Street, NW, #600, Washington, DC 20005; Tel—(202) 336-7436; Email—Judith.bayer@utc.com.

In addition, the DOE Hydrogen Program Manager is willing to visit Senator Salazar's office anytime to provide an overview and details of the DOE hydrogen program. An appointment may be coordinated through:

Jennifer A. Sollars, Advisor, Legislative Affairs, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, 1000 Independence Avenue, SW, Washington, DC 20585; Tel—(202) 586-0440; Email—jennifer.sollars@ee.doe.gov.

Senator SALAZAR. Let me ask you—this is a personal question with me. I visited NREL for about 3 hours. And I know that Senator Dorgan and others have been leading the charge with respect to ethanol, and I'm very proud of the fact that I'm one of the partners trying to push us in that direction. I was very impressed with what was happening with cellulostic ethanol research and some of the other activities going on there at NREL. It makes a big difference when you actually see these things on the ground and in the laboratory. So my simple question to you is, where can I get a similar kind of review? Do I have to go to GM? Would you be able to do something for me if I come out and visit your plant?

Dr. BURNS. Could you just repeat the very last part of your comment? I'm sorry.

Senator SALAZAR. I'd like to have the same kind of tour that I essentially had at NREL at someplace, either the DOE or maybe with some of the private sector partners, just to get a good sense of what you're talking about. Because what you're talking about, again, is revolutionary, if you are talking about replacing the internal combustion engine within a 5-year timeframe. That is just an incredible statement to make, and I want to get some kind of raw information on that.

Thank you very much for your testimony.

Senator ALEXANDER. Senator Allen.

Senator ALLEN. Thank you, Mr. Chairman. Thank you and Senator Dorgan for holding this hearing. Hopefully by the end of this week we will have passed an energy policy for this country that's gone through a lot of stalling, a lot of stalled-out vehicles on getting that thing done, but we're finally, I think, going to get it done.

And I'm one who feels that this is a very important measure for our country for a variety of reasons. One is our national security, since we're far too reliant on foreign sources of energy. Second, it will be important for jobs. Whether there are jobs here presently, or jobs in the future, some will be in this new area of technology.

And third, it's support for our competitiveness. We all need affordable, clean—if we can make it as clean as possible—energy, whether it's for transportation, for electricity, a variety of other functions. I'm one who's always embraced advances in technology and the hydrogen aspect of this measure, the incentives for it, as well as the research and development. I think is very important. And rather than being on a petroleum-based economy, or the internal combustion engines, to the extent that these new technologies can give us an affordable, reliable energy, that's important for our competitiveness. And I do believe that our energy bill does move the United States closer to this goal, and particularly the hydrogen fuel initiative, which brings in Federal agencies, universities, the private industry and others all working together. And I think the Generation IV nuclear reactors producing hydrogen fuel that these vehicles of the future will need is a good idea as well.

Now, let me ask you all some questions. I'm sorry I was late, I had to be on a conference call on some other matter. This speaks to Mr. Burns and Mr. Campbell. One of the aspects of this whole energy bill is that we need more production of natural gas here in this country, which is important not just for our own fertilizer, chemicals, plastics, wood forestry products, tires and all sorts of manufacturing. I think one of you said something to the extent that we're going to have hydrogen fuel cells made, ultimately, derived from natural gas. Did one of you say that this would only affect 3 percent of the natural gas demands of this country? Because we have such great demands, and skyrocketing prices.

Mr. FAULKNER. I said that, sir.

Senator ALLEN. Okay.

Mr. FAULKNER. I was quoting from the Energy Information Administration, an independent arm of the Department of Energy, that in that transition, we're looking now at natural gas as the first step in the transition to hydrogen production from a number of sources, hopefully renewable in the end.

Senator ALLEN. All right, so it's 3 percent. Now, let me ask you this, you mentioned——

Senator DORGAN. He was saying they wouldn't ultimately use natural gas, but they would use natural gas in the interim as a step to other fuel stops. I think that's what he was saying there.

Senator ALLEN. All right. But with our high demand for natural gas and our limited supplies, you're saying that this would take up 3 percent of the present natural gas supply, or this is what you were quoting from, Mr. Faulkner?

