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ALTERNATIVE ENERGY TECHNOLOGIES

HEARING

BEFORE THE

SUBCOMMITTEE ON TECHNOLOGY, INNOVATION, AND COMPETITIVENESS

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED NINTH CONGRESS

SECOND SESSION

JUNE 14, 2006

Printed for the use of the Committee on Commerce, Science, and Transportation

U.S. GOVERNMENT PRINTING OFFICE

64–909 PDF WASHINGTON : 2011

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov Phone: toll free (866) 512–1800; DC area (202) 512–1800
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ONE HUNDRED NINTH CONGRESS

SECOND SESSION

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ALTERNATIVE ENERGY TECHNOLOGIES

WEDNESDAY, JUNE 14, 2006

U.S. SENATE,
SUBCOMMITTEE ON TECHNOLOGY, INNOVATION, AND COMPETITIVENESS,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Subcommittee met, pursuant to notice, at 10:03 a.m. in room SD–562, Dirksen Senate Office Building, Hon. John Ensign, Chairman of the Subcommittee, presiding.

OPENING STATEMENT OF HON. JOHN ENSIGN, U.S. SENATOR FROM NEVADA

Senator ENSIGN. Good morning, and welcome to today's hearing on alternative energy technologies. I would like to thank Chairman Stevens for allowing this subcommittee to address this important issue.

In 2004, the United States consumed almost 21 million barrels of crude oil and refined products per day. Approximately 60 percent of this oil was imported from other countries. Today, approximately half of our oil imports come from OPEC nations, including Saudi Arabia, Venezuela, Nigeria, and Iraq. Oil supply disruptions pose a threat to our economy and national security, and that threat is compounded by the United States reliance on foreign sources of oil. Over the past 2 years, world oil prices have increased substantially relative to historical levels, and American consumers have paid the price. Crude oil prices hovered between $15 and $25 per barrel for the mid-1980s until 2002. Recently, however, crude oil prices have exceeded $70 a barrel. As the U.S. Government determines how it should address the Nation's expanding energy needs, an examination of various alternative energy technologies is very important.

Just yesterday, on the front page of the *Wall Street Journal* there was an article about China and its increase in energy needs. In Beijing, they have 1,000 new cars per day on their streets, literally tens of millions of new cars over the next several years. And, at that rate, it was at least mentioned in the article that the world's energy needs cannot be sustained with the increasing needs in China. As other nations consider alternative energy technologies, the United States should make sure that we remain the innovative leader in this sector.

This hearing will highlight developments in lithium-ion battery technology, fuel cell technology, solar power, wave power, and intelligent energy management products. Several of these technologies can be used for multiple power purposes. For example, fuel cells

can be used to power not only cell phones, PDAs, and other portable products, but also cars and buildings.

While these technologies are not the only alternative energy technologies being developed, they offer us promising examples of the progress that has already been made, and which can be made in the energy field in the future. Imagine the tremendous possibility of using easily rechargeable and environmentally safe lithium-ion batteries or fuel cells to power cars, buses, or other vehicles, in more efficient ways than we do with petroleum products today.

As a Nevadan, I also appreciate first-hand the potential positive impact the solar power technologies can have in improving the way homes and businesses are powered. We get a lot of sun out in Nevada, and we hope that we will be able to utilize solar power technologies in this fashion in the future.

As I have said before in several subcommittee hearings, innovation is the key to future global competitiveness of the United States. Innovation in the field of alternative energy technologies is particularly important in ensuring our Nation's future economic strength, environmental health, as well as national security.

We are pleased to have one panel of witnesses here to testify on alternative energy technologies.

Without objection, for any of the Senators that wish their statements to be made part of the record, that will be done. As far as the witnesses are concerned, please keep your testimonies to around 5 minutes. This is not a hard-and-fast rule, but if you could keep your testimonies to approximately 5 minutes, it would be wonderful for us, so we could have as much discussion back and forth as possible. But if you need a little extra time, feel free to take it.

Senator Dorgan, would you like to make any opening statement?

Senator DORGAN. Mr. Chairman, just briefly.

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

Senator DORGAN. First of all, thank you for putting this hearing together. I have another hearing that's occurring at the moment, so I came over just to tell you that I think this is exactly what we should be doing. The subjects here are very, very important.

I want to just mention two issues. One, something that I've been working on for a long while in the Energy Committee, and that is the hydrogen fuel cell issue. I'm a Co-Founder of the Hydrogen Fuel Cell Caucus, along with Senator Lindsey Graham, here in the Senate, and helped write the title that was included in last year's energy bill. It is critical that we find a way to pole vault to a new energy future, especially with respect to powering vehicles. We stick little straws in the earth in various places and suck 84 million barrels a day out of this planet. We use 21 million barrels of it in this country. The line that almost moves straight up is the transportation line. We need to find a way to convert.

My first car was a 1924 Model T Ford that I bought as a young boy for $25, and restored.

Senator ENSIGN. Was it new?

Senator DORGAN. No, no, no.

[Laughter.]

Senator DORGAN. Let me take back my original compliments.

[Laughter.]

Senator DORGAN. No, but I bought it as a high-schooler, and restored it, and then sold it. I discovered it was hard to date in a 1924 Roadster.

[Laughter.]

Senator DORGAN. But the point is, you put gas in a 1924 Model T exactly the way you put gas in a 2006 Ford. Nothing has changed. Everything else in the world has changed. Everything else about the car has changed. There's more computing power in a new car than there was on the lunar lander. And yet, we still stick the hose in the tank and put gas in the tank.

And so, I'm very interested in this issue of hydrogen fuel cells. We need to have more resources devoted to it.

The second issue is wind energy. We've been promoting wind energy. And now, what has happened is, in last year's DOD authorization bill there was a required study on wind turbines and their effects on radar systems and any impacts on military readiness. We've had two projects in North Dakota receive notice that they cannot continue. They just want to stop everything. The DOD and the Department of Homeland Security have found, the best way to mitigate whatever they think exists is just shut down these projects, and that makes no sense at all.

I think that the Administration is concerned about the aggressiveness of the FAA and others to shut some of these projects down that were moving ahead. I am told that there is an attempt to work out a compromise, but, if there is not, I intend to offer an amendment on the Defense authorization bill, either this week or next week, because we have to solve this. You know, the fact is, a turbine 15 miles away from a commercial airport has no impact on the Department of Defense and no impact on the airport at all. So it's devoid of all common sense. As someone once said, common sense is genius in work clothes. I'm not asking for genius solutions here, but I am asking the Administration to use a little common sense. There was nothing in any amendment that was ever put in a bill that requires them to stop projects that are now underway in wind energy, and I hope, in the next couple of days, we can resolve this. If not, I intend to offer an amendment on the Defense authorization bill.

But let me say this is the right subject, Mr. Chairman. I'm really pleased that you're into it and working hard on it. I'm going to have to spend my time at another Committee, as well. But thank you very much.

Senator ENSIGN. Thank you.

I am very excited about today's hearing. I would also like to thank all witnesses for being here this morning. I look forward to your testimony.

We'll start with a Nevadan. Dr. Gotcher, if you could share with us what you are doing out in Reno, with some new technologies. Dr. Gotcher is the President and CEO of Altair Nanotechnologies. Altair is based in Reno, Nevada.

STATEMENT OF ALAN J. GOTCHER, PH.D., PRESIDENT/CEO, ALTAIR NANOTECHNOLOGIES, INC.

Dr. GOTCHER. Thank you, and good morning. I'd like to thank Chairman Stevens and Co-Chairman Inouye for their leadership and for holding this hearing on nanotechnology and alternative energy production in the United States. And, further, I'd like to thank Senator Ensign for his support to ensure that Nevada is a leader and a strong supporter of nanotechnology.

I'm Alan Gotcher, President and Chief Executive Officer of Altair Nanotechnologies. I've been with Altairnano for nearly 2 years. Prior to joining the company, I held senior management positions at two major corporations that manufacture both industrial and consumer products.

Altairnano is a small, rapidly growing company which is creating advanced nanomaterials that exhibit unimaginable performance. We are Nevada-based, publicly-traded on NASDAQ, and have about 70 employees—research scientists, engineers, and, increasingly, manufacturing, marketing, and sales people—located in Reno, Nevada and Anderson, Indiana.

We perform research on the basic characteristics of nano-structured metal-oxide nanomaterials and develop products for applications in a wide range of fields, from pharmaceuticals to sensors and energy production, including high-power lithium-ion batteries and advanced hydrogen production.

Today, I want to describe how nanomaterials have made possible the first major breakthrough in battery performance in over two decades. And I'll indicate how the characteristics of nano-structured materials, such as those Altairnano has developed, and when used in lithium-ion batteries, will make possible significant advances in various forms of alternative energy production, storage, and consumption.

Altairnano's electrodes, materials, and battery designs are based on our patented materials and manufacturing processes for nanomaterials and offer a unique combination of high power, long life, reliable performance at temperature extremes, affordable cost, safety, and environmental friendliness that exceeds other battery product technologies. Altairnano's nano-structured materials offer a unique combination of performance properties.

These advances are made possible by the unique characteristics of nano-structured particles of lithium titanite spinel that form the anode electrode of Altairnano's lithium-ion batteries. Altairnano's particles are 10 to 40 times smaller than any other lithium titanite spinel and are, thus, better able to take advantage of the vastly improved electrical conductivity, low impedance, fast charge and discharge, longer cycle-life, and temperature performance offered by the material selection and the use of smaller, more uniform nanoparticles. We have the ability to engineer these particles to optimum size for a given application, and we can get extremely high, uniform particle size.

Altairnano batteries can deliver power for vehicle acceleration, uninterruptible power supply, or emergency backup power, very rapid recharge times, a wide range of temperature performance, much longer lifetime than other batteries, inherently safe operation, and the use of no hazardous materials. Moreover,

Altairnano's nanomaterial will be competitive with other commercial battery material costs.

Almost half of the U.S. consumption of imported oil comes from a dependence on the internal combustion engine used today in conventional cars and trucks. Nanotechnology may provide significant new products that can break that dependence and win the quest for a practical alternative energy vehicle. Imagine a fully-electric 6-passenger car or a full-sized pickup truck offering conventional acceleration and cruising speeds, geographical range, quick fill-ups, and 100,000-plus-mile powertrain. Altairnano's nano-structured lithium-ion battery materials provide these attributes.

For electric and hybrid electric vehicles, Altairnano's nano-structured lithium-ion batteries will provide abundant power for a 300-mile vehicle range, an under 8-minute recharge time, performance over a wide range of temperature, −40 °C to +65 °C, a 15-year life, with minimal decline in performance capabilities, low weight, and ease of design configuration, inherent safety—no fire, explosion, or environmental hazards—and no CO_2 emissions or use of hazardous materials. The technology is advanced enough that this battery technology could be used in vehicles within several years. The widespread adoption of the technology in the automotive sector would mean greatly reduced oil imports, greatly reduced CO_2 emissions, no need for complex, expensive, hydrogen or natural gas infrastructure, and increased national security and a more flexible foreign policy.

Altairnano's lithium-ion batteries also are ideal storage devices for UPS and emergency backup power applications. Their performance characteristics exceeds the batteries now available for these applications, and they make it feasible for UPS and EBP sites to become reliable nodes in a national distribution system of mini-grids, enhancing energy security and electric reliability.

Military applications, from individual soldier tactical needs to global power projection strategy, will be revolutionized by advanced battery capabilities. Early applications in the U.S. Navy include providing absolutely reliable, instantaneous power for single-generator ship operations, which could reduce ship fuel consumption by 15 to 20 percent. For the Army, Altairnano's battery may answer the infantryman's increased need for lightweight, portable, safe, and reliable power for numerous power-hungry combat components the soldier will carry and use. The same battery design will provide planes, missiles, and satellites with longer endurance, weight savings for greater payloads and speed, extreme harsh environment performance, and higher safety margins.

The Federal Government has provided policies, funding, and leadership to help the private sector invest confidently in the field of nanomaterials research and development. Altairnano's own NSF SBIR grant was crucial in assisting our company to develop its nanobattery material.

With rising concerns over environmental health and safety issues involving nanomaterials manufacture and use, the Government now has an equally important role to play in helping industry to develop a roadmap that can, one, identify and appropriately deal with potentially harmful effects of nanoparticles, while, two, stimulate U.S. industry to proceed with developing products and applica-

tions that will sustain America's leadership in nanomaterials and nanotechnology.

This is equally true for the field of alternative energy as for any other of the numerous fields in which nanomaterials will inevitably have a major impact and make significant contributions.

What is needed now from the Federal Government to assist the nanoindustry in applying its potential to alternative energy are two thrusts. One, continued funding to U.S. companies for basic and applied R&D, including priority spending on nanomaterials and system solutions to replace or decrease the use of internal combustion engines, and, thus, decrease U.S. dependence on oil; and, two, increase funding for environmental health and safety R&D, including a broad, government-funded initiative aimed at establishing empirical data and models to predict and prioritize the environmental health and safety risks of commercially-interesting nanomaterials.

I want to thank you for the opportunity to speak here today, and I invite you to visit our facilities in Indiana or Reno, Nevada. And I'll be pleased to try to answer any questions you might have.

[The prepared statement of Dr. Gotcher follows:]

PREPARED STATEMENT OF ALAN J. GOTCHER, PH.D., PRESIDENT/CEO, ALTAIR NANOTECHNOLOGIES, INC.

[Slide 1. Altairnano 'innovation at work']

Mr. Chairman, members of the Committee, I want to thank you for the opportunity today to provide remarks concerning the potential of nanomaterials and nanotechnology to contribute significantly to the development of alternative energy technologies.

I am Alan Gotcher, President and CEO of Altair Nanotechnologies, Inc. and of Altair Nanomaterials, Inc. The former is a holding company, while the later is the operating company incorporated and based in Reno, Nevada. We are a fully American company, with all of our assets, facilities, and employees located in Nevada and Indiana. Altairnano, the trade name we go by, is a development-stage company whose general business involves the development and production of nano-structured metal-oxides comprised of nano-sized particles. These nanomaterials, like our advanced battery-electrode materials for example, are being designed to dramatically improve existing products or stimulate the introduction of new products for unmet market needs.

[Slide 2. Altairnano Profile]

In 2000, when Altairnano was a small business with little revenue and 27 employees; we began to realize the promise of nanomaterials and that our proprietary, patented manufacturing process was uniquely suited for the industrial scale manufacture of a range of metal-oxide nanomaterials. Since then, we have more than tripled our staff, increase revenues and plan to be cash-flow positive in 2007. Today, as a small publicly-traded company, Altairnano is pursuing research and product development based upon nano-structured metal-oxide nanomaterials in a number of fields, including pigments and coatings; sensors for chemical, biological and radioactive agents; pharmaceuticals for chronic kidney disease and enhanced drug delivery; and alternative energy storage products including high power lithium-ion batteries and advanced hydrogen production.

The foundation of Altairnano lies in our intellectual property, our unique, patented processes for manufacturing and composition of matter patents for nano-structured metal-oxides with unsurpassed quality, performance and cost. Today, Altairnano is a company lead by strong management with track records for commercializing new technology. We have over 70 employees the majority of whom are scientists and product developers complemented by strong manufacturing, marketing and sales personnel. It is the intellectual power of this team that has made our advances possible. Altairnano has 33 patents issued and over 100 patent applications have been based on Altairnano's own research and development. The quality of our market partners include, for example, Eli Lilly, Western Oil Sands, Sulzer Metco and other tier-one automotive suppliers and aerospace companies that confiden-

tiality agreements prevent disclosure is testimony to the commercial promise of our products and the quality of our company. As Altairnano moves our nanomaterials from the laboratory to commercial-scale production, it is increasingly our intent to manufacture in the United States due to its policies that strongly support entrepreneurship and protects company intellectual property.

Nano Lithium Ion Batteries

[Slide 3. Altairnano, imagine the possibilities . . .]

Today, however, I want to focus on what has, in the past year, become Altairnano's leading effort and one that embodies the most near-term potential for significant real-world applications. This effort is to develop *an advanced nano-structured material and battery that will set a new baseline standard in energy storage and power delivery.* Altairnano is developing the most advanced lithium-ion battery in the world: high performance, affordable and environmentally sustainable, Altairnano's high power, advanced Li-ion batteries outperform conventional and other experimental battery concepts.

Altairnano's lithium-ion batteries have remarkable performance:

- Power for rapid vehicle acceleration (more power than NiCd, NiMH, Li Ion or lead-acid batteries).
- Rapid battery recharge, in just a few minutes.
- Capable of operation over wide temperatures, as low as −40 °C to +65 °C.
- A long life battery, est. to be at least 15 years or five-times longer than most batteries.
- An inherently safe battery, with no catastrophic failures in any safety test.
- And the batteries contain no hazardous materials.

This is a major breakthrough in battery performance, a unique combination of attributes not seen in any competing battery technology. This battery performance has been measured in Altairnano's product applications labs and those of quality third party partners.

I believe it will take such a major breakthrough in electrical storage and power management if our country is to make tangible, near-term achievements in reducing our Nation's increasing dependence on foreign sources of petroleum and natural gas, and thereby enhancing national security, while also reducing the amount of carbon dioxide and other greenhouse gases that are produced by our growing energy consumption without curtailing our growing economy.

Batteries, in a multitude of sizes and shapes, will be a major factor in reducing the wasteful use (and hence, wasteful production) of energy while allowing more-than-sufficient power to be stored where it is needed and available when it is needed. Batteries will also be key to the migration of the transportation sector to electricity, and away from liquid fuels, with all of the sourcing, production, transportation and storage issues associated with liquids, especially petroleum. Why? Batteries are *energy storage and transfer media.* Batteries enable end-users of power to utilize the energy stored in and generated from of a wide variety of sources: solar, wind, biomass, geo-thermal, nuclear, natural gas, coal, or petroleum. Thus batteries are a major element of introducing flexibility into the entire electricity system, from generation through distribution, storage, and ultimately, end-use. Imagine a future where an electric vehicle has a range of 300 miles and the battery can be recharged in a few minutes. This would allow you to drive your all-electric vehicle from New York to Los Angeles recharging, or re-fueling, along the way using electricity generated locally, first from nuclear power, then from clean-coal and biomass or biofuels; moving further west you recharge with electricity generated at hydro-electric plant, a solar panel farm in the desert and a wind farm in the Rockies before moving to the coast and gaining the benefits of tidal and geo-thermal electrical generation.

To fulfill this potential, batteries must meet a wide spectrum of operational and economic demands, which until now batteries have not been able to do with much success. This is where nanomaterials have a potentially huge contribution to offer across the whole range of alternative energy technologies.

Characteristics of Altairnano's Lithium Titanate Spinel-Based Lithium-Ion Batteries

[Slide 4. Altairnano Battery Performance]

Although Altairnano's nano-structured materials have utility in a wide variety of market applications, for example as pharmaceutical APIs and in drug delivery, Altairnano's near- to mid-term business strategy is to exploit the unique characteristics of our nano-structured metal-oxides in several fields of alternative energy.

Here I would like to highlight what Altairnano's battery technology offers in the way of improved capabilities for storing electricity and providing immediate, high-quality, continuous power on demand in virtually any circumstance. Altairnano offers more power than competing battery technologies and the benefits of an inherently safe and light-weight lithium-ion battery.

[Slide 5. Altairnano nano-lithium titanate spinel]

Our battery technology utilizes nano-structured lithium titanate spinel as the electrode material in the anode of a rechargeable lithium-ion battery. It replaces the graphite electrode used in conventional lithium-ion batteries, which is the source of performance and safety issues. Altairnano's technology produces 25 nm particles that are fused into 3 micron aggregates uniform in size and shape. This size is ten- to forty-times smaller than any other source of lithium titanate in the world.

[Slide 6. Altairnano battery comparison chart]

Smaller particles provide increased surface area, which translates into vastly faster discharge and charge rates, meaning that the time for recharging the battery can be measured in minutes rather than in hours. Altairnano's electrode materials also improve the useful lifetime of a battery, called cycle-life as measured in thousands rather than hundreds of cycles, 10- to 20-times longer than current lithium batteries. The nano-structured materials also provide battery performance at −40 °C to provide power at far below freezing temperatures, expanding the operational temperature range beyond what is currently achievable—over 75 percent of normal power will be available at extremes of −40 °C and +75 °C. Because conventional Li-ion batteries can not charge at temperatures below 0°C and they explode at temperatures higher than +110 °C, this latter characteristic alone will permit Altairnano's lithium batteries to be used in physical environments that today cannot be served by lithium-ion batteries due to safety concerns or because they require complex, expensive electronic control circuitry and temperature maintenance. Altairnano's battery material is inherently safe for humans and the environment; it is not hazardous in any sense, there are no hazardous disposal issues involved in its use and it will not explode or catch fire under any circumstances.

Automotive Applications

So what does this new material, lithium titanate spinel, mean to the commercial battery world? Let's take automotive design. Advanced batteries of the type Altairnano is developing will enable the U.S. auto industry to "leapfrog" the next generation of hybrid drive vehicles, where the U.S. industry and its technology are behind its Asian competitors. An Altairnano battery sized for an average 5-passenger sedan will permit auto makers to design an all-electric vehicle with no sacrifice in the performance, comfort or carrying capacity of today's internal combustion engine cars. Think of this: a 250–350 mile driving range, with maximum operational performance over that entire distance; a recharge time, from discharge to full recharge, in under 8 minutes (or about the time it takes to fill the tank of a large SUV); the ability to recharge from a 120-volt source; a battery that is completely safe from explosion or leakage of hazardous contents, eliminating those risk factors in the event of collisions; the ability to distribute the battery around various locations in the vehicle, meaning no reduction in passenger or luggage carrying space; and not least, no emissions of CO_2. As an indirect benefit, we will not have to compromise technical and economic competitiveness in the auto industry in order to have cleaner air.

Such vehicles are not 20 years away, unless the automotive manufacturers decide to take that long to design and produce them. Technically, they are just around the corner. What will the widespread adoption of such batteries mean for transportation, even accepting the intermediate step of hybrid-drive electric/gasoline vehicles? It means that cars and trucks can be fueled from electricity generated here in the U.S., rather than from petroleum pumped in other countries. It means safer, quieter, non-polluting vehicles that perform as well or better than today's vehicles. It means that the vast amounts of money required for new refineries, or for a national hydrogen fueling system, or for liquid natural gas terminals can be diverted to other purposes, private and public. Some of the money would be used to accelerate research into clean coal and to speeding up deployment of renewable energy technologies and improving them. But what it would mean most of all is greater security for our people—we would be much more in control of our transportation destiny, and thus of our economy and our national security. Our foreign policy would be that much freer from the specter of supply interruption, price manipulation, sabotage, wars, and outright blackmail that it currently has to contend with.

How could Congress, and especially the Commerce Committee, have a seminal role in transforming our economy? If Congress could encourage the U.S. automotive

industry to embrace the concept of electric vehicles, including a substantial component of all-electric vehicles in its production mix now—this is a classic chicken and egg situation—such action would stimulate tremendous competition to supply the development of alternative energy production technologies that could serve immediate local demand. It would again be an exciting time to be an innovator and entrepreneur in the U.S.

Stationary Power Applications

Let's take two other commercial applications for our advanced high-power, lithium-ion battery, in the field of stationary power: Uninterruptible Power Supply (UPS) and Emergency Back-up Power (EBP). Present day UPS and EBP systems utilize mostly lead-acid batteries, for their low initial cost and their reliability. Yet lead-acid batteries must be replaced every 2–3 years, and there are hazardous materials issues around their manufacture, handling and maintenance. Lead-acid batteries are also unreliable and lose charge quickly in extreme temperatures (<0 °C and >50 °C). Also the quality of power declines steadily with use, as does the ability to accept a recharge. By comparison, early results on prototype batteries using Altairnano's nano-structured lithium titanate electrode materials show that such an advanced lithium-ion battery is virtually unaffected by temperature extremes; its charge is fully available, immediately, and can accept a full re-charge in a few minutes—thus acting much like a hybrid ultra capacitor; it has a much longer lifetime, with no decline in performance; there are no hazardous materials issues; and, using the Altairnano processing method, the battery material in wide production will be economically-competitive with lead-acid or other competing battery technologies.

With these kinds of advantages, UPS and back-up systems could feasibly become reliable components of distributed mini-grids, linked to the national power grid in ways that would tremendously enhance electric reliability and national security. Batteries of the type being developed by Altairnano are necessary for the implementation of any large-scale alternative energy generation and delivery system. Storage of electrical power generated either by wind or solar power for use when the wind isn't blowing or the sun is not shining requires such batteries. And consider, such batteries incorporated into large buildings will enable these buildings to become nighttime storage nodes in a distributed grid system to even out supply & demand and enhance reliability during periods of excess demand.

Military Applications

On Sea

Altairnano's nano-enabled lithium-ion batteries have tremendous prospects for moving alternative energy technologies into military applications, and thus into national security calculations and into both strategic and tactical operational planning. To offer one example, ships in today's Navy generally have three on-board generators that power the turbines that drive the ships. For security—to be absolutely sure that power is available and on tap instantly whenever needed—the ships run two of the generators at all times, one for operations and one for instant backup. If the Navy could install a battery system with the operational characteristics of Altair's battery, ships could forego having a second generator operating 24 hours a day, thus *cutting their fuel use by 15–20 percent, or approximately $1 million for a six-month cruise by a single destroyer or frigate.* One of the Navy's chief strategic operational goals over the next decade is to reduce fleet fuel consumption significantly. More fuel used means fewer ships at sea, fewer days of the year, in fewer parts of the world.

Down the road, the Navy is contemplating a new generation of all-electric drive ships that would use fuel cells as the power source for the ship's drive and all ancillary functions. For fuel cells to become feasible, however, there is a need for a source of instant power-on-demand, sustainable for up to half an hour in order for the fuel cells to reach their normal operational temperature. Altairnano's new nano-enabled lithium-ion battery materials can provide a near-term solution that will meet all of the future operational requirements of the Navy; all within a relatively small footprint and being very cost-competitive with battery technologies offering less operational capability.

On Land

Moving down to ground level operations, the Army's Soldier of the Future will carry an array of electronically-powered equipment, from communications, to navigation, to all-weather vision, to climate-controlled environmental body suits, to laser weapons. That means he'll have to carry his own power source—a lot of power, high-quality power, instant, reliable and safe in any environmental condition. Right now, the U.S. Army infantry moves on small primary lithium batteries, not rechargeable.

During the invasion of Iraq, literally millions of batteries were used and *discarded on the battlefield;* and it was discovered after the invasion that the Army was within *days* of literally running out of batteries or power. Soldiers don't use rechargeable batteries today because the recharge time is too long and the depth of charge after the first use is unreliable. So a substantial portion of their personal gear and of logistics supply trains is devoted to carrying batteries. That becomes less and less sustainable as the individual soldier's needs, and those of the accompanying tactical vehicles, require more power. So the Army is very interested in batteries that can provide instant, reliable, high-energy power in a *lightweight, rechargeable, low-cost, long-lasting format.* Early testing of prototype batteries made using Altairnano's nano-LTO electrode materials show that this is an area where nanomaterials will provide game-changing performance: they will power the U.S. foot soldier of the future.

In the Air

In another scenario, think of airplanes, missiles, and spacecraft, all need reliable power-on-demand, with very quick discharge rates, in batteries that can withstand temperature extremes without any serious degradation of capability and that will have greatly extended service and charge/discharge cycle lives. Testing results with early prototype battery designs have shown that Altairnano's nano-structured lithium-ion batteries can be used to replace currently-used batteries, with no compromise in performance while significantly reducing power-pack weight and footprint, thus allowing for larger payloads, increased speeds, or extended range. What's the worth of an extra fifty pounds of payload for a satellite? Or, an extra 50 miles of range for a tactical missile? Or an extra few hours in the air for an unmanned observation plane?

The Role of Government

[Slide 7. Altairnano Imagine the Possibilities]

I cannot end my statement without acknowledging the critical role of government in assisting companies like Altairnano to carry out the research and development that has brought nanomaterials development and nanotechnologies to their present state of viability. Without the foresight, planning and hard work of dedicated public servants in the Executive Branch and in the Congress, it is questionable whether private industry would have taken on the challenges and made the investments that are beginning to provide the world with the benefits of nanotechnology. The National Nano Initiative, which originated in the minds of a few professionals at the National Science Foundation, has laid the groundwork for private industry to take the risks of developing and bringing products to markets. In our own example, Altairnano's development of advanced lithium-ion battery materials benefited tremendously from the award of an NSF SBIR grant in 2004. Although our research on nano-LTO materials had been ongoing for several years, it was at a low level of effort. The NSF grant really kick-started our program. The results of that NSF-funded research led directly to our decision to hire a full-fledged battery team and make a commitment to nanoparticle-based battery materials as our top corporate priority. Without that small grant, we would not be here today. Similar stories can be told by many, many small, development-stage nanomaterials and nanotechnology companies working in the various fields of alternative energy.

Increasingly, over the past 18 months, concerns have been raised related to the safety of some nanomaterials and calls for government oversight of the emerging nanomaterials industry in areas of environment, health and safety (EHS). Altairnano has chosen to be an industry leader in working voluntarily with agencies like the Environmental Protection Agency and the National Institute for Occupational Safety and Health (NIOSH) to identify possible issues of concern in the manufacturing processes for our nanomaterials. We are strongly committed to the principle that our workers, workers at our marketing partners who incorporate our enabling nanomaterials into their products and the consumers using those products will not come into contact with any even-potentially harmful materials during manufacture, use or disposal of such materials and products. We are working diligently to address whatever potential EHS issues might be related to those processes. NIOSH has not found any negative EHS factors involved in our nanomaterials or their manufacture and use, and we are confident that our products and processes will pass any reasonable standard of evaluation. The experience however has led us to think long and hard about how, not whether, nano-materials, products, and processes should be examined, evaluated and possibly regulated. We have submitted comments in response to the EPA's draft nano-EHS knowledge-gap white paper and are working with a broad coalition of partners to promote a joint industry-government effort to establish a "roadmap" for EHS issues that sets priorities for identifying and

dealing with potentially harmful nanomaterials, products, and companies while letting the United States' nanomaterials industry continue in its position of global leadership. If we collectively get this right, we will establish a global set of criteria for safe and sustainable development and use of nanomaterials in which U.S. companies and technologies will have economic dominance.

We at Altairnano believe that nanotechnology will be the technological underpinning of economic growth in the 21st century, and that it must be developed and exploited in a manner that is responsible and sustainable. While a regulatory framework needs to be developed that protects the environment, workers and consumers, it must be done in a way that neither bogs down the regulatory agencies nor cripples the development of nanoscience and technology in the U.S. We have some ideas, along the lines used by the Food and Drug Administration for regulating the development of new prescription drugs, for example. This is an oversight paradigm that increases in stringency as ideas move from the researchers' minds, through development, and become incorporated into commercial products. A considered and future-friendly approach needs to be developed in partnership with all stakeholders. Time is critical; we are already seeing alternative energy technologies and products first developed in the U.S. go on to large scale deployment elsewhere—along with the economic benefit to industry that goes with scale.

Our present lead in nanotechnology can, and will, help the United States gain the lead in alternative energy technologies and their deployment, and thus lead to energy security. But there are serious roles for government, in collaboration with industry to foster the safe and responsible development of new nanomaterials and nanotechnologies, and to do so in a manner that provides positive support for this infant industry at a critical stage of its development.

Thank you, gentlemen for your time and your interest. And I invite you to visit our facilities in Indiana or Reno, Nevada. I'm prepared to answer any questions you may have.

'innovation at work'

Altairnano
innovation at work

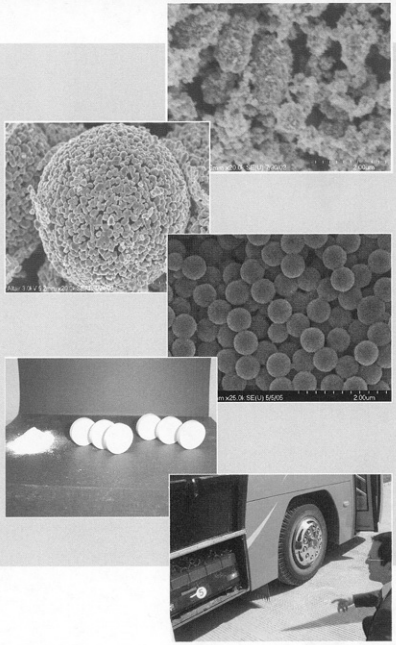
Altairnano presentation to

The Senate Commerce Committee

June 14, 2006

Alan J. Gotcher
President & CEO

With the exception of historical information, matters discussed in this presentation regarding product development, target markets, revenue and income projections, are forward looking statements that involve a number of risks and uncertainties as defined under the Private Securities Reform Act of 1995.



Altairnano Profile

Altairnano
innovation at work

A small, publicly traded company today…

NASDAQ:	ALTI
Shares Outstanding:	59 million
Year End:	December 31
Locations:	Reno, NV
	Anderson, IN
Employees:	70
Market Capitalization:	~ $200 M

Enabling unexpected product performance…

Imagine the Possibilities…

Altairnano
innovation at work

Nano-structured materials enable…

- High performance power, lithium ion batteries
  - Enables POWER to vehicles for rapid acceleration
  - Enables rapid battery recharge in a few minutes
  - Performance over wide temperature range -40°C to +65°C
  - Allows 4 times longer battery life, est. to be 15+ years
  - Provides an inherently safe battery
  - And, the batteries contain no hazardous materials

Enabling unexpected product performance

3

Battery Performance

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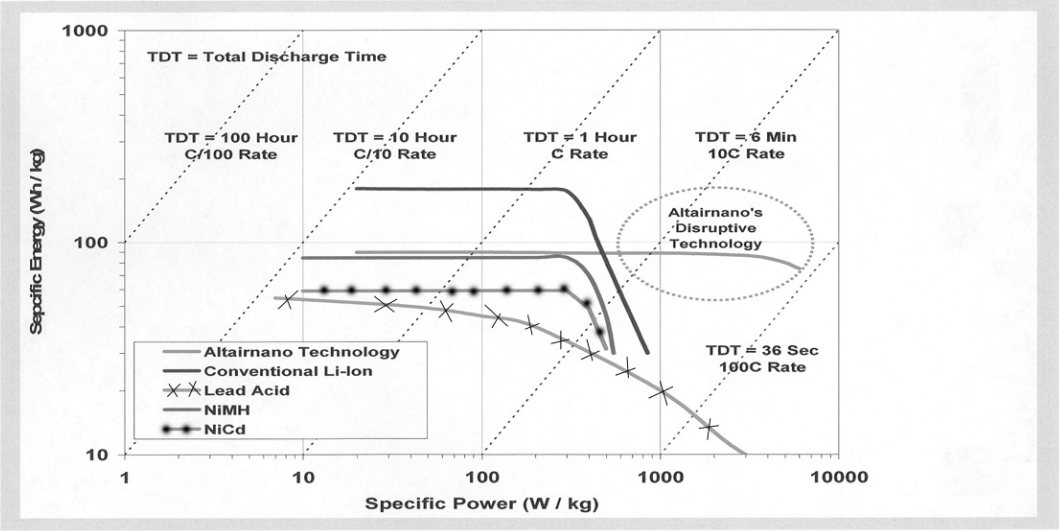
Nano-Structured Electrodes Provide Advantages

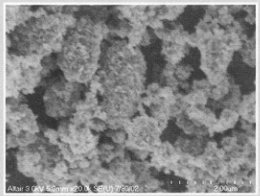


Safe lithium ion batteries with <u>POWER and life!</u>

nano-Lithium Titanate Spinel

Altairnano
innovation at work

High performance lithium ion electrode materials



- Li ion battery electrode materials
  - Motive power industries
    - HEV, plug-in and all electric
  - Stationary power industries
    - Telecom, uninterruptible power supply (UPS)
- Li ion batteries and battery packs
  - Product design & engineering
  - Rapid prototyping & testing
- Hybrid ultra capacitors
  - High instant power, rapid charge / discharge
  - Greater energy density

Power from nano-structured electrodes

5

Battery Comparison Chart

Altairnano
innovation at work

Unmatched, Unique Advantages

Feature	Lead Acid	NiCD	NiMH	Altairnano Li-Ion
Energy Density (Wh/Kg)	30 - 40	20+	~60	60 - 90
Cycle Life (Full Depth of Discharge)	50 - 180	300 - 600	300 - 500	9,000+
Safety (Fire Hazard)	Fire Hazard	Moderate	Fire Hazard	Safest
Charge Time (0 - 100%)	~ 10 Hours	3 Hours	3 Hours	3 Minutes
Operating Temp Range	-10° to 60°C	0° to 50°C	0° to 40°C	-50° to 75°C
Environmental Impact	Toxic	Toxic	Low	Minimal
Pulse Power Utilization Range	Narrowest	Narrow	Moderate	Broadest
Leakage (Dissipation)	Lowest	High	Highest	Low
Memory Effect	Very Low	High	Moderate	None
Power Delivery	Good	Moderate	Moderate	High
Manufacturability	Easy	Adequate	Adequate	Easy
Weight	Heavy	Moderate	Moderate	Moderate
Maintenance	Moderate	Moderate	Moderate	Minimal
Market Position	High Volume	Sliding	Modest	Rising
Cost	Cheap	Tied to Ni	Tied to Ni	Moderate

Lithium Batteries with POWER

Imagine the Possibilities…

Altairnano
innovation at work

Nano-structured lithium titanate spinel materials enable

- High performance lithium ion batteries
  - Rapid battery recharge in a few minutes
    - Charge and discharge rates of 80C
  - Performance over wide temperature range
    - -40°C to +65°C
  - Allows 4 times longer battery life
    - Estimated to be 15+ years
  - Provides an inherently safe, green battery design

Enabling Unexpected Performance

Altair Nanotechnologies

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innovation at work

Remember…

Small Is Huge

Senator ENSIGN. Thank you.

Next, we will hear from Dr. Francis Preli, Jr., the Vice President of Engineering at UTC Power. I look forward to hearing your testimony.

STATEMENT OF DR. FRANCIS R. PRELI, JR., VICE PRESIDENT, ENGINEERING, UTC POWER

Dr. PRELI. Thank you, and good morning, Mr. Chairman.

My name is Frank Preli. I'm Vice President of Engineering for UTC Power, a United Technologies Corporation company.

With more than 40 years of experience, UTC Power is the world leader, and the only company in the world, that develops and produces fuel cells for applications in each major market—on-site power, transportation, and spaceflight applications.

Fuel cells provide an opportunity to address a variety of U.S. energy needs, including reducing the dependence on foreign oil, delivering assured, high-quality, reliable power, decreasing toxic air and greenhouse gas emissions, and improving energy efficiency.

UTC Power does not see any show-stopper technical barriers to the advancement of fuel cells, but continued U.S. commitment to research, development, demonstration, and market transition initiatives are essential to reduce cost, improve durability, and enhance performance.

Hydrogen storage and infrastructure requirements representing challenging obstacles for automotive applications, but near-term opportunities exist with fleet applications such as transit buses. Stationary fuel cells for assured power represent another opportunity for near-term commercialization.

Fuel cells are available today for transit buses and stationary markets. Near-term successes in these applications are required to create public awareness and acceptance, establish a viable supplier base, and stimulate continued investment. The Energy Policy Act provides the basic framework for a comprehensive strategic focus, but a sustained national commitment to robust funding will be critical to our success.

Hurricane Katrina reconstruction efforts represent an opportunity to deploy assured-power fuel cells—to enable schools to serve as emergency shelters and hospitals, for example. Fuel cell deployment at government installations in the Gulf Coast Region could also help to kick off the Fuel Cell Government Procurement Program that was established in last year's energy bill.

Fuel cell transit buses offer the best strategic, near-term option to address our energy needs. The zero-emission hybrid fuel cell buses currently powered by our fuel cells in service in California, are demonstrating greater than twice the efficiency of a conventional diesel bus. These vehicles represent an opportunity to begin to reduce oil imports and provide environmental benefits.