Mr. FAULKNER. I believe what EIA said was, it would only increase natural gas demand by 2025 by less than 3 percent.

Dr. BURNS. I may be able to help with that a bit. We've done an analysis that if you were going to put 10 million fuel cell vehicles on the road in the United States, recognizing there's over 200 million vehicles in the United States today, but to get this started, when you are thinking about the first 10 million, that that would increase the demand for natural gas by 2 percent, so that's a calculation that we've done.

Our view is that hydrogen can come from so many different sources. That's what we like. So we don't think in terms of relieving 98 percent dependence on petroleum and shift that all the way

over to 98 percent dependence on some other energy pathway. In fact, what we'd like is to get a little bit from a whole bunch of sources.

Senator ALLEN. All right. Mr. Faulkner mentioned something about renewable hydrogen; is that what you're talking about, or are you talking about hydrogen from some other sources, from gasoline, from what other sources?

Dr. BURNS. We would certainly like to see it come from coal. It can come from nuclear in the form of electricity, electrolyzing water, hopefully down the road, nuclear in terms of direct hydrogen creation, renewable—wind, geothermal, solar, biological sources—whatever the local economy sees as their strength, as the most cost-effective way to create the hydrogen in an environmentally friendly way is the one that should win out in the marketplace, and we'd like to see all these pathways competing on a daily basis for our customers' energy dollar.

Senator ALLEN. All right. Now it comes down to cost, Mr. Campbell. I was reading your testimony where you actually have hydrogen fuel cell vehicles, mostly buses, in different places around the world. Mr. Burns, you have Senator Salazar all fired up and he's probably thinking, "Hey, we're going to have fuel cells in 5 years in our vehicles," but regardless, what is the operating cost difference right now, because affordability does matter? What is the operating cost difference from having the propulsion from fuel cells versus conventionally powered? And I realize there can be a cost difference, I'm just talking about absolute dollars or yen out of the pockets, and then you can say, well it costs a little bit more, but look, we don't have any of the emissions, the by-product is water. But if you could share that with us. If you've said it already, I'm sorry, but I'd just like to know what that is.

Mr. CAMPBELL. Well, thank you, I'll try to answer your question, Senator. A couple of ways to look at it—if you look at the energy cost, various studies have reported—and Mr. Faulkner has better data on this than I do, probably—that the energy cost per mile driven for hydrogen used in a fuel cell is actually lower than the energy cost per mile driven in a piston engine car. So the cost of operation, in other words, fuel costs, as one component of the operating costs should actually be less for a fuel cell vehicle.

Senator ALLEN. Is it less in these situations, these programs you're involved in?

Mr. CAMPBELL. Yes, if you can buy the hydrogen at $2 to $3 a kilogram, yes.

Senator ALLEN. Well, can you?

Mr. CAMPBELL. I think the station that was recently opened in Washington, where the President was pumping gas, was $4.50?

Mr. BENTHAM. That's about right. A lot of the cost, ultimately, in hydrogen is not the fuel itself, but it's the cost of distributing the fuel and having the facilities to bring that forward. Clearly, as you go into an established market, those costs come down—you don't have to distribute as far, you don't have to have the same kind of network optimization issues that you would have when you're only doing a demonstration. So we have a line of sight that brings us to that point, that in a fully developed market, the supply of hydrogen, the price of hydrogen per mile traveled would be of

the same order as it currently is with gasoline. Clearly there are a number of steps toward that point, but in a fully established market that is the goal, and we have a line of sight on that.

Senator ALLEN. Well, that's very encouraging, because some of the concerns we've had—I'm very much in favor of this hydrogen economy, so to speak. The concern is you use so much energy just to create the hydrogen that it increases the cost of hydrogen. And while there's the environmental benefits from it, you may not have all of the environmental benefits, unless the way that you're actually going through the entire process is also a clean process. And then, ultimately, you get the final price. To the extent it ends up being a distribution issue, that's something that does have to be solved, but that could be more easily solved for fleets, as Mr. Campbell's company is doing, where you know the defined number of miles that they'll be driving and coming back to that distribution center. Ultimately, that's some of the problem that we've found over the years in, say, natural gas-powered vehicles, they simply don't have Shell gas stations or Wawa's or Flying J's or whatever one has all over. So that's very, very encouraging that you actually believe that the actual cost of the fuel, notwithstanding the distribution system, is the same.