As we enter the summer hurricane and electric grid blackout season, concerns regarding reliable assured power increase. In light of this vulnerability, we believe there is an opportunity to enhance the value of fuel cell vehicles by enabling them to provide power, during times of emergency, to shelters, hospitals, and critical infrastructure. UTC Power is currently working with the Department of

Defense to validate this concept using our PureMotion™ 120 heavy-duty fleet fuel cell power system.

Advanced vehicle technology proposals being considered by Congress should be revised to include the demonstration of export power capability for fuel cell vehicles.

The basic concepts of fuel cell technology have been proven. Now we need to enhance key performance characteristics, reduce costs, validate the technology in real-world operating conditions, and identify and incorporate cost-effective solutions.

Three strategies are necessary for cost reduction: public-private partnerships to reduce costs through material substitution, longer life, and fewer parts; improved manufacturing processes and identification of high-volume manufacturing solutions; and incentives to help increase volume and spread costs over a larger product base.

Last year's enactment of the Energy Policy Act establishes a framework for a comprehensive national strategy to achieve fuel cell commercialization, but more work needs to be done. Budget requests and appropriation figures for this year fall far short of levels authorized by Congress. We recognize that there are tight budget constraints, but, given the benefits of fuel cell technology and the price we pay today for imported oil, health costs associated with poor air quality, and lost productivity due to the lack of reliable power, substantial increases in fuel cell technology investment represent a fiscally-sound strategy.

While we are pleased the Energy Bill provided a fuel cell tax investment credit, the term is only 2 years. We support legislative efforts, such as S. 2677, to extend the tax credit until 2016.

We believe more attention needs to be paid to ensuring the successful commercialization of near-term fuel cell applications, such as transit buses, fleet vehicles, and stationary units. There are many opportunities today for government purchases of fuel cell technology to help commercialize, and these examples require serious consideration.

Thank you, Mr. Chairman, for the opportunity to testify. I'd be happy to answer any questions.

[The prepared statement of Dr. Preli follows:]

PREPARED STATEMENT OF DR. FRANCIS R. PRELI, JR., VICE PRESIDENT, ENGINEERING, UTC POWER

Good morning, Mr. Chairman. My name is Frank Preli. I am Vice President of Engineering for UTC Power, a United Technologies Corporation (UTC) company. With more than 40 years of experience, UTC Power is the world leader and the only company in the world that develops and produces fuel cells for applications in each major market: on-site power, transportation and space flight applications. We are also the world leader in the development of innovative combined cooling, heating and power applications in the distributed energy market.

Summary

Fuel cells provide an opportunity to address a variety of U.S. energy needs including:

- Reducing dependence on foreign oil;
- Delivering assured, high-quality, reliable power;
- Decreasing toxic air and greenhouse gas emissions; and
- Improving energy efficiency.

UTC Power does not see any "show-stopper" technical barriers to the advancement of fuel cells, but continued U.S. commitment to research, development, demonstration and market transition initiatives are essential to reduce cost, improve du-

rability and enhance performance. Hydrogen storage and infrastructure requirements represent challenging obstacles for transportation applications, but near-term opportunities exist with fleet vehicle applications such as transit buses that minimize these concerns. Stationary fuel cells for assured power represent another opportunity for near-term commercialization at lower cost targets.

Fuel cells are available today for the transit bus and stationary markets. Near-term successes in these applications are required to create public awareness and acceptance, establish a viable supplier base and stimulate continued investment. Last year's Energy Policy Act provides the basic framework for a comprehensive strategic focus, but a sustained national commitment to robust funding will be critical to our success. Hurricane Katrina reconstruction efforts represent an opportunity to deploy fuel cells in schools to serve as emergency shelters, hospitals and other critical infrastructure facilities to demonstrate their ability to provide sustainable energy for assured power requirements.

As we enter the summer hurricane and electric grid blackout season, concerns regarding reliable assured power increase. UTC Power believes there is an opportunity to enhance the value of fuel cell vehicles by enabling them to deliver power to the grid or other critical infrastructure such as emergency shelters. We are currently working with the Department of Defense to validate this concept with our heavy duty vehicle PureMotion™ 120 fuel cell power plant system.

Company Experience and Leadership

UTC Power has led the development and introduction of fuel cell technology for more than four decades. We hold the unique distinction of having:

- produced all the fuel cells that provide electrical power and drinking water for both the Apollo and Space Shuttle missions;
- sold more than 255 stationary 200 kW units that have produced more than 1.2 billion kilowatt-hours of electricity and have accumulated more than 7 million hours of operating time by customers in 19 countries;
- provided stationary fuel cells that have a stack life of 40,000 hours (an 80,000 hour life cell stack is in the final stages of development);
- developed fuel cells for a number of automotive customers including Hyundai, Nissan and BMW and working with almost all of the major automobile manufacturers on fuel cell-powered vehicles; and
- provided 120 kW fuel cell power systems that are currently powering four zero emission transit buses in revenue service in California.

UTC Power has participated in public-private partnerships with the Departments of Defense, Energy and Transportation in the development of its technology solutions for the stationary and transportation markets. Our proprietary low pressure drop, internally-humidified natural water management proton exchange membrane (PEM) fuel cell technology has led to significant advances in efficiency, power density and cold weather performance.

Our longstanding involvement in these varied markets and applications provides a unique vantage point to discuss how fuel cell technology can help address U.S. energy needs, the status of technology today and the barriers we face.

Need for Short-Term Successes

Our dependence on imported oil is well documented and personal automobiles consume the lion's share. Deployment of fuel cell vehicles powered by renewable sources of hydrogen can break our dependence on imported oil and at the same time take transportation out of the environmental debate. The auto market also represents the highest volume market, which is another reason this sector has received so much attention. But fuel cell vehicles for private use in meaningful quantities are a decade away since they represent the most demanding application in terms of cost, packaging and infrastructure. Existing electrical infrastructure and state and Federal regulations create hurdles for any form of base load distributed generation to overcome.

Nothing breeds success like success. We therefore need to increase our immediate focus on near-term applications that are available today such as stationary and fleet vehicles, including transit buses, to stimulate early volume and build the industry's supplier base. Since fuel cells represent a disruptive technology, the supplier base is reluctant to make the necessary investment. Early successes in the transit bus and stationary applications will help to overcome these fears.

In addition, stationary and fuel cell fleet vehicles have less demanding requirements and can compete at costs higher than those required by autos. Concentrating on these applications would enhance our ability to establish a profitable industry

today and create stepping stones to the most demanding longer-term auto application. Few companies can survive the next 10 years waiting for the high volumes offered by the car market. Instead, they must find applications where profits can be realized today that will support the development of a strong industrial base in preparation for the future auto market. Success in these early applications can build the necessary public awareness and public confidence.

Transit Buses and Fleet Vehicles

Fuel cell transit buses offer the best strategic, near-term potential to address the energy concerns cited above. In 2002, transit buses consumed the equivalent of more than 43,000 barrels of crude oil per day. The fleet of zero emission hybrid fuel cell buses currently powered by our fuel cells in revenue service in California is demonstrating greater than twice the fuel economy of a conventional diesel bus. Transit buses and fleet vehicles present an opportunity to begin to reduce oil imports in the near-term while also improving air quality and reducing greenhouse gas emissions.

Buses and heavy duty commercial vehicles travel a relatively low percentage of the Nation's vehicle miles, but they produce significant levels of toxic air emissions in densely populated urban areas. The transit buses equipped with UTC Power's PureMotion™ 120 fuel cell power system significantly reduce overall emissions due to the zero-emissions technology inherent in hydrogen fuel cells.

As we enter the summer hurricane and electric grid blackout season, concerns regarding reliable assured power increase. In light of this vulnerability, we believe there is an opportunity to enhance the value of fuel cell vehicles by enabling them to deliver power *to* the grid rather than *from* the grid as some people have proposed with the plug-in hybrid approach. The "exportable power" approach could improve reliability and provide assured power during times of emergency to shelters, hospitals and critical infrastructure.

UTC Power is currently working with the Department of Defense to validate the ability of our PureMotion™ 120 fuel cell power system for heavy duty vehicles to export power to the grid or to provide power to emergency shelters. This approach would enable a transit authority, military base or school system to use their fuel cell buses to transport people in zero emission, efficient, hydrogen powered, quiet buses under normal conditions and provide emergency power during natural disasters or terrorist incidents.

Bus durability requirements assume a life of more than 30,000 hours for a system that must operate up to 16 hours per day, but with frequent starts and stops. We offer a warranty of 4,000 hours for the four buses that are operating today in AC Transit and SunLine Transit revenue service in California and have a technology plan to increase the life of these power plants to 25,000 hours by 2010 and up to 40,000 hours by 2015.

Cost targets for buses are more forgiving than for autos and their infrastructure requirements are limited since they rely on centralized fueling and maintenance. The four buses produced last year cost over $3 million per bus, but we have been able to reduce this cost to under $2.5 million and with volume of 100 units per year we can see a path to $1 million per bus. We are actively engaged in pursuing a number of worldwide opportunities to aggregate bus orders and achieve volume sales that will result in potential near-term commercialization of the technology in this strategically important application.

Stationary Fuel Cells

We also view stationary fuel cells as another near-term opportunity to address air quality, climate change, reliability and energy efficiency concerns. The stationary fuel cell mission involves 24/7 steady state operation and a life of at least 10 years or 80,000 hours.

Early adopters have been attracted by the ability of these systems to operate as base load grid-connect or grid independent assets. We've deployed units at schools, hospitals, law enforcement, research, telecommunications and military facilities to address assured power and other customer concerns. In addition, one of our units is operating at a Connecticut high school that enables the school to be designated as an emergency shelter. This concept could be replicated in areas subject to natural disasters to provide additional community benefits.

We also believe there's a significant opportunity in the Katrina reconstruction effort to rebuild with sustainable energy objectives. For example, we could reduce the environmental footprint of power generation and increase reliability by installing on-site, assured power fuel cells to help meet future emergency needs at schools serving as mass care shelters, hospitals and healthcare facilities, prisons, and other critical infrastructure facilities.

Since fuel cells can be deployed at the point of use, in addition to not relying on the vulnerable transmission and distribution assets of the grid, customers can benefit from the ability to capture waste heat and put it to constructive use for space heating, domestic hot water heating and industrial processes. Our units operating in the combined heat and power mode can operate at 85–90 percent efficiency thus generating energy savings that can reduce the cost of electricity by four to five cents per kilowatt hour.

Our PureCell™ stationary fuel cell power plant uses phosphoric acid technology and has demonstrated best in class durability with 27 of our units surpassing 40,000 hours without significant maintenance or replacement of the original cell stack. Our current high time unit has 60,000 hours and we are testing a new generation of technology that we plan to introduce to the market in the next several years that we are confident will achieve 80,000 hours.

The cost of these units is currently around $4,500 per kilowatt, but at volumes of 500 units per year and with the aggressive cost reduction efforts we have underway, we expect our next-generation technology to be competitive at less than $2,000 per kW.

Automobiles

Cars are only driven an average of 2 hours a day which means their life requirement is low compared to other applications, However, autos experience many starts and stops and changes in speed that create unique needs for a robust and durable system through many different duty cycles. The Department of Energy's (DOE) short-term durability goal for cars is 2,000 hours by the end of the learning demonstration program in 2008 with 5,000 hours as the ultimate objective.

We are participating along with Hyundai in DOE's Hydrogen Fleet and Infrastructure Learning Demonstration program as part of the Chevron-led team. Ten cars using our power plant are currently operational with a total of 32 vehicles planned.

As part of this initiative, we have cars on the road today that have passed the 500 hour mark and are still accumulating hours. In the laboratory we have run stationary loads for 13,000 hours, auto stress-test cycles of 5,000 hours and one million acceleration cycles, which gives us confidence that we can meet the goal of 5,000 hours in production vehicles.

Fuel cell cars must be capable of both starting and operating in cold conditions if they are to gain broad market acceptance. The consensus performance criteria are the ability to survive at −40 °C and start at −30 °C. Great progress is also being made in this arena. For example, one of our cars has run 25 cycles from frozen conditions as low as −10 °C and we have demonstrated 43 cycles at −35 °C in the laboratory.

Barriers

In short, technology development barriers for transportation fuel cells are being addressed at a rapid pace. At a small scale, we can meet the identified requirements and we don't envision any formidable show-stoppers. This doesn't mean, however, that we don't need to continue our public-private partnership research, development or demonstration efforts. We strongly endorse the continuation of these activities and increased financial commitment to accelerate the progress we have made in the last few years.

The basic concepts of fuel cell technology have been proven. Our task now is to enhance key performance characteristics (such as durability); reduce costs; validate the technology in real-world operating conditions; identify hidden failure modes through extended operation; and then identify and incorporate cost-effective solutions. In the case of transportation applications, infrastructure and hydrogen storage still represent key challenges.

Three strategies are necessary for cost reduction:

- Internal programs to reduce cost through material substitution, longer life parts, and fewer parts. Examples include less expensive membranes; better seals; reduced use of platinum; enhanced performance materials for bipolar plates; and reduced system complexity;
- Improved manufacturing processes to eliminate labor intensive processes and identify high volume manufacturing solutions; and
- Incentives to help increase volume thereby spreading costs over a larger product base.

Recommended Actions

When I testified before this committee in 2003, I called for a comprehensive national strategy to achieve fuel cell commercialization. Last year's enactment of the Energy Policy Act (EPAct) establishes such a framework, but more work needs to be done.

Budget requests and appropriation figures for this year fall far short of levels authorized by Congress. We recognize there are tight budget constraints, but given the benefits of fuel cell technology and the price we pay today for imported oil, health costs associated with poor air quality and lost productivity due to lack of reliable power, substantial increases in fuel cell technology investment represent a fiscally sound strategy.

While we are pleased that EPAct provides a fuel cell investment tax credit, the term is only for 2 years. We support legislative efforts to extend the tax credit timetable for the maximum length possible.

In addition, as I stated earlier, we believe more attention needs to be paid to ensuring the successful commercialization of near-term fuel cell applications such as transit buses, fleet vehicles and stationary units. There are opportunities today for government purchases of fuel cell technology as part of Katrina reconstruction and pilot programs for schools powered by fuel cells to double as emergency shelters, as well as the concept of fuel cell vehicles exporting power to the grid or critical infrastructure that merit consideration.

Thank you Mr. Chairman for the opportunity to testify. I would be happy to answer your questions.

Senator ENSIGN. Thank you.

Next we will hear from Dr. K.R. Sridhar. Dr. Sridhar is the Chief Executive Officer of Ion America Corporation. I had the honor of visiting your headquarters, and I look forward to hearing what new products you are coming up with and what progress you have made.

STATEMENT OF DR. K.R. SRIDHAR, PRINCIPAL CO-FOUNDER/CEO, ION AMERICA

Dr. SRIDHAR. Thank you, Chairman Ensign, for this opportunity.

My name is K.R. Sridhar, and I'm the Principal Co-Founder and CEO of Ion America, a California-based fuel cell company that's intent on making a revolutionary change in America's energy future.

Ion America's vision is to make distributed energy generation ubiquitous, providing clean, efficient, high-quality, reliable power anywhere. Our technology can be extended to offer a viable energy storage solution. These storage solutions are required for solar and wind; and, also, an economical pathway to the hydrogen economy. That's what Senator Dorgan talked about, of being able to produce hydrogen.

To realize this vision, Ion America has pioneered the development of the first commercially-viable planar solid oxide fuel cell system. This type of stationary fuel cell, operating at higher temperatures than the ones being developed for cars, offers the potential to be more efficient, more reliable, and, importantly, fuel flexible—we have shown that we can use natural gas, propane, ethanol, diesel, all these fuels in the same system—and the least expensive of all fuel cell technologies to manufacture in high volume and also to operate. So, it's the total cost of ownership.

While the high temperature offers great benefits, it also had some inherent technical challenges. And what we have done at Ion America is solve these significant challenges, and we are in the cusp of releasing our first commercial units.

My company can trace its roots to the Federal Government's commitment to innovation. My Co-Founders and I began our fuel

cell research as part of the NASA mission to the Moon and Mars. So, there's a very clear role that the government can play, in terms of innovation, in these fields.

When I left academia and NASA projects 4 years ago to found Ion America, I embarked on a new mission, which was to create an innovative, clean energy technology company with a world-changing commercial product. The key there is creating a clean product that can compete with the grid, at a price point that can compete with the grid. But, in order to achieve that widescale adoption and get to those cost targets, it can only occur when economies-of-scale are reached.

And how do we get there? The way I think the government can help, Mr. Chairman, is not in the classic tools that the government has used to foster innovation. In order to foster the adoption of new innovative energy technologies, the Government needs to take a completely different approach, an approach more about vision and leadership than about new tax policies or research grants.

The Federal Government's key role in our generation's energy independence mission is to ensure two critical things. One, offer us a level playing field between new energy technologies and legacy petroleum-based solutions. So, that level playing field is number one. Number two, be an early adopter marketplace that can help take these new products to their economical sales volumes.

So, let me highlight number two. The Federal Government is the single largest consumer of energy in this country, consuming almost 1 quadrillion BTU's of energy annually, and, in addition to that, spending over $200 billion on products and services. That fact gives it a lot of power and a lot of influence over the energy sector, a lot more influence, perhaps, than legislation ever could. The power of the single largest consumer to shape a market should not be underestimated.

Given the market size and the opportunity, it is my belief that private capital will be readily deployed to develop innovative energy technologies. It's already happening. Venture capital investment dollars can usher new technologies up through product development and testing stages. That's not the bottleneck. But the U.S. Government needs to commit to help American clean-tech companies cross the proverbial chasm and become commercially-viable. This is post-product-development, pre-commercialization. The Federal Government needs to be an early adopter and leading consumer of viable, innovative alternative technologies. Congress should consider putting an alternative energy consumption quota in the Federal budget. If the government mandated that each year 25 or 50 percent of its energy spent will go to alternative energy sources that meet a minimum set of criteria, be it efficiency, or be it energy independence, it would signal a real commitment toward achieving a lasting energy solution. And, on this point, it is very important that the limit that you set is not a fixed limit, it's very dynamic. It is a moving bar; and keep raising that bar.

This isn't a mandate on the private sector. Rather, it's a way for the Federal Government to lead by example; thereby, taking steps to commercialize emerging energy technologies. Once the public sector takes the lead helping technologies achieve scale, the private

sector will follow, and we will be on our path toward energy security and independence.

It is my belief that if the U.S. Government would exercise its buying power when buying power, it would be a monumental step toward supporting innovation and ending our addiction to oil.

Thank you very much for this opportunity, Mr. Chairman.

[The prepared statement of Dr. Sridhar follows:]

PREPARED STATEMENT OF DR. K.R. SRIDHAR, PRINCIPAL CO-FOUNDER/CEO, ION AMERICA

Thank you, Mr. Chairman and members of the Subcommittee, for the opportunity to present testimony on the critical role of the U.S. Government in fostering innovation and technology development in alternative energies.

My name is K.R. Sridhar and I am the Principal Co-Founder and CEO of Ion America, a California-based fuel cell company intent on making a revolutionary change in America's energy future.

Ion America's vision is to make distributed energy generation ubiquitous; providing clean, efficient, high quality, reliable power, anywhere. Our technology can be extended to offer a viable energy storage solution and also an economical pathway to the hydrogen economy.

To realize this vision, Ion America has pioneered the development of the first commercially-viable planar solid oxide fuel cell system. This type of stationary fuel cell, operating at higher temperatures than the ones being developed for cars, offers the potential to be more efficient, more reliable, "fuel flexible," and the least expensive of all fuel cell technologies to manufacture in volume and operate.

While the high temperature offers great benefits, it also poses inherent challenges that have inhibited the commercialization of Solid Oxide Fuel Cell technology . . . until now. Ion America has solved these significant challenges and is on the cusp of releasing our first commercial units.

My company can trace its roots to the Federal Government's commitment to innovation. My Co-Founders and I began our fuel cell research as part of the NASA Mission to the Moon and Mars. For NASA, we were encouraged to look for innovative solutions. Our mission was clear and we knew we had the support of the Federal Government behind us.

When I left academia and NASA projects 4 years ago to found Ion America, I embarked on a new mission: A mission to create an innovative, clean energy technology company with a world-changing commercial product: A fuel cell that produces clean, reliable, on-site electricity at a price competitive with the grid. But in order to achieve wide-scale adoption, products like ours need to achieve the cost reductions that can only occur when economies-of-scale are reached.

How do we get there?

I am here today to testify to the importance of the government's role in continuing to foster innovation—and help companies like mine in our national quest for a clean, secure, energy future. I am here to urge you, Mr. Chairman and Members of the Senate, to take the necessary steps to help commercialize the next generation of innovative energy technology.

How can the government help?

I don't think the answer lies in the classic tools that the government uses to foster innovation. In order to foster the adoption of new, innovative energy technologies, the government needs to take a different approach—an approach more about vision and leadership than about new tax policies, or research grants.

The Federal Government's key role in our generation's "energy independence mission" is to ensure two critical things:

(1) a level playing field between new energy technologies and legacy petroleum-based solutions, and

(2) an early adopter marketplace that can help take new products to their economical volumes.

The Federal Government is the single largest consumer of energy in the country, consuming almost 1 quadrillion BTUs of energy annually and spending over $200B on products and services. That fact gives it a lot of power and a lot of influence over the energy sector. A lot more influence perhaps than legislation ever could. The power of the single largest customer to shape a market should not be underestimated.

Given the market size and opportunity, private capital will be readily deployed to develop innovative energy technologies. Venture capital investment dollars can usher new technologies up through the product development and testing stages, but the U.S. government needs to commit to help American clean-tech companies cross the proverbial chasm and become commercially-viable.

The Federal Government needs to be an early adopter and *leading consumer* for viable, innovative, alternative energy technologies.

Congress should consider putting an alternative energy consumption quota in the Federal budget. If the government mandated that each year 25 or 50 percent of its energy spent will go to alternative energy sources that meet a minimum set of criteria, it would signal a real commitment toward achieving a lasting energy solution. This isn't a mandate on the private sector. Rather it is a way for the Federal Government to lead by example, thereby taking significant steps to commercialize emerging energy technologies. Once the public sector takes the lead helping technologies achieve scale, the private sector will follow and we will be on the path toward energy security and independence.

In order to foster innovation, to enable new energy technologies that address the country's power needs, and to ensure the success of our energy-independence mission, the Federal Government must take the lead. If the U.S. Government would exercise its buying power when buying power it would be a monumental step toward supporting innovation and ending our addiction to foreign oil.

Thank you.

Senator ENSIGN. Thank you.

Our next witness will be Mr. Thomas Werner. Mr. Werner is the CEO of SunPower Corporation.

STATEMENT OF THOMAS H. WERNER, CHIEF EXECUTIVE OFFICER, SUNPOWER CORPORATION

Mr. WERNER. Thank you, Chairman Ensign. I'm honored to have the opportunity to discuss the rapid growth of the solar power industry and how, with strong policy leadership, we are poised for solar to become a mainstream energy resource for the United States within a decade.

Let me start first by telling you a little bit about SunPower Corporation, just briefly. We are the fastest-growing U.S.-based publicly-traded technology company, as measured in terms of revenue growth over the last five quarters. We manufacture the world's most efficient solar cells and panels commercially available. What we do is, we convert sunlight into power. And we do that up to 50 percent more efficiently than anyone else in the world. And you can see, in the picture here, the applications—it's a wide variety of applications—powerplants, built into new homes, residential retrofit, which is the mainstream market, and commercial applications. This is an example of—Microsoft has installed a large system on their building.

Now, let me talk about the market next. The solar market today is a big market. It's a $10 billion market. And it will double, by 2010, to $20 billion. Significantly, the solar market hasn't had a decrease in growth in 25 years. It's grown 20 percent, on average, for 25 years. And, since the year 2000, it's grown 40 percent per year. This is driven by policymakers looking for pollution-free fuel, risk-free, secure peaking power that is well matched to demand for the most expensive power.

Last year, there was about 1,500 megawatts of solar installed. And, to put that in perspective, that's about the size of Pacific Gas & Electric Company's annual revenue, or it is 1/36 of Exxon's revenue. Independent analysts agree that the—however, that the market will double in size by 2010.

And we have about 30 years of market data for solar. And we can look at its ability to reduce cost. And from this data, we can see that if you were to fit a line that, for every doubling of market size, 20 percent of the cost comes out of the product. And, in fact, in 2002, the National Renewable Energy Lab predicted that within the next decade, solar would become economic compared to grid power.

Let's look to an example of this in Japan, where Japan had a 10-year incentive program that just ended. And what we see here, by the bars, is that the blue bar indicates that the price after subsidy, after the 10-year program ended, is now at parity to what it was pre-subsidy. And then, by the triangles, we see that there are over 50,000 systems installed—solar systems installed in Japan without subsidy. So, we see that the idea of an incentive over 10 years—a declining incentive over 10 years has worked in another market.

So, how do we do that in the United States? Let's look at the economics as they exist today. The red line on this chart indicates the economics in Northern California of a 4-kilowatt residential system. And the Y axis indicates the capital cost of that system. And, on the X axis, we have time. And we see that a system today, with incentives, in California, pays back in about 9 years.

Now, SunPower, and the solar industry, in general, is dedicated to creating a market where we don't need incentive. We believe we can accomplish that within the next 5 to 10 years. And you see that in the yellow line. And you see that we'll be able to get to cash-flow breakeven for a consumer that would be less than 5 years. And, again, we think we can accomplish that within the next 5 to 10 years.

Now, let me talk a bit more about SunPower, because we think it's a really good example of how public policy has led to private investment and to a very successful publicly-traded company.

We were founded to develop high-concentration solar PV dish applications, which is to concentrate a lot of sunlight onto a piece of silicon. Those solar cells were very high efficiency, and they're unique in that as much as that their architecture is an all-back contact architecture. These unique high-efficiency solar cells, however, were quite expensive, and were only good for—or were uniquely suited for applications like the NASA *Helios* solar plane.

The company, throughout the 1990s, was seeking ways to pull cost out of the product. And, in early 2002, went to Cypress Semiconductor and created a relationship to move the product into high-volume manufacturing. And this relationship of taking mass production innovative approaches from a semiconductor company and applying them to a solar company has borne fruit. And SunPower has become quite successful marketing the product that you see here. And you see, on the left-hand side, because of the unique architecture, that we have an esthetic advantage, and you see, by the caption on the bottom, that our panel on the same-sized footprint creates more power, and up to 50 percent more power.

So, in summary, the solar power industry has hit commercial production volumes. Solar power is within a decade of achieving mass market adoption in the United States. Predictable policy is driving billions of dollars of private investment. Solar grew up with government research, but now, as we scale, private investment and

innovation is moving it down the cost curve and making it economic with the grid.

And let me end with—the most important thing that you could do to support us would be to extend the long-term solar investment tax credit.

And I look forward to answering your questions.

[The prepared statement of Mr. Werner follows:]

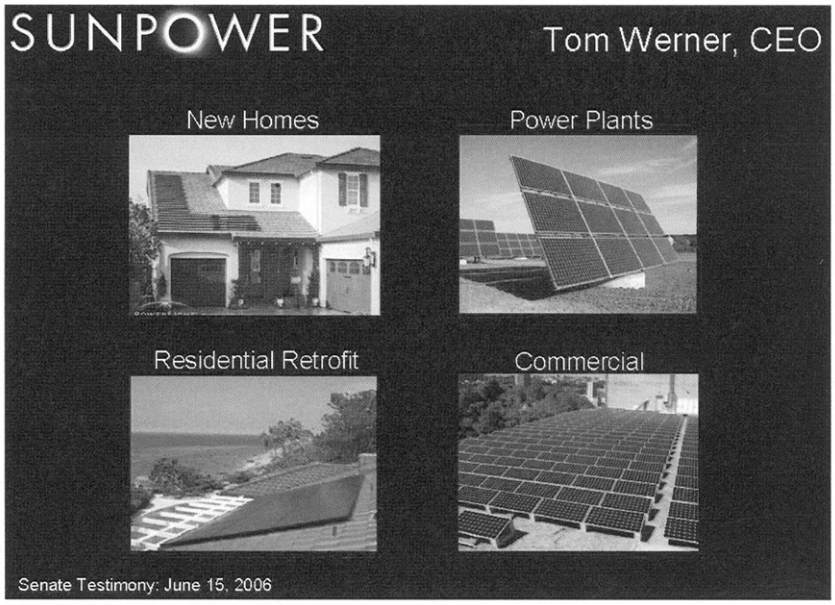
PREPARED STATEMENT OF THOMAS H. WERNER, CHIEF EXECUTIVE OFFICER, SUNPOWER CORPORATION

Thank you, Chairman Ensign, Ranking Member Kerry, and members of the Subcommittee. I am honored to have the opportunity to discuss the rapid growth of the solar power industry. With strong policy leadership, solar power is poised to become a mainstream energy resource for the United States within a decade.

As an example of the current pace of the solar industry, consider my company, SunPower Corporation. We are the fastest growing U.S.-based, publicly-traded technology company in terms of revenue growth over the last 5 quarters.

We design and manufacture the world's most efficient solar power cells and panels commercially available. Our solar technology is up to 50 percent more efficient than conventional technology, meaning that our customers get up to 50 percent more power than conventional technology per unit area. As shown on Slide 1, SunPower solar is used in a wide variety of applications, from suburban rooftops in New Jersey and Japan, to the roof of Microsoft's Silicon Valley campus, to solar power plants in Germany and Spain.

Slide 1: SunPower Solar Power Applications

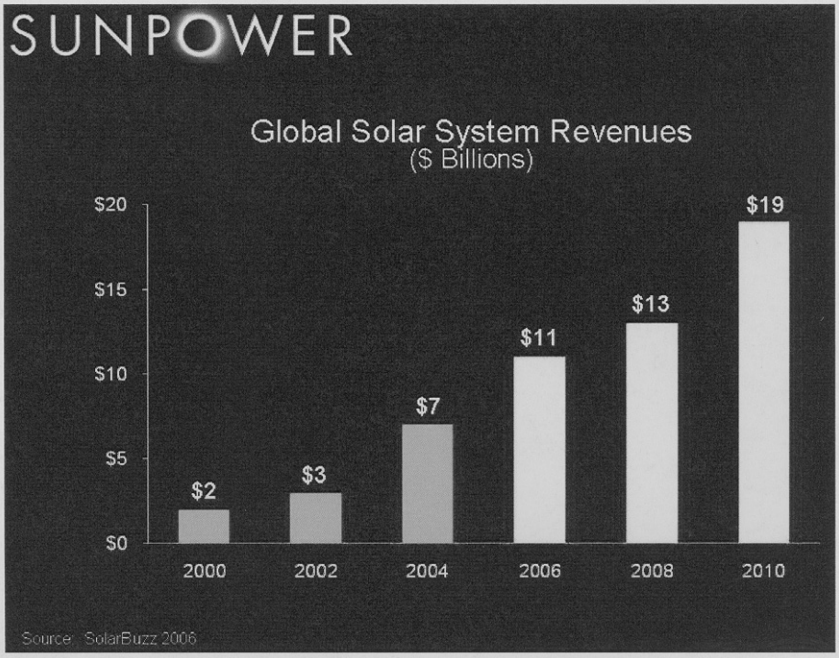


Our growth is tied to the overall development of the global solar market. Most of our solar panels are shipped to Europe and Asia, the location of the most advanced solar markets, while about a quarter of our panels will go to U.S. markets this year. The irony is that the world's two biggest solar markets, Germany and Japan, have far inferior sunlight as compared to most of the U.S.

For the last 25 years, the global solar market has been growing consistently and admirably at a compound annual growth rate in excess of 20 percent. However, since 2000, the global solar market has exploded, growing a compound rate of over 40 percent annually. This very impressive growth started from a small base. In

2005, the about 1,500 megawatts of new solar power were installed, the size of three new natural gas-fired power plants. This translates to about $10 billion in revenue for the industry, a figure expected to double by 2010, as shown in Slide 2. To put this in context, 2005 global solar revenues were comparable to those at Pacific Gas and Electric Company, and ExxonMobil's were 36 times higher.

Slide 2: Global Solar System Revenues by Year



Driving the growth of the solar market are three long-term trends: the persistent decline in the price of solar power technology, the increasing cost of fossil fuels that results in increases in electric retail power rates, and policymakers' focus in increasing the diversity and lowering the risk of our electric power resource mix.

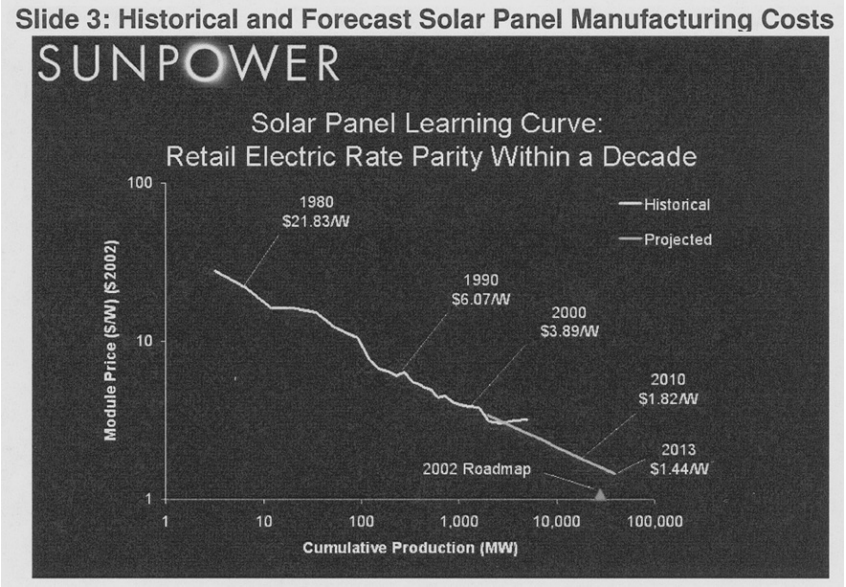
Solar has features that are particularly valuable to energy policymakers. First, because solar is a peaking power resource that generates best when the sun is shining, it is well-matched to the air conditioning demand that drives our growing need for the most costly power in much of the country. As a peaking resource, solar can directly displaces natural gas to the tune of over 4 trillion cubic feet of natural gas, save consumers over $32 billion in the next 20 years. As a customer-sited resource that does not require new transmission lines, solar improves grid reliability and extends the life of current infrastructure. And as a domestic resource, solar is intrinsically lower risk which will reduce our demand for new LNG while creating tens of thousands of new, local jobs. Finally, solar is a particularly popular renewable energy resource. It creates no air pollution, carbon emissions, radiation, or noise, and requires no water.

For just these reasons, much of the early research in solar electric, or photovoltaic, power was performed in the U.S. supported by both public and private funding. As a result, we have 30 years of high-quality cost data showing a classic path of lower product costs achieved with greater manufacturing scale.

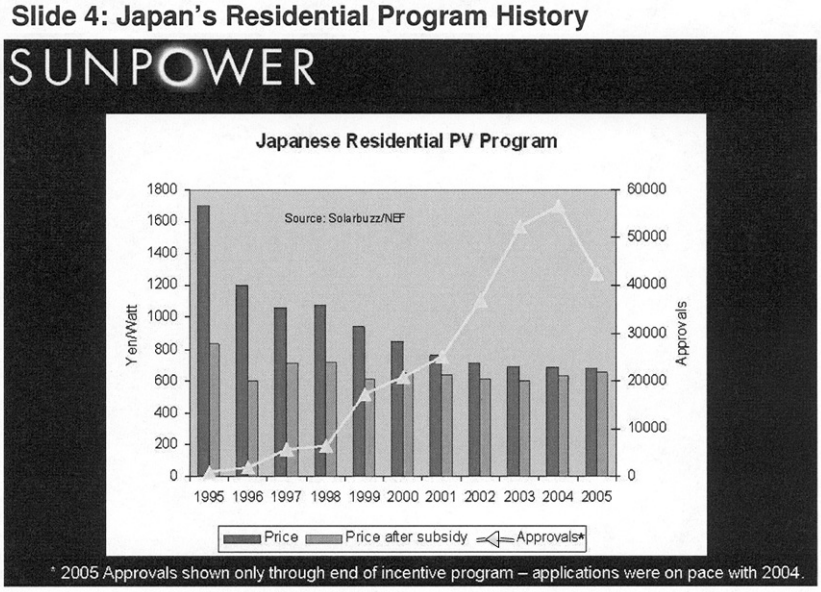
This decade has seen a series of major milestones achieved due to the commercialization of solar power. Manufacturing scale has hit mass-production quantities. Solar market success has squeezed our supply chain and suppliers are racing to catch up to demand for our primary feedstock—polysilicon. And a variety of new, entrepreneurial companies, like SunPower, have formed, begun production and gone public.

All of these indicators support the analysis by the team of industry and academic researchers coordinated by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) in 2002 to assess when solar will meet cost parity with

developed country retail electric rates. They predicted that nexus to occur between 2010 and 2015, as shown in Slide 3. We agree.



With consistent market development policy, commercialization can occur quickly. I say that with confidence because last year Japan concluded their decade-long program of Federal incentives for residential solar systems. Japan's residential market now operates without any federal incentives, installing in excess of 50,000 residential solar systems on existing and new homes annually, as shown on Slide 4.[1]

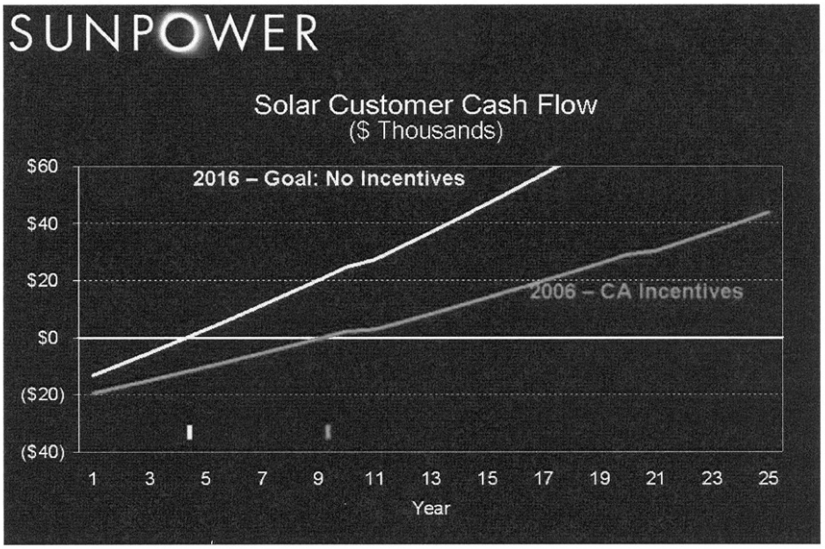


[1] Note that the Japanese federal solar program concluded before the end of 2005, so approvals are for a partial year only, which explains the apparent drop of approvals year on year in 2005.

In the U.S., we have a federal investment tax credit of $2,000 per residential system and a variety of state programs. We are seeing the most market activity in states that have programs to supplement the Federal tax credit, which we are working with our national trade association to extend.[2] With a decade of consistent policy, the solar industry will invest in the technology, manufacturing scale-up and customer delivery infrastructure to bring solar power into the mainstream in most of the country.

Consider the economics for a customer putting solar on their home today in Northern California, as shown on Slide 5. Based on Federal and state incentives and current electric rates, a customer's payback on a solar system can be about 9 years. With the system cost declines we project, and very modest increases in power rates, we expect that payback to drop to under 5 years within a decade. At that point, we believe solar will become a mainstream item that comes with the building, just like a water heater or air conditioning.