Let me ask this final question, Mr. Faulkner. Mr. Chairman, if I may. I'm aware that this is another alternative, and I'd like to get your view of this, and this is the Solid State Energy Conversion Alliance within the Department of Energy that's leading efforts to commercialize what is called low cost solid oxide fuel cells for application in industrial uses, households and military applications. Is there any effort to utilize this solid oxide fuel cell technology in the transportation sector? If you're aware.

Mr. FAULKNER. If I could, if you'll let me, I'd like to make one point on the conversation you just had about natural gas.

Senator ALLEN. Yes.

Mr. FAULKNER. One reason we won't use as much natural gas as you may think is that all the different pathways for producing hydrogen for fuel cell vehicles would use less energy, total energy than the gasoline internal combustion engine. As you noted, I think we would use more energy, maybe, up front, producing the hydrogen, but you gain a lot more on the back end because the fuel cell vehicles are more efficient than internal combustion engines. The SECA, the acronym for that, I'll have to get you something on the record, sir, I'm not as familiar with that as I probably should be.

[The following was received for the record:]

Solid oxide fuel cells (SOFCs) operate at high temperatures (650-1000°C) therefore they take a long time to start up. They are much less suited for passenger vehicle applications than direct-hydrogen polymer electrolyte membrane fuel cells (PEMFCs). PEMFCs operate at lower temperatures (80°C), can start up quickly, and are very good at load-following.

SOFCs are proposed for stationary applications where steady-state performance and a long start up time are acceptable and where the high quality heat can be used for cogeneration applications. To accelerate development of SOFC technology, the DOE Office of Fossil Energy's Solid State Energy Conversion Alliance (SECA) focuses on SOFC research and development (R&D) for stationary applications such as centralized power plants and distributed generation applications (e.g., 10-100 kW). FY 2005 funding for the SECA program was $54.2M.

SOFCs have some limited transportation applications such as auxiliary power units in heavy-duty trucks to minimize diesel engine idling, thus saving oil and providing environmental benefits. DOE's Office of Energy Efficiency and Renewable En-

ergy has a very small R&D effort ($750K in FY 2005) on solid oxide fuel cells for transportation applications. This effort includes projects to design, develop, and perform in-vehicle demonstration of diesel-fueled SOFC auxiliary power unit systems configured to provide electrical power for the sleeper cabs in heavy-duty trucks.

Senator ALLEN. Are any of you aware of this concept of the solid oxide fuel cells?

Dr. BURNS. Yes, we are.

Senator ALLEN. Could you comment on that and any of their applications to transportation?

Dr. BURNS. There are a couple of different classes of fuel cell technology. We use what's called a PEM fuel cell, a proton exchange membrane. You mentioned the solid oxide. The latter is really more conducive for auxiliary power. So let's say you have a large truck that you're using for transportation of freight, and it pulls into a rest stop and it wants to generate power for the vehicle to run its accessories. We think that's a nice application for this solid oxide, but the industry pretty much started down, I guess it was about a decade ago, when we were looking at challenges like power density, and the extreme range in which you have to operate automobiles. We concluded that the PEM technology had the most promise for transportation applications, certainly for accessories and other things, for military uses. We think the latter technology has promise.

Mr. CAMPBELL. If I could add to that, just to explain the difference between a solid oxide and a PEM fuel cell. A PEM fuel cell operates at low temperatures—85 degrees Celsius—so it starts up very quickly and it has great load-following capability. So it's really good for an automobile with lots of transient behaviors. A solid oxide fuel is a very high temperature device—800, 900 degrees Celsius. So it takes a long time to warm up, and you want to run it for a steady state over long periods of time. So it's great for distributed generation, it's not very good for standby or backup power, it's not very good for automotive. So it may be good for a locomotive-type application, for a rail application, but not for a car or a truck.

Senator ALLEN. Mr. Bentham, you seem to know what all this is, too. Do you have any comment on the solid oxide?