Slide 5: Solar Customer Cash Flow Current and Forecast



Achieving this goal in this time-frame is dependent on policy. SunPower is the poster-child for how public and private research dollars lead to major private investments to commercialize technology. We were founded over 20 years ago by Stanford Engineering Professor, Dick Swanson. He was funded by both Federal and private research and development funds to work on very high-efficiency solar cells for use in utility-scale solar power plants. In the 1990s, SunPower developed the highest efficiency solar cells in the world, but they were hand-crafted, expensive and used for specialty applications, like the NASA-funded *Helios* aircraft. *Helios* set the world altitude record for an aircraft and was powered by SunPower solar cells.

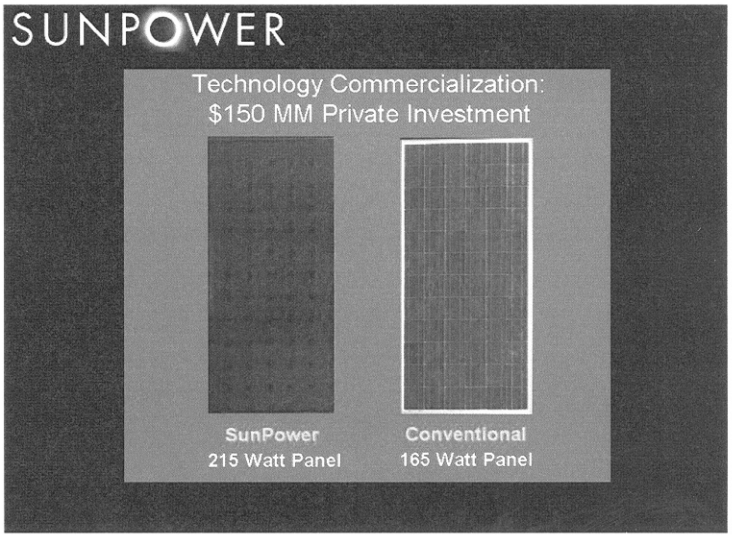
Success with these kind of projects drove SunPower to investigate whether mass manufacturing scale could drop costs to compete with conventional solar technologies. Initially, Dick and his team connected with Cypress Semiconductor for access to manufacturing scaling expertise. In 2002, Cypress bought a controlling interest in SunPower, contributing a total of $150 million of capital as well as manufacturing and management expertise. After proving our ability to commercially produce our high-efficiency solar cells on schedule and on budget, we went public on NASDAQ last November.

Our technology is a step-change in sunlight-to-power conversion efficiency and our technological advantage is driving the competition to improve their solar cells efficiency as well. Improvements in solar cell efficiency combined with the move to thinner solar cells, better solar panel design and development of scalable customer delivery infrastructure will drive solar power costs to parity with retail electric rates within a decade in much of the U.S.

[2] The Solar Energy Industries Association supports S. 2677/H.R. 5206.

In addition, the aesthetic improvement offered by our technology, an outgrowth of our all-back contact solar cell, has turned out to be a major competitive advantage, because customers prefer a solar panel that blends into their roof, as demonstrated by Slide 6. This kind of basic product design and marketing will be crucial as we move from the early stages of market adoption of solar power to mass-market adoption.

Slide 6: SunPower Solar Panel Comparison to Conventional Technology



Let me emphasize, the solar power industry will reach grid parity with incremental improvements in engineering and business processes. We do not need new breakthroughs in the science of sunlight conversion to power to achieve mass market adoption of solar. We do need to improve the packaging of solar cell into solar panels, a task SunPower is working on under a DOE contract, and we need to radically improve the customer's buying experience. We appreciate President Bush's interest and support of our industry, in the form of the Solar America Initiative, and strongly endorse extension of the solar investment tax credit.

In summary:

- The solar power industry has hit commercial production volumes.
- Solar power is within a decade of achieving mass-market adoption.
- Predictable policy is driving billions of dollars of private investment.
- Solar grew up with government research; it now needs engineering.

Senator ENSIGN. Well, thank you very much.

Next we'll hear from Peter Corsell. Mr. Corsell is the President and CEO of GridPoint, Incorporated.

STATEMENT OF PETER L. CORSELL, PRESIDENT/CEO, GRIDPOINT, INC.

Mr. CORSELL. Good morning, Mr. Chairman. Thank you for inviting me today and for giving GridPoint the opportunity to discuss our perspective on the emerging clean energy industry and how these technologies can benefit the American consumer, as well as the country's energy infrastructure and the broader U.S. economy.

My name is Peter Corsell, and I'm President and CEO of GridPoint, an intelligent energy management company headquartered here in Washington, D.C. We are a privately-held com-

pany and have funded our product development entirely with private equity.

Mr. Chairman, with your permission, I would like to insert my written statement in the hearing record, and I will provide a brief summary.

We, at GridPoint, believe the——

Senator ENSIGN. By the way, all of your full statements will be made part of the record.

Mr. CORSELL. We, at GridPoint, believe the energy industry can adopt some of the same models used in the personal computer, Internet, and telecommunications markets to empower users with information and communication tools that will reduce energy costs and increase energy efficiency. At GridPoint, our mission is to introduce a transformative technology for the energy industry, one that applies intelligence to energy consumption and empowers the consumer to enjoy cleaner, more reliable, and more affordable energy.

GridPoint has developed a suite of intelligent energy management products that integrate renewable energy sources, reduce energy costs, increase reliability, and automatically manage energy consumption. In doing so, we have created an entirely new product category, applying the same logic used by digital video recorders to energy. For this reason, our initial product offering has often been described as a "TiVo for energy management."

GridPoint's flagship energy management product is an elegant turnkey appliance that serves as an intelligent hub between the customer, the electric power grid, and a renewable energy source. The appliance combines batteries, power electronics, and a computer that makes intelligent decisions in a real-time, data-rich environment to optimize energy usage. The appliance provides four key benefits to the consumer: a simple way to integrate solar panels, wind turbines, and fuel cells; a significant reduction in electricity costs; instant, clean, silent backup power in the event of an outage; and the ability to monitor and automatically control energy consumption.

The GridPoint appliance is about the size of a small refrigerator and is installed in the basement, garage, or storeroom of a home or business. It connects to a renewable energy source, electric utility meter, the main circuit-breaker panel, and GridPoint's network operations center over a broadband or dial-up Internet connection. Just like TiVo, each GridPoint appliance is in constant communication with our network operations center, obtaining up-to-the-minute information on utility rate schedules, weather forecasts, and more. Users access the system by logging onto a personal account on our website, similar to online banking, which provides clear and detailed information on the user's energy consumption and production, aggregate savings, and environmental impact.

GridPoint's intelligent energy management technology works hand-in-hand with various renewable energy generation technologies, such as those represented on today's panel. Our goal is to empower mainstream consumers to more easily integrate and benefit from these brilliant innovations. For example, in the context of a solar photovoltaic installation, the GridPoint appliance serves as

an advanced operating system and meets an emerging need in the market for renewable energy integration.

Traditionally, solar energy pioneers have been hobbyists who build custom systems for specific applications. As we've just heard, that's changing, and solar is going mainstream. This former approach resulted in unnecessary costs and complexities, and did little to fuel the mainstream adoption for solar panels. These systems generally took days to assemble and lacked any meaningful safety or performance monitor. In contrast, GridPoint has integrated the various pieces and parts associated with the traditional solar installation into an advanced turnkey appliance that is easy to install and safe to operate.

GridPoint also allows customers to create a personal energy profile to automatically manage energy consumption based on their individual preferences. For instance, when a home or business is unoccupied, users can select a profile to interrupt high-energy-consuming devices, or, conversely, to operate key appliances during periods when utility rates are low.

In short, GridPoint's technology transforms consumers from passive energy users into active energy market participants. For example, GridPoint products have the capability to automatically leverage time-of-use pricing, purchasing electricity when utility rates are low, and tapping stored energy when utility rates are high. The Energy Policy Act of 2005 passed by Congress mandates that utilities provide such rate schedules to their customers by February 2007. This is an important capability, because a utility's prices can change as much as 7—as much as 37 times during a single day. A typical average would be 8 cents at off-peak, and 31 cents at peak, but it can rise to more than $1 per kilowatt-hour during critical peak-pricing events.

Electric utilities also benefit from our technology, because they can draw upon the stored power in each GridPoint appliance; thereby, reducing their peak-demand costs, enhancing grid reliability, and introducing a measure of network elasticity into the electric grid. For example, a group of 5,000 GridPoint appliances can deliver approximately 36 megawatts of power into the electric grid for several hours, the equivalent of a modest powerplant operating at peak capacity.

Rather than attempting to address the enormous and costly issues associated with strengthening our aging electrical system at the transmission level, GridPoint is using advanced technology to enhance the grid's reliability at the point-of-use, in the home and business.

Once thousands of GridPoint appliances have been deployed, our company will become an important enabler of the emerging "Smart Grid," which uses computing technology to dramatically improve the reliability and efficiency of the electric power grid.

The government can play a key role in the adoption of alternative technologies, especially by establishing programs, rebates, and tax incentives to stimulate the adoption of renewable energy systems. For example, the ENERGY STAR© Program, implemented by the Environmental Protection Agency to help customers choose energy-efficient appliances, equipment, and homes, is a terrific program with which GridPoint is proud to be associated.

We, at GridPoint, believe that empowering consumers to take control of their energy consumption is critical to solving our current and future energy supply challenges, as well as reducing our negative impact on the environment. We are pleased to offer our expertise and experience to Congress and the Administration as you address these issues.

Thank you, again, for allowing me to testify. I look forward to answering any questions you might have.

[The prepared statement of Mr. Corsell follows:]

PREPARED STATEMENT OF PETER L. CORSELL, PRESIDENT/CEO, GRIDPOINT INC.

Mr. Chairman, Ranking Member, and other members of the Committee, good morning. Thank you for inviting me today and for giving GridPoint the opportunity to discuss our perspective on emerging clean energy technologies and how they can benefit the American consumer, as well as our country's energy infrastructure and the broader U.S. economy.

My name is Peter L. Corsell and I am President and CEO of GridPoint, an intelligent energy management company headquartered here in Washington, D.C. We are a privately held company and have funded our product development with private equity. Mr. Chairman, with your permission, I would like to insert my written statement in the hearing record, and I will provide a brief summary.

We at GridPoint believe the energy industry can adopt some of the same models used in the personal computer, Internet, and telecommunications markets to empower users with information and communication tools that will reduce energy costs and increase energy efficiency. At GridPoint, our mission is to introduce a transformative technology for the energy industry, one that applies intelligence to energy consumption and empowers the consumer to enjoy cleaner, more reliable and more affordable energy.

GridPoint has developed a suite of intelligent energy management products that integrate renewable energy sources, reduce energy costs, increase reliability, and automatically manage energy consumption. In doing so, we have created an entirely new product category, applying the same logic used by digital video recorders to energy. For this reason, our initial product offering has often been described as the "TiVo of energy management."

GridPoint's flagship energy management product is an elegant, turnkey appliance that serves as an intelligent hub between the customer, the electric power grid, and a renewable energy source. The appliance combines batteries, power electronics, and a computer that makes intelligent decisions in a real-time, data-rich environment to optimize energy usage. The appliance provides four key benefits to the consumer: (1) a simple way to integrate solar panels, wind turbines, and fuel cells; (2) a significant reduction in electricity costs; (3) instant, clean, silent backup power in the event of an outage; and (4) the ability to monitor and automatically control energy consumption.

The GridPoint appliance is about the size of a small refrigerator and is installed in the basement, garage, or storeroom of a home or business. It connects to a renewable energy source, the electric utility meter, the main circuit breaker panel, and GridPoint's network operation center over a broadband or dial-up Internet connection. Just like TiVo, each GridPoint appliance is in constant communication with our network operations center, obtaining up-to-the minute information on utility rate schedules, weather forecasts, and more. Users access the system by logging on to a personal account on our website, similar to online banking, which provides clear and detailed information on the user's energy consumption and production, aggregate savings, and environmental impact.

GridPoint's intelligent energy management technology works hand-in-hand with various renewable energy generation technologies, such as those represented on today's panel. Our goal is to empower mainstream consumers to more easily integrate and benefit from these brilliant innovations. For example, in context of a solar photovoltaic installation, the GridPoint appliance serves as an advanced operating system and meets an emerging need in the market for renewable energy integration. Traditionally, solar energy pioneers were hobbyists who built custom systems for specific applications. This approach often resulted in unnecessary costs and complexities, and did little to fuel the mainstream adoption of solar panels. These systems generally took days to assemble and lacked any meaningful safety or performance monitoring. In contrast, GridPoint has integrated the various pieces and parts

associated with traditional solar installations into an advanced, turnkey appliance that is easy to install and safe to operate.

GridPoint also allows customers to create a personal energy profile to automatically manage energy consumption based on their individual preferences. For instance, when a home or business is unoccupied, users can select a profile to interrupt high energy consuming devices or, conversely, to operate key appliances during periods when utility rates are low. In short, GridPoint's technology transforms consumers from passive energy users into active energy market participants.

For example, GridPoint products have the capability to automatically leverage time-of-use pricing, purchasing electricity when utility rates are low and using stored energy when utility rates are high. The Energy Policy Act of 2005 passed by Congress mandates that utilities provide such rate schedules to their customers by February 2007. This is an important capability because a utility's prices can change as much as 37 times during a single day. A typical average would be 8 cents at off-peak and 31 cents at peak, but it can rise to more than $1 per kilowatt-hour during critical peak pricing events.

Electric utilities also benefit from our technology because they can draw upon the stored power in each GridPoint appliance, thereby reducing peak demand costs, enhancing grid reliability, and introducing a measure of network elasticity to the electric grid. For example, a group of 5,000 GridPoint appliances can deliver approximately 36 megawatts of power to the electric grid for several hours—the equivalent of a modest power plant operating at peak capacity.

Rather than attempting to address the enormous and costly issues associated with strengthening our aging electrical system at the transmission level, GridPoint is using advanced technology to enhance the grid's reliability at the point-of-use—in the home and business. Once thousands of GridPoint appliances have been deployed, our company will become an important enabler of the emerging Smart Grid, which uses computing technology to dramatically improve the reliability and efficiency of the electric power grid.

The government can play a key role in the adoption of alternative energy technologies, especially by establishing programs, rebates, and tax incentives to stimulate the adoption of renewable energy systems. For example, the ENERGY STAR© Program—implemented by the Environmental Protection Agency to help consumers choose energy-efficient appliances, equipment, and homes—is a terrific program with which GridPoint is proud to be associated.

We at GridPoint believe that empowering consumers to take control of their energy consumption is critical to solving our current and future energy supply challenges, as well as reducing our negative impact on the environment. We are pleased to offer our expertise and experience to Congress and the Administration as you address these issues. Thank you again for allowing me to testify. I look forward to answering any questions you might have.

Senator ENSIGN. Thank you.

Our next witness, Dr. Taylor, is the CEO of Ocean Power Technologies.

Dr. Taylor?

STATEMENT OF DR. GEORGE W. TAYLOR, CHIEF EXECUTIVE OFFICER, OCEAN POWER TECHNOLOGIES, INC.

Dr. TAYLOR. Thank you, Chairman Ensign.

Senator ENSIGN. Dr. Taylor could you please pull the microphone closer to you. Thank you.

Dr. TAYLOR. OK. Thank you, Chairman Ensign. I am very honored to be here today and to be able to share with you the progress that we have made toward the commercialization of wave energy conversion technology as a means of supplying clean, renewable, and much-needed power to our Nation's grid.

While significant progress has been made, there is much more to do to realize the potential of the energy stored in the Earth's oceans. I hope that in the next few minutes I can impress upon you that the wave energy is commercially-viable, that it has the potential to supply significant amounts of power in areas where it is

needed most, and that the Federal Government can, and should, play a role in encouraging and supporting the growth of this rapidly advancing technology.

Let me start by saying why we believe wave energy makes sense for the United States. More than 53 percent of the U.S. population live near the coast, so, in the future, where are we going to put new power stations? We contend that the ocean is one of the best answers. In fact, the world's energy demand could be met if only 0.2 percent of the ocean's untapped energy could be captured. And while we do not propose that all the Nation's power needs can be supplied from wave power, we believe that a significant portion can. A good example of this is California. Several hundred square miles of surface area of the ocean off the long coastline of California could supply the electrical power needs for all the homes in California.

The Electrical Power Research Institution, EPRI, has conducted a comprehensive economic study of wave power generation. This study concludes that the economics of wave energy could be at least as favorable as wind generation if the same resources that have been invested in wind and solar energy were invested in wave energy. We believe that the cost of wave-generated energy has the potential, with the proper investment, to approach that of conventional fossil fuel energy in the next 5 years.

Wave energy has several distinct advantages over other types of renewable energy. It has the highest power density, excellent availability, and predictability. Water is about 1,000 times more dense than air, and this allows smaller, lower-cost wave energy conversion devices to extract more from a smaller footprint.

Think of waves as a natural means of storing energy. Solar radiation creates the wind, and the wind creates the waves. Long after the wind subsides, the waves continue across the ocean until they reach the shoreline. And waves don't know night from day, which is why, on some parts of the coast, the availability of wave power stations can be as high as 80 to 90 percent.

One of the major advantages of wave power is that at nighttime, when the electrical energy usage is low, wave energy can be used for economically powering desalination plants using the saltwater where the electricity is being generated. Equally well, it can be used, with an electrolyzer, to convert the water into hydrogen and oxygen, and, thereby, provide the hydrogen needed for fuel cells.

Wave propagation is also highly predictable. As much as 24 hours in advance, one can tell what the wave energy is going to be. And these two advantages, of availability and predictability, have caught the attention of electrical utilities as they search for emerging technologies that can supply reliable power to our Nation's grid.

While there has been much debate concerning the aesthetics of other forms of renewable energy, our wave power systems are primarily concealed below the surface of the ocean. They have a very low surface profile, making them almost invisible from the land. In discussions that we've held with coastal residents in different parts of the U.S. and other parts of the world, we have learned that the low visual impact of our system is seen as a tremendous benefit.

I'd now briefly like to give you an overview of our company, where—and particularly where we are from the standpoint of commercialization.

Ocean Power Technologies, or OPT, is based in New Jersey. It's focused on commercializing our device, which we call our PowerBuoy™, for both utility-scale wave power stations that are connected to the grid, as well as autonomous remote systems for ocean-based defense and security. From 1994 to 2003, our company was primarily focused on research and development. Since then, we have been developing, for the U.S. Navy, a wave power station at the Marine Corps Base in Hawaii that will be connected to the Oahu grid. This project has received strong support from the Hawaiian and the New Jersey Congressional delegations, for which we are very appreciative. And I'd particularly like to point out that we've had tremendous encouragement from Senator Inouye in what we have been doing in Hawaii.

It's also worth noting that an independent environmental assessment was conducted in Hawaii, with a finding of no significant impact. In September of 2004, we successfully ocean tested, off the State of Washington, a prototype of an autonomous PowerBuoy™ system for a contract that Lockheed Martin has with the Navy.

Various governments in Europe have put into place strong initiatives to foster wave energy projects. Recognizing the European demand for renewable power, we have signed agreements with Total, the large French oil company, and with Iberdrola, the utility in Spain which is the largest utility in Europe, in terms of its usage of renewable energy. These two projects to build prototype wave power stations in France and Spain are underway. The British Government, interestingly enough, has recently set aside 50 million pounds to encourage wave energy.

We also received a contract from the Department of Homeland Security this year to provide power for ocean-based security systems. And we are currently evaluating opportunities in the U.S. for utility-scale wave power stations.

However, as we seek to progress from demonstration to the implementation of large commercial wave power stations, we believe there needs to be a more cohesive national policy to facilitate the commercial roll-out of wave power. As I noted, other countries, such as the U.K., are doing this. We have the momentum here in the U.S. And, while Europe has profited, in the early years of wind-energy development, we believe the U.S. is in a strong position to lead the world in wave energy commercialization.

We request that this committee include, or help to include, wave energy in the Nation's comprehensive policy to use renewable energy. This will give a strong message to the Nation's utilities, capital markets, and investment community that wave power is recognized by the government as an important source of renewable energy.