Mr. BENTHAM. Just to re-emphasize the point that Mr. Campbell was stating, that we've seen the solid oxide fuel cell as being very good technology for those stationary power applications, where you want something that will run for 50,000 hours, nonstop, but you don't want to be starting it up and shutting it down every few minutes.

Senator ALLEN. Thank you, all four of you gentlemen, and thank you, Senator Dorgan, also and our chairman. Thank you for your answers and insight. I'm very much looking forward to working with you all and we can all use your insight and knowledge. And I think that people ought to be encouraged about the future. I think we'll work on a bipartisan basis with the incentives to make sure that this research and development goes forward with the proper incentives also for the private sector, the marketplace. I think it makes great sense. I'm not one who likes dictates or mandates, I like carrots rather than sticks, and you've given me some good evidence here to continue with that advocacy. Thank you all.

Senator DORGAN [presiding]. Senator Allen, thank you very much. The Chairman had to leave, and asked me to adjourn the hearing as the ranking member. Let me just make an observation. The reason that I asked you to yield for a moment is I think that natural gas will certainly be used as a source of hydrogen, but I think it's also the intention of virtually everyone to find sources of hydrogen from many other areas. But initially, I think, as a start-up, you rely more heavily on natural gas, and the question you asked on that is a perfectly important question.

I also think that in every area of this type there are the skeptics, that is, people who believe that this science doesn't exist, or will never exist. And then there are the incumbents, in whose interest it is never to change what is. So I understand that. I happen to be a big fan of ethanol, I like growing energy in our fields, and pulling up to a service station and saying, "Fill it up with corn." I kind of like that approach. But I also know that the incumbent providers of our fuel have done all sorts of studies saying that it takes more energy to produce ethanol than you get from ethanol, which is patently nonsense. The studies are just fatally flawed. But nonetheless, it ricochets around the Internet, and the same will happen with respect to hydrogen. We will have people continue to say, "This can't work, it won't work, it doesn't add up," and I understand that. I know my colleague from Virginia understands that.

I am encouraged by your comments as well, because I think there's a sizable group of us here in Congress who are determined to try to chart a different course so that we have greater capability to control our own destiny, rather than have the destiny of our country and its economy controlled by someone else, somewhere else. I just think this is a very important issue, and I think your contribution to that body of knowledge today is very important.

I'm pleased to work with the U.S. Fuel Cell Council and the Natural Hydrogen Association and many others who are engaged in this work. There are a lot of interests engaged in this, as well as the Department of Energy, and having the benefit of all of their combined knowledge is very, very important, as we proceed to make what we hope is good policy. And I do think if, at the end of this week, the President signs this conference report on energy, if he does that, the hydrogen title, dealing with hydrogen fuel cells both in that title and also in the vehicle title, authorizes about $3.73 billion. It's a huge step forward in an exciting new direction, and that will be good news for our country. With that, we thank you all, and we adjourn the hearing.

[Whereupon, at 4:22 p.m., the hearing was adjourned.]

APPENDIX

Responses to Additional Questions

Responses of Jeremy Bentham to Questions From Senator Domenici

Question 1. Other nations also support programs in hydrogen and fuel cell development. Is the United States government coordinating effectively with other governments in developing codes and standards for hydrogen and fuel cell vehicles? Please explain.

Answer. The U.S., through efforts led by DOE and NREL have effectively shaped the hydrogen codes and standards process in the U.S. and helped in the organization of global efforts through the International Partnership for the Hydrogen Economy (IPHE) as well as other existing channels such as U.S. TAG in the ISO arena. The impact of these efforts have helped identify areas needing research and data generation and have allowed multiple stakeholders and organizations to efficiently communicate and share information.

Question 2. Your testimony addressed the importance of public awareness and understanding and the need for government actions to foster such understanding. Are there other nations who have model efforts in this regard? What can the United States learn from public education in other countries?

Answer. One major point should be made at the outset: No other country has the scope or the market to serve as a template for a program on the scale of U.S. needs.

That being said, Iceland, a country about the size of Kentucky, with a population of nearly 300,000, is highly dependent on imported sources of energy. As such, the government of Iceland has taken the step of establishing a multi-stakeholder (industry, government, NGO, etc.) initiative group to develop hydrogen strategies for enhancing public awareness in Europe as part of the European Hydrogen and Fuel Cell Technology Platform (HFP).

Responses of Jeremy Bentham to Questions From Senator Bunning

Question 1. The biggest hurdle to full implementation of fuel cell vehicles has often been cited as the creation of the refueling infrastructure. Estimates peg the cost of such infrastructure at $10 to $15 billion. Where do you envision the funding coming from? What do you think should be the role of the federal government?

Answer. As noted in the testimony, we don't believe the infrastructure is the biggest hurdle. We believe that hurdle will be the widespread availability of mass-produced, customer-pleasing hydrogen vehicles. Focusing on the isolated question of fuel supply infrastructure, however, we believe that fuel supply can be achieved on a fully commercial basis once there is sufficient demand to ensure that facilities are reasonably utilized.

For a limited period, therefore, some publicly funded, market-based initiatives will be necessary to support first-phase investment from industry. Federal and state policies will need to recognize this. Overall, and in the long term, the bulk of the investment will come from business.

Question 2. What specific programs and agencies, other than the Department of Energy and the Department of Defense would you like to see included in developing the federal government's hydrogen policies?

Answer. The Department of Agriculture could be a leader in sponsoring programs exploring the adaptation of fuel cell and hydrogen technology by Agribusiness. The government also sets standards for storage and transportation and the relevant departments should be involved in maximizing public safety. Agencies such as NASA have a great deal of hydrogen experience. All of these have practical and regulatory experience with hydrogen questions. All that will be involved eventually should be involved now.

Question 3. The price of hydrogen is also a potential hurdle to widespread implementation. Given the efficiency advantage, what price range do you believe hydro-

gen needs to reach to be competitive? What policies would you recommend to reach that goal?

Answer. Customers will make decisions on vehicles taking into account many factors including vehicle prices, fuel prices, and safety, among others. We believe the development of the FC vehicle industry will be best stimulated by having the fuel price per mile-driven, comparable to that the familiar gasoline fuel.

Where there are many complex questions of technology and motorist acceptance to be answered, it is our aim—and expectation—to be able to develop a cost position comparable to gasoline. Fuel taxation policy both for hydrogen and traditional fuels will play a role in shaping the price range that customers will accept.

When the discussion widens beyond customer acceptance, there are some facts to consider. While 50 million tons of hydrogen are produced around the world each year, for industrial use, hydrogen is not yet a commodity in the sense natural gas or coal is. Its production and use are restricted to isolated regional industrial complexes with minimal national or international trade.

Apart from limited demonstration fleets, it is not yet used as a fuel for vehicles, so no retail "market price" for hydrogen fuel exists. Once hydrogen becomes a large-scale commodity, that will change. We expect it will then move to direct comparability with gasoline. As such, it would be economically competitive.

The chief variable, apart from taxes, would be the manufacturing source. If hydrogen largely comes from conventional, low-cost, natural gas reforming, costs may remain fairly stable. We believe, with the gradual introduction of renewable/sustainable hydrogen increasingly added to the mix of sources, costs could still be relatively stable thanks to R&D, growing economies of scale, and expanding commercial application.

Question 4. How do you see hydrogen technology affecting job growth? What are your projected estimates for job growth related to transitioning to this energy source?

Answer. The degree of job creation will be largely a factor of which country develops the definitive technological next-step first. Shell has a high degree of confidence that hydrogen and fuel cell technology could come in any of a number of forms and will come in at least one. The main question of both job-and wealth-contribution is whether the fuel cells and FCVs come *from* the U.S. or *to* the U.S.

If the advances come from the U.S., hydrogen and fuel cells will represent major technological opportunities leading to the creation of significant new jobs in many companies in many industries.

Particularly significant job growth may occur as revolutionary fuel cell engines and electric drive systems replace steel engines, transmissions and mechanical drive components.

A hydrogen economy will not happen overnight. It will be phased in as other systems phase out. Both the phase-in and the phase-out will be providing some level of new jobs. For example, new vehicle fuels will require new stations and means of transmission of bulk quantities of fuel for storage and resale. Naturally, new R&D will be required to support jobs and maximize the opportunities presented by the new energy source.