To this end, I would like to encourage Congress, and this committee, to consider the following actions to provide support for wave energy commensurate with that which has been provided previously for wind and solar, include wave energy in the production tax credit, modify the FERC's statutes to allow for the rapid permitting of wave power stations, and ensure that the MMS rules

that are being developed allow for the timely development of wave power systems.

In conclusion, I'd like to thank you for your judgment to include wave energy in this hearing. The success of new technologies is about vision, leadership, and courage to do what has never been done before.

Thank you.

[The prepared statement of Dr. Taylor follows:]

PREPARED STATEMENT OF DR. GEORGE W. TAYLOR, CHIEF EXECUTIVE OFFICER, OCEAN POWER TECHNOLOGIES, INC.

Good morning, Chairman Ensign, and distinguished Committee members. My name is Dr. George Taylor and I am the Chief Executive Officer of Ocean Power Technologies, Inc. I am honored to be here today to share with you the progress that has been made toward the commercialization of wave energy conversion technology as a means of supplying clean, renewable—and much needed—power to our Nation's electricity grid. And while significant progress has been made, there is much more to do to realize the potential of the energy stored in our Earth's oceans. I hope that in the next few minutes I can impress upon you that wave energy is commercially-viable, that it has the potential to supply significant amounts of power in areas where it is needed most, and that the Federal Government can and should play a role in encouraging and supporting the growth of this rapidly advancing technology.

Let me start by saying why we believe wave energy makes sense for the United States. More than 53 percent of the U.S. population lives near the coast. So in the future, where are we going to put the power stations?

We contend that the ocean is one of the best answers. In fact the world's energy demand could be met if only 0.2 percent of the oceans' untapped energy could be captured. And while we do not propose that all of the Nation's power needs can be supplied from wave energy—we believe that a significant portion can. For example, several hundred square miles of area off the California coast, could supply the electrical power needs for all of California's homes.

The Electrical Power Research Institute, EPRI, has conducted a comprehensive economic study of wave power generation. This study concludes that the economics of wave energy could be at least as favorable as wind generation if the same resources that have been invested in wind and solar energy were invested in wave energy. We believe the cost of wave generated energy has the potential—with the proper investment—to approach that of conventional energy in the next 5 years.

Wave energy has the distinct advantage over other renewable energy sources, in that it has high-power density, excellent availability, and predictability. Water is about 1,000 times more dense than air allowing smaller, lower cost wave energy conversion devices to extract more energy from a smaller footprint. Think of waves as a natural means of storing energy. Solar radiation creates wind. Wind creates waves. Long after the winds subside, the waves continue. And waves don't know night from day—which is why on some parts of the coast the availability of a wave power station could be as high as 80 to 90 percent. One of the major advantages of wave power is that at nighttime, when electrical energy usage is low, wave energy can be used for economically powering desalination and hydrogen production utilizing the surrounding water. Wave propagation is also highly predictable as much as 24 hours in advance. Availability and predictability are two features that have caught the attention of electric utilities as they search for emerging technologies that can supply reliable power to our Nation's grid.

While there has been much debate concerning the aesthetics of other forms of renewable energy, our wave power systems are primarily concealed below the surface of the ocean. They have very low surface profiles, making them almost invisible from land. In discussions with coastal residents we have learned that the low visual impact of our system is seen as a tremendous benefit.

I would now like to give you a brief overview of our company, with emphasis on where we are from the standpoint of commercialization. Ocean Power Technologies, Inc. (OPT), based in New Jersey, is focused on commercializing its proprietary PowerBuoy™ technology for both utility-scale wave power stations that are connected to the grid, as well as autonomous remote power systems for ocean-based defense and security systems.

From 1994 to 2003, our company was primarily focused on research and development and ocean testing of small PowerBuoys™.

Since then, we have been developing for the U.S. Navy a wave power station at Marine Corps Base Hawaii, that will be connected to the Oahu grid. This project has received strong support from the Hawaii and New Jersey Congressional delegations, for which we are very appreciative. It is also important to note that an independent environmental assessment was conducted, with a finding of no significant impact. In addition, in September of 2004 we successfully ocean-tested off the State of Washington a prototype of our autonomous PowerBuoy™ system with Lockheed Martin, under a Navy contract.

Various governments in Europe have put in place strong initiatives to foster wave energy projects. Recognizing the European demand for renewable wave energy, we have signed agreements with Total and Iberdrola to develop wave power stations in France and Spain. Total is one of the largest oil and gas companies in the world, and Iberdrola is Europe's largest utility in renewable energy. These projects are now moving forward.

In 2005, we completed the installation of a PowerBuoy™-off-the-coast of Atlantic City, New Jersey to further validate the viability of the technology. This project was funded by the New Jersey Board of Public Utilities as part of their significant support of green energy.

In early 2006, we received a contract from the Department of Homeland Security for the first phase of a project to provide power for ocean-based security systems.

Today, our company is evaluating additional opportunities in the United States for utility-scale wave power stations. However, as we seek to progress from demonstrations to the implementation of large, commercial wave power stations, we believe there needs to be a more cohesive national policy in place to facilitate the commercial roll-out of wave power technologies. Other countries *are* doing just that.

Today we have momentum. While Europe profited in the early years of wind energy development, we believe that the U.S. is in a strong position to lead the world in wave energy commercialization.

We request your action to include wave energy in this Nation's comprehensive policy to increase utilization of renewable energy. This will serve to give a strong message to the Nation's utilities, capital markets and investment community that wave power projects are recognized by the government as an important source of renewable energy. With the resulting commitment of all those parties, will come the development needed to make wave energy commercially competitive.

To that end, I encourage Congress and this committee to consider the following actions:

1. Provide support for wave energy commensurate with that which has been provided previously for wind and solar energy.
2. Include wave energy in the Production Tax Credit (PTC).
3. Modify FERC statues to allow for the rapid permitting of wave power stations.
4. Insure that the MMS rules that are being developed allow for the timely development of pilot-scale wave energy projects.

In conclusion, let me thank your for your judgment to include wave energy in this hearing. The success of new technologies is about vision, leadership, and courage to do what has never been done before.

Senator ENSIGN. Thank you.

Our final witness today, Mr. Daniel Raudebaugh, is the Executive Director of the Center for Transportation and the Environment.

STATEMENT OF DANIEL J. RAUDEBAUGH, EXECUTIVE DIRECTOR, CENTER FOR TRANSPORTATION AND THE ENVIRONMENT (CTE)

Mr. RAUDEBAUGH. Thank you, Mr. Chairman, for the opportunity to address the Committee today about the challenges related to alternative energy technologies.

I appreciate your focus on this important topic in these days of challenging gas prices and the struggles related to our dependence on foreign oil. As the Executive Director of a transportation-focused nonprofit consortium, my members address these challenges on a

daily basis and appreciate the larger and more comprehensive issues we face.

I am the Executive Director for the Center for Transportation and the Environment. CTE has played a pivotal role in the development of many clean, advanced transportation technologies throughout the United States. Our nonprofit is a facilitator for research and has managed more than $80 million in cost-shared research, demonstration, and development projects in partnership with more than 100 businesses, universities, and government entities.

CTE is also recognized nationally for our expertise in the design, measurement, and evaluation of transportation demand management programs. CTE conducts research in Georgia, Arizona, and Montana, and manages the National Association for Commuter Transportation.

In 2004, CTE expanded our efforts and initiated the Southern Fuel Cell Coalition, a member-based organization established to promote and accelerate hydrogen fuel cell transportation technology development in the Southeastern U.S.

As you know, the U.S. consumes 25 percent of the world's petroleum, two-thirds of which is consumed by the transportation sector. Some of the transportation technologies our members have been working on offer a great promise to reduce our petroleum dependency by bringing electric, hybrid electric, and fuel cell-powered vehicles into the marketplace.

A couple of examples I'd like to mention today:

First, a flywheel battery system developed by the University of Texas and tested by Test Devices, Inc. in Massachusetts. This flywheel system has the potential to become an enabling technology to bring hybrid and fuel cell vehicles into the marketplace. It offers unmatched power recovery and delivery profile, and it shows the potential to have a cycle-life greater than the life of the vehicle itself. A computer-controlled active suspension system, also developed at the University of Texas, that not only improves ride and handling, but can extend the life of the critical vehicle systems and has the potential, in a hybrid vehicle configuration, to recover energy typically lost as heat in mechanical suspension systems. A hybrid electric drive developed by SK International, a Georgia-based small business, that achieves 17.5 miles per gallon in a 35-foot, 30,000-pound bus, as tested by our testing and research partner, ATTI, in Chattanooga. A bus this size typically gets approximately 6 miles to the gallon. A hybrid vehicle developed by DRS, in Huntsville, Alabama, that, when tested on a Humvee for the military, delivered twice the power of a traditional Humvee, and also demonstrated twice the fuel efficiency. DRS is now focusing, as one of my colleagues from United Technology Corporation mentioned earlier, on the ability of a hybrid-powered vehicle to provide amounts of electric power to electric-consumer loads. This is of significant importance to both the Departments of Defense and Homeland Security. Hybrid-powered buses, trucks, and civil government vehicles can easily provide emergency power for traffic light operation, emergency shelters, emergency operation centers, and hospitals.

CTE has just been named as one of the four finalists to manage the FTA National Fuel Cell Bus Program. Our portfolio is high-

lighted by a fuel cell bus demonstration project in Hawaii that leverages both—work done by the Air Force and the Hawaii Center for Advanced Transportation Technologies. Some other CTE members focusing on fuel cells for transportation include Stennis Space Center, in Mississippi, Georgia Tech, United Technologies, in Connecticut, and Savannah River National Lab and Oak Ridge National Lab, in Tennessee.

Beyond the technologies, my full statement provides additional information on four key areas we would like to see more emphasis placed as we move down the path toward energy independence. One, we must bridge the gap between basic research and commercialization. Two, we must take advantage of the tremendous potential that lies outside the major automobile manufacturers and energy suppliers. Three, we must not overlook the value of the heavy-duty vehicle industry, particularly the transit bus market. As Congress considers the best agency to increase discretionary research funding, the FTA's a great place to start. And, four, we must increase our focus on developing prototype vehicles and getting them into the marketplace.

To make sure the United States is a leader in the clean transportation market, it will require a commitment on the part of the U.S. Government to support more than just pure research. We must invest heavily in getting our products out of university laboratories and onto the streets. We must invest in prototype development, market appraisal, and manufacturing analyses. We must increase funding to encourage collaborative efforts between government, utilities, and industry, including incentives for small businesses to partner with the universities to capture the potential for innovation that lies within each. We must focus more on the heavy-duty vehicle market, not only for its impact on petroleum use, but because the bus market offers the best testbed for new transportation technologies. CTE works to establish the needed industrial/university/government relationship to bridge the gap between basic research and commercialization and to bring the best transportation research ideas to market.

We look forward to working with the Senate Subcommittee on Technology, Innovation, and Competitiveness from both a public-policy and a technology research and demonstration perspective as we pursue energy independence for the United States and cleaner air for our citizens.

Once again, thank you for the opportunity to share our progress with you today, and I'm happy to take questions.

[The prepared statement of Mr. Raudebaugh follows:]

PREPARED STATEMENT OF DANIEL J. RAUDEBAUGH, EXECUTIVE DIRECTOR, CENTER FOR TRANSPORTATION AND THE ENVIRONMENT (CTE)

About CTE

Since its founding in 1993, the Center for Transportation and the Environment (CTE), formerly the Southern Coalition for Advanced Transportation (SCAT), has played a pivotal role in the development of many clean, advanced transportation technologies throughout the United States. A 501(c)(3) nonprofit, CTE has managed a portfolio of more than $80 million in cost-shared research, demonstration, and development projects in partnership with more than 100 businesses, universities, and government entities involved in the advanced transportation industry. These projects have included a broad range of transportation-related challenges including technology development, testing, public awareness campaigns, educational pro-

grams, marketing research, and commuter behavior studies. CTE has facilitated funding for these projects from the Departments of Defense, Energy, Interior, and Transportation, U.S. Army, and NASA as well as from state and local sources.

The following is a sample list of a few of the more than 70 Electric and Hybrid Electric Vehicle Demonstration programs CTE has successfully managed over the past 12 years:

Flywheel Safety and Containment Program—Resulted in flywheel systems with known lifetimes and known margins of safety at the end of their specified lifetimes. This information provides a solid technical basis for emerging flywheel applications for transportation and for space.

Development of Advanced Technologies for a Hybrid Electric Bus—Working with the University of Texas Center for Electromechanics, this project developed and/or integrated four advanced technologies (flywheel battery, wheel motor, active suspension, and vehicle management system) onto an advanced technology transit bus originally developed by Northrop Grumman.

Advanced Locomotive Propulsion System—Working with six public and private team members, developed a fossil fueled locomotive capable of sustained speeds of 150 mph with acceleration comparable to an electric locomotive, improved reliability and efficiency, and reduced emissions.

Accelerated Fleet Integration of Medium- and Heavy-Duty EV/HEV Technologies—Launched an aggressive technical support program to accelerate the introduction of electric vehicle and hybrid electric vehicle technologies into fleets in Atlanta and surrounding regions.

Georgia Bus Project—Designed, manufactured, and tested a low-speed industrial motor system in a heavy-duty, 34-foot Blue Bird bus owned and operated by Georgia Power.

Fast Charge Evaluation—Over a twelve-month testing period at Hartsfield-Jackson Atlanta International Airport, demonstrated the viability of industrial rapid charging and the cost effectiveness of electric ground support equipment in a high demand application for airlines.

Integrated EV/HEV Drive System for Enhanced Vehicle Performance and Range—Significantly increased the performance of electric and hybrid electric transit buses and military vehicles in terms of range, longer battery life, and the ability of the vehicle to climb significant grades of 12 percent or higher.

Advanced Battery Charge Management—Using a newly patented fuzzy logic methodology in combination with known electronic diagnostic techniques, this program reliably determined state of charge in lead-acid batteries, ultimately as a means to improve the accuracy of electric vehicle "gas gauges."

Hybrid Electric HMMWV—Developed and tested a hybrid electric tactical vehicle (Humvee) for the U.S. Armed Forces that exhibited superior automotive performance, increased fleet average fuel economy by 30 percent, and provided 30 kW of mission and/or off-board auxiliary power, thus eliminating the need for towed generators and certain prime movers.

Advanced Hybrid Electric HMMWV—Incorporated numerous advanced technologies and components into the existing hybrid electric HMMWV developed under DARPA funding to improve and expand various capabilities such as mobility, silent watch, survivability, active suspension, and advanced electronic concepts.

Solid State Heat Capacity Laser Mobility Platform and Pulse Forming Supply—Provided a close-in air defense advanced laser weapon system mounted on a suitable mobile platform for increased protection of the front-line troops.

Improved Cost and Performance EV/HEV Powertrains—Developed an improved cost and performance inverter for electric/hybrid powertrains in conjunction with GE and Analog Devices.

Diesel Auxiliary Power Unit (APU)—Developed a natural gas APU using the Unique Mobility 75 kW traction motor and a John Deere engine.

Back Bay Project—Developed a transportation system to move visitors to a state park and Federal wildlife refuge. This system uses all-electric trams and a custom-developed all-terrain beach vehicle.

Computer Controlled Suspension—Demonstrated concept in a single wheel test rig, developed 4-corner algorithm, and then developed a linear actuator which significantly exceeded its goals. The system, developed by the University of Texas is now being tested on a HMMWV with impressive results to date.

APU for 22′ Bus—Integrated a Capstone Turbine into an AVS 22′ electric bus.

Efficient EV Lighting—Developed, built and tested LED light fixtures to replace less efficient incandescent bulbs for EV light sources. The program was led by the Florida Solar Energy Center.

31-Foot All Electric Bus—Developed AVS 31′ Electric bus; includes 2 Solectria A/C drive motors and Saft Ni-Cad batteries. The bus was placed in service with the Chattanooga Area Regional Transit Authority (CARTA).

Electric Shuttle Bus—Developed and evaluated a 32′ all electric shuttle bus. This Blue Bird bus was equipped with a Northrop Grumman drive train and demonstrated on Georgia Institute of Technology's campus.

Brush Testing—Developed and tested fiber brushes for use on magnetically levitated trains. The University of Texas led this project.

Climate Control System—Developed a compressor motor (Fisher) for use on A/C and heat pump system for EVs.

EV/HEV Virtual Test bed—Developed models and simulations on critical EV/HEV components. Program led by Georgia Institute of Technology.

Monitoring EVs in Various Climates—Tested an EV in Vermont in the winter and Florida in the summer.

CTE's centralized management of work programs enables team members to concentrate on exceeding project goals and ensure production of deliverables in a clear and well-coordinated manner. CTE has in place a proven project management approach based on key principles that have emerged from our collective experience in managing large government contracts and cooperative agreements. These principles include:

- Establishing and maintaining a high degree of involvement of government staff;
- Installation of controls to ensure proper tracking of information flow, timely completion of tasks requiring multi-disciplinary approaches, and excellent quality assurance of products developed by the project team; and
- Ensuring access to the most highly-qualified and internationally-recognized partners and their staffs.

Focused Hydrogen Research: The Southern Fuel Cell Coalition (SFCC)

In 2004, CTE initiated the Southern Fuel Cell Coalition, a member-based organization begun in partnership with the Federal Transit Administration to promote and accelerate the development and demonstration of hydrogen and fuel cell transportation technologies. SFCC has a particular focus on attracting attention and funding opportunities to the southeastern region of the United States. Currently funded through 2009, the SFCC will provide seed funding to as many as eight demonstration projects throughout the region and its activities are at the center of a growing network of universities, corporations, nonprofit organizations, and individual entrepreneurs working in partnership with Federal, state, and local governments to develop new industrial and manufacturing capacities in response to a market that is expected to exceed $7 billion by 2015.

The following is a sample list of Southern Fuel Cell Coalition related programs CTE is successfully managing:

Atlantic Station Fuel Cell Implementation Plan—Assembled a panel consisting of six fuel cell experts from around the country to develop a 10-year implementation plan for installing 3.6 megawatts of fuel cell capacity at the Atlantic Station brownfield redevelopment site in Midtown Atlanta.

Chattanooga Fuel Cell Bus Demonstration—Completed evaluation and data collection to determine feasibility and sizing of a replacement fuel cell pack for an in-service dedicated electric bus. Design and development of the fuel cell pack is in progress.

Texas DOT Strategic Hydrogen Infrastructure and Vehicle Plan—Leading a panel of experts in the creation of a Strategic Plan with recommendations for Texas DOT's adoption of hydrogen vehicle and refueling infrastructure technologies.

Development of Hydrogen Fuel Cell Industrial Vehicles—Working with three private team members in development, demonstration, and evaluation of a fuel cell system as a direct battery replacement in a forklift application as well as an industrial tow tractor.

Development of Hydrogen Fuel Cell Airport Tow Tractor—Working with three private team members and one university in development, demonstration, and

evaluation of a fuel cell system as a direct battery replacement in an airport tow tractor application.

Stennis Space Center (SSC) Hydrogen Refueling Station—Working to establish a plan for hydrogen fueling station installations that takes advantage of SSC's existing hydrogen infrastructure. The station would be part of SSC's hydrogen initiative project and has potential to tie into the I–10 corridor and the Discovery Center.

Beyond Technologies: Managing Transportation Demand

During the energy crisis in the 1970s, nationwide efforts provided commuting alternatives to ease the energy strain. From the energy crisis came a practice known as *demand management.* Demand management programs nationwide arose promoting the use of transit, vanpools, and carpools as alternatives to driving alone.

The practice of demand management has emerged to encourage the use of travel options for work commutes but also for daily travel. They have become an integral part of our transportation system, helping to create efficiencies, reducing congestion by feeding travelers into public transportation, vanpools, carpools, and high occupancy vehicle networks, or removing the overall need to travel. These strategies are becoming even more important as the costs of congestion rise. According to a recent Texas Transportation Institute study, congestion problems cost the country more than $63 billion in 2003. In terms of lost fuel, congestion costs more than 2.3 billion gallons per year.