These and other possibilities can develop in the U.S. if the right environment is fostered. But it should be noted that the U.S. is no longer the only country with an R&D infrastructure able to develop the next generation of products, or a manufacturing system able to support this scope of change, or a steady mass demand for the new products that will be created. In today's global market, other countries that unite cheap labor, multiple gas and coal hydrogen sources, and aggressive technical development pose a threat to our economic leadership that really didn't exist in recent decades.

Question 5. Do you envision a hydrogen-refueling infrastructure based on hydrogen pipelines or based on on-site hydrogen production?

Answer. We believe the appropriate refueling infrastructure will be driven the local market circumstances such as the density of local demand, the degree of urbanization, the availability of land, etc. It will also be influenced by the most economical locally available primary source of hydrogen manufacture, (e.g., coal, natural gas, etc.), and the degree to which CO_2 needs to be captured and sequestered.

Finally, it will be influenced by the need to support the development of a hydrogen pipeline transportation and storage network if that is competitive with local availability of hydrogen fuels from local sources.

The optimal infrastructure will be a mix of different approaches driven by these various local market conditions.

Question 6. Do you see hydrogen technology taking off in certain geographic areas of the country at a faster rate? How do we ensure that fuel cell technologies penetrate rural areas of the country?

Answer. We anticipate that the earliest markets for fuel cell vehicles and hydrogen will be California and the Northeast U.S. due to the high population and vehicle density, high concentration of early adopters, and receptive state governments. Shell Hydrogen demonstration projects—already underway—and our planned Lighthouse Projects are focused on these two early markets.

Given the need of vehicle providers to build up a service network, and given the economic importance of facility utilization to fuel providers, it is important to encourage concentrated activity in major urban centers during the first phase of the industry development.

Rural customers, may well, however, choose fuel cell technology for distributed electricity generation from a very early point.

With respect to the hydrogen fuel penetration of *rural areas*, it is worth noting that 100 years ago, the auto fuel industry was starting from an effective baseline of zero. Yet within 20 years, there was scarcely a small town in rural America without the representation of at least two to four brands of gasoline. It seems safe to say, the penetration of new fuels today will proceed at least as fast as the penetration of gasoline did in the conditions of the early 1900s.

RESPONSES OF DENNIS CAMPBELL

Question 1. In the FreedomCAR partnership, clearly both fuel cell manufacturers and automobile manufacturers must work closely together. Is that partnership structured in a way that representatives of both of these industries can be at the table together, and collaborate effectively? What are the strengths and weaknesses of the current partnership structure?

Answer. The FreedomCAR partnership continues to play a central role in the commercialization of fuel cell and hydrogen technology for the transportation sector. The partnership's effectiveness resides in its model of public-private collaboration, which enables members of industry, DOE, and the national labs to work together toward the shared vision of the hydrogen economy.

The membership of the partnership—Ford, DaimlerChrysler, GM Corporation, BP America, ChevronTexaco Corporation, ConocoPhillips, ExxonMobil Corporation, and Shell Hydrogen—effectively captures the major automotive and energy supply companies involved in the transition to the hydrogen economy in the United States. It does not, however, provide for representation for automotive fuel cell manufacturers.

Reflecting the highly interdependent relationship between the fuel cell, the corresponding system that enables it to power a vehicle, and the vehicle design itself, the FreedomCAR partnership could be strengthened by including relevant automotive fuel cell manufacturers in a formal advisory role capacity. This addition will allow DOE to more accurately identify, enable, and monitor progress toward key technical targets for the automotive fuel cell.

Question 2. In the last six years, fuel cell power has increased by a factor of seven. Do you believe we can continue to make such rapid strides in size and efficiency, or are there limiting physical or technological parameters on the horizon?

Answer. Earlier this year, Ballard released a roadmap that provides milestones by which we will measure progress toward the goal of developing commercially viable fuel cell technology by 2010. Power density is one of the four areas of measurement, and we are on track to meet our target for 2010 of 2500 watts/liter for the fuel cell stack.

As our roadmap indicates, we do not expect power density for the automotive fuel cell stack to increase at a rate equal to that previously achieved. Importantly, however, similar gains in power density are not required to support the development of a commercially viable automotive fuel cell stack.

Lastly, the efficiency ratio of the fuel cell to internal combustion engine is approximately 2.4 and is not expected to increase dramatically.

Question 3. What specific programs and agencies, other than the Department of Energy and Department of Defense, would you like to see included in developing the government's hydrogen policies?

Answer. The fuel cell provisions in Title XII (*Vehicles and Fuels*) and Title XIII (*Hydrogen*) of the National Energy Policy Act of 2005 can make an important contribution to the current public-private sector effort to accelerate the hydrogen economy. These programs should be fully funded and implemented.

Federal and State Procurement of Fuel Cell Vehicles and Hydrogen Energy Systems (Title XII, Sec. 782) should be elevated, and its funding levels significantly increased, so that it represents the third major component (following R&D and Demonstrations) of the national strategy for the hydrogen economy.

Broadcast early enough and with sufficiently clear guidelines, a clear commitment by the Congress to make a specific and sizable annual outlay for the fiscal years 2010 to 2015 on federal and state agency procurement of fuel cell vehicles and supporting hydrogen infrastructure would: (a) support early volume production by automotive OEMs and suppliers that is necessary to drive cost down; (b) support the build out of hydrogen fueling stations; (c) draw additional private capital into the sector, and (d) provide the American public with a large scale introduction to the hydrogen economy.

Question 4. The price of hydrogen is a potential hurdle to widespread implementation. Given the efficiency advantage, what price range do you believe hydrogen needs to reach to be competitive? What policies would you propose to reach that goal?

Answer. A recent Stanford University study, the results of which were published in the June 24, 2005 Science journal, is instructive in this area. Reflecting the health and climate benefits of hydrogen generated from wind, the study focused on this renewable energy feedstock. It estimated that the unsubsidized near-term mean cost (<10 years) of supplying wind-generated hydrogen to the end-user is $3 to $7.4 per kg or $1.12 to $3.20 per gasoline gallon equivalent. This places the *mean* cost of wind-generated hydrogen at a competitive $2.16 per gasoline gallon equivalent.

The study found that this already competitive position improves when the societal costs of gasoline—including reduced health, lost productivity, hospitalization, death, and the remediation of polluted sites—are considered. These externalities add $0.29 to $1.80 to the cost of a gallon of gasoline.

The government role in facilitating the supply of cost-competitive hydrogen fuel includes a robust national procurement program (as outlined above) that will serve to kick-start the build out of fueling infrastructure; continued support for R&D programs that increase efficiencies in hydrogen production and delivery; and meaningful tax policies that encourage private sector investment in hydrogen production, distribution, and delivery infrastructure.

Question 5. How do you see hydrogen technology affecting job growth? What are your projected estimates for job growth related to transitioning to this energy source?

A mature hydrogen economy will have profound economic growth implications for the United States. This job growth will occur as wealth that is now transferred overseas for foreign oil is instead invested domestically in a diverse set of energy feedstocks (including clean coal, nuclear, and renewables) that produce hydrogen to fuel our transportation sector.

To date, there has not been a comprehensive analysis of the economic benefits of a hydrogen economy. As such, reliable job growth figures are not yet available.

Question 6a. Do you see hydrogen technology taking off in certain geographic areas of the country at a faster rate?

Factors such as an early commitment to a hydrogen infrastructure and state regulatory policies are likely to determine which areas of the country lead the transition to the hydrogen economy. California, with its hydrogen highway plan and "Zero Emission Vehicles" (ZEV) policies, is an example of one state that is helping to pioneer the commercialization of hydrogen and fuel cell technology. Massachusetts, Rhode Island, Maine, Vermont, Connecticut, New York, and New Jersey have also adopted ZEV regulations while Oregon, Washington, North Carolina, and Maryland are at various stages of opting into a ZEV regulatory regime.

Question 6b. How do you ensure that fuel cell technologies penetrate rural areas of the country?

The level of hydrogen fueling infrastructure will be an important determining factor in the rate of penetration for fuel cell vehicles in a given community. Accordingly, rural communities should actively support and use federal and state programs that promote the development of hydrogen fueling infrastructure, including demonstration and procurement initiatives and tax policies.

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