Demand management has become both simple and sophisticated sets of tools that help manage and operate transportation systems to impact *route choice, mode choice, time choice, travel location* or *travel demand.* It has also become a key preparedness business continuity tool that allows employers and employees to continue business operations through the use of travel options during events that significantly impact travel.

CTE has expanded its expertise from a pure technology focus to include the measurement and evaluation of transportation demand management (TDM) programs and since 1999 has led the Georgia Department of Transportation's (GDOT) analysis of TDM programs in the Atlanta region. CTE's recommendations serve GDOT program managers in making appropriate decisions for funding, program focus, and asset allocation.

CTE, under contract, manages the Association for Commuter Transportation (ACT), an international trade association representing transportation professionals involved in TDM activities. ACT has more than 800 members across the country who develop and manage commute and alternative transportation programs that provide congestion relief, improve air quality, and reduce energy dependence.

Other TDM-related projects that CTE has managed or partnered on during the past 7 years include:

CarShare Atlanta—Managed a pilot to implement a shared car program in the Atlanta region. The pilot program allowed registered users access to electric city cars. Also led the creative process to brand this initiative, developing a name and logo based on input from all partners in the project.

Missoula in Motion—Partnered to develop a TDM Project Strategic Plan for Missoula in Motion (Missoula Office of Planning and Grants with the Montana DOT). Completed an inventory and review of existing Missoula in Motion programs and provided guidance and recommendations for improving programs, with a specific emphasis on using program evaluation and monitoring to improve programs.

TMA Measurement—Led a team of TDM experts in conducting a TDM opportunity analysis for Transportation Management Associations (TMAs) in the metropolitan Atlanta region. The team conducted regional commuter surveys, compiled and analyzed existing research data, and held focus groups to develop key opportunity strategies for each TMA.

Arizona Ridesharing and Vanpool Program—Currently researching the potential for a statewide ridesharing and vanpool program for Arizona. The product of this research will be an implementation plan that includes key corridors, start-up considerations, staffing, and operational guidelines, as well as funding options for capitalizing the statewide program.

The Transportation Sector—Defining the Energy Problem

The transportation sector constitutes a large part of the United States' total energy consumption. It is a logical place to begin looking for ways to reduce the amount of energy consumed and to use that energy more efficiently. Twenty-eight

percent of the United States' energy is used by the transportation sector alone, second only to the industrial sector, which uses approximately 33 percent of total energy consumption. Of the 28 percent of the total energy consumption that is used by the transportation sector, more than 96 percent of that energy is in the form of petroleum, which is mainly derived from places outside the United States.

The fact that the United States is so dependent on foreign sources for oil, and that the demand for it continues to grow is an alarming trend. In fact, with only 4 percent of the world's population, the U.S. uses more than 25 percent of the world's oil. Although it is never wise to be fully dependent on foreign resources, the U.S. relies on the oil from foreign countries to keep up with the growing demand as Americans continue to crave bigger and less efficient cars, not taking the necessary steps to decrease its dependency. In 1973, the year of the oil embargo, the U.S. imported 35 percent of its oil and today the U.S. imports 56 percent of its oil from foreign sources. The U.S. Department of Energy estimates that by 2020 the U.S. could be importing as much as 65 percent of its oil from foreign sources.

While the demand for oil increases in this country, it is growing even faster in other parts of the globe, especially in Asia. China is the fastest growing consumer of oil in the world with other countries such as India, Thailand, and Indonesia expected to add to the increasing need for oil. These countries' growing need to import oil could potentially compromise U.S. relations as we all compete for the supply of foreign oil.

U.S. Consumption of Petroleum and Use by Mode

- U.S. transportation petroleum use as a percent of U.S. petroleum production: 202.4 percent (2005)
- Net imports as a percentage of U.S. petroleum consumption: 59.8 percent (2005)
- U.S. consumption of petroleum is 20.5 million barrels per day or 24.9 percent of world consumption (2004)
- Transportation share of U.S. petroleum consumption: 66.8 percent (2005)
- Transportation share of U.S. energy consumption: 28.0 percent (2005)
- Petroleum share of transportation energy consumption: 96.4 percent (2005)
- Transportation energy use by mode (2003):
  - —Light-duty vehicles (cars, light trucks, motorcycles): 61.5 percent.
  - —Medium- and heavy-duty trucks and buses: 19.7 percent.
  - —Non-highway (including air, rail, water, pipeline): 18.8 percent.

Economic Impact

- In the *Costs of Oil Dependence: A 2000 Update,* authors Greene and Tishchishyna indicate that the oil market upheavals caused by the OPEC cartel over the last 30 years have cost the U.S. in the vicinity of $7 trillion (present value 1998 dollars) in total economic costs, which is about as large as the sum total of payment on the national debt over the same period.
- The latest study conducted by the National Defense Council Foundation 2003 puts a price of $49 billion dollars/year for the defense of oil in the Middle East.

Trade Deficit

- In calendar year 2005, the U.S. trade deficit in goods totaled nearly $782 billion, with nearly half (47.5 percent) attributed to transportation-related activities (petroleum (29.3 percent) and vehicles, engines, and parts (18.2 percent)).
- Since 1989, the transportation sector alone has used more petroleum than the United States produces. The current projections indicate that by the year 2020, the transportation sector will consume about twice as much petroleum as domestically produced.

Trucking Contribution

- Between 1991 and 2002, heavy truck energy use grew at a faster rate than for any other mode.
- Combination (Tractor-trailer) trucks and buses accounted for 5 percent of vehicle miles traveled in 2003.
- Heavy-duty trucks represent only 2.7 percent of trucks in use but consume 21.6 percent of fuel used by the truck sector.
- Trucks moved more than $6 trillion dollars worth of goods in 2002.

Buses

- In 2003, 78,000 transit buses and trolley buses traveled 2,435 million miles and 21,438 million passenger-miles.
- In 2003, there were more than 631,000 school and intercity buses in operation.

Introducing Clean Transportation Technologies to the Marketplace

There is a tremendous opportunity for alternative energy technologies in the United States, but we run a very serious risk of importing these technologies from abroad if we fail to capture the benefits of our technology and innovation. Domestic technology and innovation are impressive, ranging from hybrid vehicles today to improved mass transit and fuel cell vehicles tomorrow.

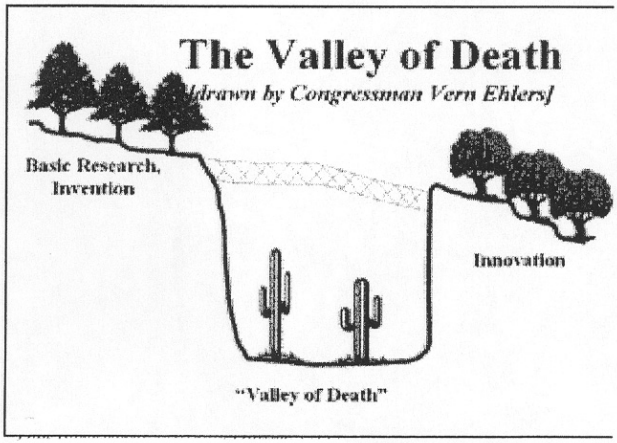
It is in our national interest to do more to facilitate appropriate research and technology transfer of these promising technologies to introduce them into the marketplace. The following are four areas where more emphasis should be placed as we move down the path toward energy independence.

1. Bridge the Gap Between Basic Research and Commercialization

Given the importance of energy, its rising cost, and concern over the potential impact on the environment, alternative energy technologies are being pursued worldwide. This was underscored during the visit of Chinese President Hu to the U.S. last April. One of the key themes he chose to stress, in accepting President Bush's invitation to visit, was clean energy and increasing bilateral trade in clean energy technology.

Alternative Energy Technologies is a broad field encompassing the production, distribution, and use of energy. My experience and focus is on the use of energy for transportation. In the U.S., transportation accounts for about 28 percent of our energy use and about 97 percent of that energy is from petroleum (2003 data).

There are outstanding examples of transportation research, development and innovation producing world-leading technologies. An important challenge is to get these technologies through the "Valley of Death" in the U.S. The figure below shows the Valley of Death as visualized by Congressman Vern Ehlers.



While he was interested in innovation as an outcome from basic research, I'd like to focus our attention on a subset of that innovation, commercialization. The Center for Transportation and the Environment works to establish the needed industrial-university-government consortia to bridge the valley and bring research ideas to market. The Senate should consider two particular attributes of this valley, the first of which is general and the second particular to transportation.

A Combination of Public Policy and Market Forces Are Widening the Valley

U.S. public policy over the past couple of decades has in most areas of technology, including transportation, focused on basic research. A key justification for the focus was that the commercial sector could do a better job of anticipating what could be commercially successful than could the government. Without the proper "technology-to-commercialization bridge," the more mature research programs, which were those closest to the Valley of Death tended to be discontinued. This widens the valley. At

the same time, the corporate business model has changed to focus research and development investment on commercialization steps rather than on extracting new products from the research laboratory. Thus, their investment has focused closer to commercialization, further widening the valley. This wider valley can be bridged in at least two ways. First, companies can shop globally for promising new technology if they have the capital needed over a long enough time to bring the technology across the valley. A second approach, and that embraced by the Center for Transportation and the Environment is to establish a university-industrial-government consortium to reduce the commercialization path.

Internationally, Transportation Investment Capital Tends To Allow More Time for Technology To Develop Than in the U.S.

In much of the developed world, provision of mass transportation is considered to be a governmental function. As a result, governments play a large role in the development of mass transit technology to fit their specific needs. The countries consistently invest in new technology and testing of their systems to a much greater extent than in the U.S. Consequently, offshore companies with patient capital can extract the best of U.S.-developed transportation technology. This results in the U.S. importing much of its mass transit technology from abroad. These countries are looking for the best basic research, nurturing it through the Valley of Death, and then exporting it to the world.

The U.S. has the pieces in place to capture more of this emerging technology for the benefit of the U.S. Specific actions are needed to turn these pieces into a coherent program that benefits the U.S. These actions include:

- Expand funding for the industrial-university-government consortia that is bringing emerging transportation technologies to market.
- Develop incentives for smaller companies to partner with universities to capture the innovation potential in each of these types of organization.
- Initially focus on the heavy-duty vehicle sector of transportation where the U.S. is competitive, and then try to capture back a larger share of the mass transit market.

It appears the Nation is at a tipping point in this technology. Program increases now of tens to hundreds of millions of dollars can grow markets of billions of dollars per year as the technology matures. This approach will not only help to assure our energy future, it will also stimulate the growth of good manufacturing jobs in the U.S. and increase exports.

2. Take Advantage of the Tremendous Potential That Lies Outside of the Major Automobile Manufacturers and Energy Suppliers

The United States should not count on the "Big Three" U.S. automakers and the major energy suppliers to develop all of our next-generation transportation technologies. Universities, small businesses, laboratories, and others offer collaborative partnerships, research investments, and quick-to-market solutions for transportation and energy challenges.

That is not to say that cooperative research with automakers and energy suppliers is not very productive and valuable; it certainly is. However, there is tremendous potential with small, medium, and large companies throughout the United States to work in partnership with universities, trade associations, and our national labs to bring new and innovative clean transportation technologies to market.

3. Do Not Overlook the Value of the Heavy-Duty Vehicle Market

The heavy-duty vehicle market is the fastest growing market within the transportation sector over the past fifteen years. One segment of the heavy-duty vehicle market, the bus market, is an excellent place to demonstrate new technologies:

- Buses are centrally refueled, so it is not necessary to provide extensive infrastructure. One refueling station will suffice.
- There are less space and weight restrictions on a bus than on smaller vehicles, making these vehicles exceptional test beds.
- As buses are often on fixed routes, new technologies can be engineered and optimized to meet specific route requirements, making it an easier proposition than for vehicles with the requisite flexibility to travel anywhere at any time.
- Transit buses are not mass-produced in the same manner as passenger vehicles. They are built in quantities in the tens and hundreds, as opposed to passenger vehicles that are built in tens of thousands of units. Therefore, a single prototype transit bus can be purchased reasonably close to the market price of existing transit buses. A prototype passenger vehicle simply cannot be produced at

a price point that comes anywhere close to that of an existing mass-produced passenger vehicle.

Eighty percent of the cost of buses purchased for transit use in the United States is paid for by the Federal Government, through the Federal Transit Administration (FTA). If the U.S. Government wants to set the right example for encouraging the electric and hybrid electric vehicle market, the transit bus market offers a great opportunity to do so.

Given that the bus market is such an ideal place to develop and test prototype vehicles and transportation technologies, the FTA is an excellent candidate for a significant increase in discretionary research funds. The FTA is not always viewed as the ideal place to spend research dollars. This perception needs to change.

4. Focus on Prototype Development

The best way to bring ideas outside the research laboratory and into the marketplace is through prototype development. The United States Defense Department (DOD) has made a fundamental change in the way they do business in developing new combat vehicles and technologies over the past 20 years. Instead of specifying the next-generation vehicle, taking several bids and working with the winning bidders to build hundreds, the military has emphasized a process under which all bidders must first build prototypes. This process allows the customer, in this case the DOD, to test the prototypes and choose the best one for the application. This method results in a much higher-quality product and generates input and ideas from a wider sector of participants.

As we move into the next generation of transportation technologies, building prototypes is a critical element to connect industry with university research and ultimately with the market. Technologies that work in the university research laboratory may not work in real-world applications. University researchers are then forced to look more closely at the environment of the marketplace in designing a solution.

Prototype development brings all component suppliers together, establishes relationships and often generates a synergy that cannot be found in the lab. Occasionally, enabling technologies are developed through the prototype development process to allow lab-tested parts to work properly in the vehicle. These technologies would not be available to us without the prototype development phase.

Building prototypes also brings smaller component manufacturers and their new technologies to the market and allows them to demonstrate their technologies on a vehicle. For smaller suppliers, building an entire vehicle to demonstrate only a very small part of the vehicle is cost prohibitive. Last, prototypes allow the end-user to work closely with the researchers and component suppliers to ensure the final product meets market demands.

Alternative Transportation Technologies: Select CTE and SFCC Member Highlights

CTE and SFCC members represent efforts to develop solutions to the transportation sector's energy and petroleum consumption challenges through technology development and deployment.

Following are examples of CTE and SFCC member initiatives currently underway:

University of Texas Center for Electromechanics—Austin, Texas

Texas DOT Strategic Hydrogen Infrastructure and Vehicle Plan

The University of Texas at Austin is currently teamed with the Southern Fuel Cell Coalition and the Texas Department of Transportation to plan a series of steps that could be taken to introduce fuel cell vehicles to develop the experience and patterns-of-use that are needed to stimulate both technology and infrastructure development.

Flywheel Battery System Development

A prototype hybrid bus that incorporated flywheel energy storage and an engine fueled by compressed gas was developed and demonstrated by staff at the University of Texas at Austin. The flywheel is an energy storage system that lasts the life of the bus as contrasted with chemical batteries, which carry a $10,000–$20,000 annual replacement cost for urban transit buses, depending on the route. This hybrid technology is currently proposed under the Department of Transportation's National Fuel Cell Bus Program for use with a fuel cell powered bus to minimize the size and cost of the fuel cell required. European organizations, as early adopters, are moving ahead to capture these fuel-savings benefits for themselves.

The University of Texas at Austin is also demonstrating the flywheel battery system on a larger system, a hybrid passenger train. The program has developed a

high-speed generator that couples directly to a gas turbine, an energy-storage flywheel, and the associated power electronics needed to power such a train. Portions of this system are being demonstrated at the Philadelphia Navy Yard. This system provides an effective high-speed locomotive with storage capability so that little energy is wasted stopping and starting the train at stations. Simulations show this approach saves 10 0920 percent of the fuel depending on the specific route. Much of the technology is also applicable to commuter trains where the energy savings should be larger. European organizations are aggressively pursuing similar approaches.

Computer Controlled Active Suspension System

Researchers at the University of Texas at Austin have also made a significant advance in another technology that reduces wasted energy in vehicles. In today's vehicles, the springs and shock absorbers convert the relative motion between the wheels and the body of the vehicle into heat. The researchers have developed an electromagnetic suspension that provides better performance while allowing this energy to be reused. The system is currently being developed for a range of military vehicles. In tests by the U.S. Army, vehicles with this new suspension system reduced by 90 percent the unwanted motion of a conventional vehicle, could go three to four times faster in off-road conditions, had twice the carrying capacity of the same vehicle with a conventional suspension, had improved high-speed handling, and saved about 15 percent on fuel in off-road testing. With the military making early use of the technology, it should be making its way into commercial markets soon.

SK International, Inc.—Athens, Georgia

Hybrid Propulsion System Technology

SK International (SKI) became a small-business leader in hybrid electric bus technology in the 1990s. SKI's primary business is to build hybrid electric buses, including the design and integration of the bus systems and its components. SKI was awarded a contract to develop two hybrid electric buses in the U.S. by the Pollution Control Department of Thailand. The buses were one of the strategies the Royal Thai Government pursued to address Bangkok's air quality problems. The proven performance of the SK International drive system over several years of service in Thailand demonstrates the functionality and reliability of the hybrid electric drive system design.

SKI's successful venture in Thailand exemplifies the key role small businesses can play not only in the domestic development of advanced transportation technologies, but also in developing products that can be exported to the world market. However, small businesses face significant challenges in bringing viable emerging technologies to market largely due to cost issues. Raising sufficient capital funding is a barrier for many small businesses with promising ideas or products.

SKI continues to lead the way in the development of hybrid propulsion system technology. SKI's business model of incorporating existing, proven components into design is allowing this small business to leverage its resources and bring a reliable and, in turn, viable technology to the market. SKI's design and continued improvement of its hybrid propulsion system technology is focused on three main objectives:

- maximize reliability;
- maximize fuel efficiency; and
- minimize cost.

SKI approaches the reliability issue from two fronts: component level and system level. The component reliability issue is addressed by using off-the-shelf, heavy-duty, industrial motor drives with many years of proven records. On the system reliability issue, SKI relies on thorough testing before introduction of the product and quick-response improvement thereafter.

Hybrid systems provide substantial fuel savings. A series hybrid system can realize fuel savings of 30–40 percent while the parallel hybrid system can achieve around 15–20 percent savings. The parallel system is more suitable (more efficient) for long distance arterial service routes while the series system is more suitable to central city urban routes. SKI is currently focused on series hybrid systems. SKI is able to push the series hybrid technology further by using the smallest internal combustion engine possible to minimize the fuel consumption. According to a transit authority feedback, SKI hybrid trolleys achieve 14 miles per gallon (mpg) while the conventional diesel counterparts average 8–10 mpg. Like most of the hybrid systems in the market today, the SKI system is capable of increasing energy efficiency by idle reduction and regenerative braking. Also, the use of a hybrid configuration allows the engine speed to be managed within its most efficient operating range to

obtain more fuel savings. SKI is developing a System-Wide Power Flow Management Unit. The unit manages the power generation unit (engine and generator) according to the load requirement and energy storage condition. Analytical results show that an additional 10 percent fuel savings can be realized over an unmanaged series hybrid system. Opportunities also exist to modify the engine to operate on renewable, emissions-friendly, domestic fuel sources including ethanol or biodiesel. The hybrid buses can be equipped with engines tailored to meet customer fuel preferences.

Cost is the third issue for this emerging product. While cost issues are usually resolved with volume production, the U.S. bus market will not likely generate sufficient demand to significantly reduce costs. Currently, the capital costs of a hybrid bus ranges from 140–200 percent of its comparable diesel counterpart. The life-cycle cost of the hybrid buses can match that of conventional diesel buses. SKI addresses the cost issue by using off-the-shelf components that are already in mass production for other industries. Furthermore, SKI invented a unique Battery Management System that allows its hybrid system to use maintenance-free lead-acid batteries. Advance-technology batteries, such as nickel-metal hydride (NiMH), may account for 30 percent of the total propulsion system cost while the lead-acid batteries account for only 10 percent.

DRS Test and Energy Management, Inc.—Birmingham, Alabama

Providing Electric Power and Energy on Future Battlefields and for Homeland Security and the Role of Hybrid Vehicles and Energy Sources

Hybrid electric powered vehicles are demonstrating their ability to improve domestic transportation fuel economy every day. This is being achieved through application of new technologies and the inherent ability of a hybrid to optimize its operation for lowest fuel consumption. What has not been as evident is the ability of hybrid-powered vehicles—if properly designed—to provide large amounts of electric power to electric consuming loads. This is of significant importance to both the Departments of Defense and Homeland Security as they address the many new operational requirements brought on by the GWOT and the transformation process.

Impact on the Army and the Department of Defense

Providing high quantities of high-quality conditioned electric power for use on current and future battlefields is becoming more and more difficult as the power requirements of new weaponry and supporting intelligence equipment continues to escalate. Tactical Operation Centers, Radars, Directed Energy Weapons and general utility power is on an ever increasing spiral that has already strained available resources and increased the size of operational units when the objective is to reduce its footprint. Traditional means of providing electrical energy via mobile and fixed generators is becoming ineffective because of the increased size of these higher power devices, the lack of available trucks to tow or haul these large devices and poor overall performance of the conditioning and distribution systems. Furthermore, new directed energy weapons and support systems present new requirements for extremely high-pulsed power that is not within the normal operating envelope of these existing power systems. The provisioning of this power is further complicated by the tactical need for light, highly mobile and transportable, self-sustaining weapon and support energy systems as required by our transformational objectives.

By addressing these power issues with a holistic, systems approach to an integrated energy system enabled by the use of hybrid electric vehicles and power systems, it is possible to address this new spectrum of power needs while significantly reducing the footprint of current and future forces and improving their ability to move (and survive), shoot and communicate. At the same time, the fuel efficiency of these vehicles can be significantly improved as has already been demonstrated in the U.S. through commercial hybrid passenger vehicle use.

DRS Test and Energy Management, Inc, located in Huntsville, AL, has been addressing this issue for more than 15 years through its work with hybrid powered vehicles and associated integrated power and energy management and distribution systems for military applications. In this work, DRS has developed, tested and demonstrated prototype hybrid electric vehicles (a hybrid electric High Mobility Multipurpose Wheeled Vehicle (HMMWV) with exportable electric power capability) and powered transportable platforms that support an exportable electric power architecture that has promise of significantly impacting the theater of operations with its intrinsic power provisioning capability. DRS has also been working with several energy dependent system developers and U.S. Army and Air Force users to develop continuous and pulse power-conditioning systems that work with hybrid powered vehicles and support these energy dependent military systems. Applications investigated to date have included Tactical Operation Centers, Radar Systems, Command

and Control Systems, Land Warrior Battery Charging Systems, and several directed energy systems including tactical Lasers, Non-Lethal High Power Millimeter-wave Active Denial Systems, and other systems. This work has successfully demonstrated the capability of hybrids to support these increased energy requirements while providing significant savings in the size, weight, and volume of the total power system.

The basis of this holistic power approach lies in the use of the intrinsic power generation capability of hybrid electric vehicles and their robust embedded energy conditioning systems. Typically, these hybrid vehicle systems consist of one or more power generation sources such as a diesel (or other) fueled generator, turbine generator (or future fuel cell) that provide the average energy level required, and a second energy storage device such as battery, capacitor or flywheel that supports the peak power needs for acceleration of the vehicle, for pulsed-type loads and for uninterruptible electrical power (UPS). With suitable system designs, these vehicles can intrinsically produce power levels that dramatically exceed the vehicle's ability to tow or transport a trailer-mounted generator of equivalent capability. In the case of the Army's hybrid electric powered HMMWV the vehicle is capable of providing 75 kW of continuous power and over a megawatt of power for short duration pulses using the HE equipment located "under the hood" and within the vehicle's frame. This same vehicle powered conventionally with a diesel engine can only tow a generator capable of 15 kW when mounted on a trailer which also dramatically reduces mobility and its transportability. In a similar fashion, the Army's conventionally powered FMTV truck is capable of transporting a 60 kW generator but converted to hybrid drive it will be capable of producing approximately 225 kW of continuous power. Along with this power capability, a hybrid vehicle provides many advanced operational features such as silent watch, silent move, instant response to battle action, uninterruptible power, and other mission capability improvements

An example of the impact of such concepts on the theater of operations is best seen by examining the U.S. Army's Stryker Brigade Combat Team (SBCT) Tactical Operation Centers. These assemblies of various intelligence gathering equipment configured in many different physical configurations require significant levels of high-quality, uninterruptible electric power for support of computer systems, video displays, radios, and other sophisticated equipment. In addition, large air conditioning and heating systems are required to maintain tolerable ambient environments for equipment and personnel. These systems require significant manpower, vehicles, and equipment to field and maintain. In the case of the SBCT's TOC, an impressive list of equipment can be eliminated if 3 to 4 of the existing HMMWV vehicles are converted to hybrid drive and this energy used to power the TOC. In this case study, it is estimated that the footprint of the TOC could be reduced by at least 16 percent. Considering all of the TOC's within an SBCT unit, the total impact to the brigade's compliment of TOC's is estimated to yield a 20 percent reduction in air sorties needed to transport these TOCs to the theater. In addition, the inherent ability to produce power more efficiently will result in better fuel economy resulting in an even larger logistic and operational footprint reduction.

In a similar case studying the impact on a prolific Army radar system, the footprint of a single operational unit was reduced from 3 vehicles to two, from 3 trailers to 1, and the number of transport aircraft from 2 to 1 when the conventionally powered HMMWVs being used were converted to hybrid drive.

In near-term future battlefield environments, directed energy weapons, active defense and other electric-based systems requiring extreme levels of pulse power are envisioned. A hybrid-based power architecture is uniquely suited to support these systems through the pulse energy capability of the system's load leveling battery. Again, DRS has been working on a number of prototype systems that have already demonstrated the impact of hybrid systems in this area. In one tactical solid state laser weapon concept (demonstrated at Lawrence Livermore Laboratory), a prototype hybrid vehicle power system is supplying 10 megawatt pulses for 0.5 msec. to fire this tactical solid state laser capable of cutting a hole in a one inch piece of steel in about two to 3 seconds. This integrated power system is projected to be 80 percent lighter than a conventional industrial power supply. Here, this technology affords a total laser system design that could fit on a HMMWV-sized vehicle rather than a semi-truck.

In another prototype system, DRS has provided a full mobility solution to a High Power Microwave non-lethal weapon system providing 300 kW of power while *on the move* and firing this advanced directed energy weapon.

Using hybrid vehicles for provisioning of electric power, there are numerous other benefits affecting the mobility of the vehicle including increased fuel economy, silent move, extended silent watch, operation of the system without starting of the main engine, enhanced mobility, and the ability to remain self-sustaining on-site for extended periods.

Much of this energy-centric work has been focused on the Hybrid Electric HMMWV as a "Point of the Spear" in moving toward acceptance by the U.S. Army. However, the mobile power concepts apply to any number and size of ground vehicles, ships, and aircraft applications whether wheeled, skid mounted, or semi-transportable and are scaleable over the full spectrum of military power needs anticipated for the foreseeable future. Importantly, these power and mobility concepts are equally germane for Homeland Security.

Impact on the Department of Homeland Security

While the impact of hybrid electric vehicles on DOD battlefields has potential to dramatically affect its operations, deployability, mobility, mission effectiveness, and the fuel economy of our forces, the potential for similar impact on Homeland Security operations is of equal or even greater significance. Homeland Security has a myriad of responsibilities to protect our borders, our ports of entry, to protect against terrorist activities, and to provide emergency response to natural disasters, such as floods, hurricanes, earthquakes, and even civil unrest. All of these activities require copious amounts of mobile and transportable electric power to support these activities either in a mobile or semi-permanent installation or in locations that may have been ravaged by natural disaster with resulting loss of local infrastructure.

The application of a holistic approach to providing energy in support of these activities enabled by hybrid vehicles has far reaching implications in maintaining and restoring the viability of local infrastructures (known as Nation Building) as well as providing enabling technology for new non-lethal directed energy weapons.

Similar to military applications, the support of mobile command posts, radar (weather/airline) and communications must be provided that can quickly move into a setting and establish command centers with full communication capability and "islands-of-power" that service these operations. Hybrid-powered vehicles can provide all of this power even to include air conditioning and heating power while also providing the transport of equipment into a given area.

Hybrid-powered buses, trucks, and civil government vehicles can easily provide emergency power for traffic light operation at individual roadway intersections, emergency shelters, emergency operation centers, hospitals, communication centers, and kitchens. Vehicles suitable for support of these operations include National Guard HMMWVs and FMTVs, garbage trucks, mass transit buses, to name a few. These vehicles are widely distributed in almost all municipalities making them readily available for provisioning of power when and where they are needed.

Included in this power architecture is the ability to form micro utility networks where one or more vehicles can be used to power a local utility network to distribute higher levels of power to a broad geographical area to provide electric power to homes and other installations.

When not involved in specific Homeland Security operations, these same hybrid powered vehicles will go on to provide enhanced normal operations with improved fuel economy and operational performance in the many daily tasks required of these vehicles.

Summary

Hybrid-powered vehicles are finding increased public acceptance as fuel efficient passenger cars as is evident by their rapidly increasing national sales and demonstrated improvement in fuel economy. This trend is expected to continue as fuel prices continue to rise throughout the world and as the cost of this hybrid technology continues to be reduced. What is not as readily recognized is the ability of these vehicles to provide high levels of electric power and energy to on-vehicle payloads and off-board electrical loads at levels that far exceed a given vehicle's ability to tow or carry conventional generators and with little additional cost to the basic hybrid-powered vehicle. In many applications, this capability to provide electric power can result in significantly higher overall cost savings than that of the fuel economy savings alone.

Within the U.S. Army, this exportable power capability of hybrids has direct application and favorable impact to the transformation of our force structure by reducing the logistics footprint of the deployed force through elimination of vehicles, equipment, maintenance personnel, and transporting aircraft. It also improves the operational effectiveness of the force by providing tactical grade power to the battlefield with the first deployment of troops. It also enables the effective fielding of lethal and non-lethal weapons that are so dependent on mobile high density, high peak power energy systems. These benefits, along with the improvement in fuel economy, have potential to have a significant impact in the operational effectiveness of our forces and, in turn, the cost of these operations.

In a similar way, the impact of hybrid electric vehicles supporting Homeland Security functions is expected to yield significant improvements in responding to border and port security and in rapidly and effectively responding to natural disasters. It is important to consider the impact to the aftermath of Katrina in New Orleans if every vehicle driven into the area by the National Guard could have also provided exportable electric power to the equipment it brought in, to surrounding installations and to emergency shelters and buildings in the area, the plight of New Orleanians could have been dramatically improved much more quickly and at nominal cost.

Efforts continue within the industry and within the U.S. Army to evaluate exportable power concepts which can be applied to the DOD and Homeland Security. Key to this continuing effort is the treatment of these vehicles as an "energy delivery system" and not just as another "hybrid-powered vehicle." With this energy mindset, a holistic approach to providing energy can be applied and supported effectively by these vehicles. What is needed today is additional funding that permits maturation of these energy centric prototype vehicles and related components into pre-production products suitable for extended field evaluation. Second, additional testing and acceptance of these concepts are needed by DOD and Homeland Security.

Using this energy centric approach, hybrid vehicles can have an even greater impact on our economy and on our ability to address current and future issues of the global war on terrorism and Homeland Security.

University of Alabama Birmingham—Birmingham, Alabama

The Hydrogen Fuel Research Program (Sponsor: U.S. Department of Energy)

Research Partner: Argonne National Laboratory

This program supports several parallel lines of research related to the use of hydrogen as a vehicle fuel. The research projects are interrelated and support the overall goal of understanding what impacts a large scale deployment of hydrogen-fueled vehicles would have on air quality and the vehicle fueling infrastructure. Specific tasks include:

- Emissions testing of hydrogen-fueled vehicles, both fuel cell and internal combustion, to obtain emissions profiles and vehicle performance characteristics.
- Development of models that incorporate the results of the emissions testing to generate performance and emissions profiles for a wide range of potential hydrogen-fueled vehicles.
- Incorporation of the modeled vehicle profiles into larger air quality models to assess what impacts a large-scale hydrogen vehicle deployment would have on regional air quality and overall vehicle emissions in the Southeast. Current models lack good data on the performance characteristics of hydrogen fueled vehicles or hydrogen production methods.
- A realistic assessment of the fueling infrastructure required to support a large scale hydrogen vehicle deployment. No vehicle deployment plan can succeed without adequate infrastructure, and this task is looking at the most efficient ways to manufacture and transport hydrogen for given vehicle deployment levels, as well as the types and number of fueling stations that will be required. Life cycle costs for a hydrogen infrastructure are being calculated.
- An assessment of the potential uses of fuel cells for stationary power generation.

This research is ongoing and includes a public education component. UAB has teamed with the Center for Transportation and the Environment to co-sponsor a conference in Atlanta that will highlight the results of this research.

Fuel Cell Bus Demonstration Program (Sponsor: Federal Transit Administration)

The goal of this program is to design, build, and demonstrate a fuel cell bus with the ultimate goal of advancing the commercialization of fuel cell transit vehicles. Transit agencies provide an ideal environment for demonstrating emerging hydrogen technologies because they have trained personnel, centralized fueling facilities, and their own maintenance resources. Giving transit agencies hands-on experience with these vehicles facilitates eventual commercialization. Transit agencies also provide an excellent forum to educate the public on hydrogen technologies. There is currently some public resistance to accepting hydrogen technologies, largely due to misconceptions about the fuel itself. Introducing hydrogen-fueled buses in regular transit service will help the public become accustomed to their use.

This program is ongoing and is currently in the design phase. When complete, one or two fuel cell-powered buses will be demonstrated in Birmingham and likely in another city in the Southeast. The demonstration will also include design and con-

struction of a hydrogen fueling station in Birmingham, one of the first in the Southeast. Throughout the demonstration we will gather data on the performance and reliability of the test vehicles and assess their viability for broader deployment.

General Hydrogen Corporation—Gallatin, Tennessee

How New Technologies Can Help in Addressing U.S. Energy Needs

Hydrogen Fuel Cell Power Packs are a commercial reality now in that they are being sold in direct competition to conventional batteries without subsidies. The principal applications for the Hydrogen Fuel Cell Power Pack are as a drop-in replacement for conventional lead-acid batteries in electric forklifts (800,000 in the U.S. alone), automated guided vehicles, tuggers, other airport electric vehicles, and electric shuttle buses.

Key points about their current positive and potential benefits can be highlighted thus:

- Stimulating the switch from fossil-fueled small/medium industrial vehicles to electric power;
- Stimulating productivity and competitiveness of U.S. industry (tripled run-times at high output);
- Stimulating the proliferation of an industrial vehicle-based fueling infrastructure;
- Providing a viable start to the Hydrogen Age in the U.S. based on sound economics now;
- Potential to introduce APU's to slash the billion-gallon annual wastage of diesel fuel by trucks; and
- Potential for use in 22′ electric shuttle buses to encourage people to leave their automobiles garaged.

There is a growing adoption trend for electric industrial vehicles, particularly those that work in enclosed spaces. Typically, outside forklifts, airport ground support equipment are diesel or LPG fueled. Currently, in high-use, multi-shift working environments, where the case has been made to switch from LPG fueled forklifts to battery-powered units, the economics for going directly to fuel cell power equipped ones, is a sound value proposition/economic case now. Typical payback is 2 to 3 years. New U.S. tax incentives of $1,000 per kW will reduce that payback by about a year.

Many U.S. airports are under intense pressure to zero any increases in emissions and, indeed, lower them. Unions are pushing hard to protect workers from the harmful effects of carbon monoxide and particulates, by demanding that only electric vehicles be used where vehicles have to enter buildings such as baggage facilities and hangars.

In the case of manufacturing plants and distribution centers, companies not only desire higher productivity to stay competitive, they also want to lower energy costs and enhance the work environments not only in terms of safety but also health.

Fuel cell power packs triple run-time performance. An average forklift lead-acid battery only lasts 4 to 6 hours and throughout its use, the voltage is dropping causing productivity to decline. With fuel cell power packs, voltage is constant until the last molecule of hydrogen is exhausted and the only emission is invisible water vapor. Furthermore, they eliminate the need for large number of lead-acid batteries (three sets per vehicle in high use), the charging infrastructure, thus freeing-up large areas of internal space that can be put to more productive use.

In the case of automated guided vehicles (AGV) equipped with fuel cell power packs, they can run for more than 24 hours instead of going offline every 35 minutes for a seven-minute charge. Anecdotally we have been told by one operation that fuel cell power packs in AGV use, will save the operation millions of dollars annually as the productivity increases has been rated at over 30 percent.

Fuel cell technology is also potentially applicable for Auxiliary Power Use, most particularly for super-heavy trucks (Classes 8/9) where idling is a major concern in the U.S. Truckers run their engines to provide their cabs with "hotel" power for air conditioning/heating, television, etc. According to the EPA heavy truck idling accounts for the waste of 800 million to a billion gallons of fuel a year. General Hydrogen has produced a 3 kW APU for a super-heavy truck. While not price competitive yet, demand could bring prices down considerably.

Perhaps what is not well understood is that industrial hydrogen has been a commonly available gas for decades as it is in widespread use in vast volumes by the petro-chemical and food industries. It can literally be dropped off in your drive at home in large K bottles (tall, slim steel bottles at 4,000 psi). Current fueling sta-

tions can be replenished by a truck-borne liquid hydrogen tanks, or the gas can be produced simply by on-site electrolysis.

What is envisaged is that as the industrial use grows, the fueling infrastructure will eventually proliferate to big box stores in shopping malls (they use narrow aisle electric forklifts), where the fueling will be made available to the general public, thus working both sides of the equation as automotive fueling stations start to grow in number as a result of state, commercial or even Federal initiatives.

We also see some significant potential for the adoption and extension of small shuttle bus systems. Current transit electric buses have certain power limitations (*e.g.,* CARTA in Chattanooga). CARTA is proposing a significant extension of its popular downtown services, but lead-acid batteries do not have the capacity for one particular hilly section. Fuel cell power packs will provide more than adequate power.

Oak Ridge National Laboratory—Oak Ridge, Tennessee

Development Centers and Laboratories

The *National Transportation Research Center* (NTRC) is a window to transportation research programs at ORNL and the University of Tennessee (UT). NTRC offers one of the most diverse concentrations of transportation researchers in the United States. The center provides access to ORNL and UT expertise in fuels, engines and emissions; power electronics; logistics; ITS; GIS; policy and data analysis; modeling and simulation.

The *High Temperature Materials Laboratory* (HTML) is a National User Facility that helps solve materials problems that limit the efficiency and reliability of advanced energy conversion systems. HTML has extensive capabilities for characterizing the microstructure, the microchemistry, and the physical and mechanical properties of materials over a wide range of temperatures.

The *Fuels, Engines, and Emissions Research Center* houses ORNL's vehicle and engine dynamometers and unique analytical equipment used in research, development, and evaluation of advanced fuels, engines, vehicles, and emission control systems.

The *Heavy Vehicle Safety Research Center* (HVSRC) is a major initiative of the National Transportation Research Center (NTRC). It will contribute to meeting national goals related to the reduction of truck-related fatalities, while maintaining and enhancing the economic viability of the U.S. trucking industry.

Researchers in the *Power Electronics and Electric Machinery Research Center* develop and prototype the next generation of cost-effective converters, adjustable-speed drives, electric utility and distributed-generation applications, motor controls, and efficient, compact electric machines.

ORNL conducts extensive materials R&D from theory to prototype development on lightweight structural materials and functional materials (*e.g.,* propulsion materials, catalysts, batteries materials, and thermoelectric materials for waste heat recovery).

Example of Current ORNL Validation/Demonstration Activity

ORNL is currently conducting the Heavy Vehicle Duty Cycle (HVDC) Project for the Department of Energy (DOE) which involves collecting more than 90 channels of data including data on fuel usage, emissions, situational status (temperature, precipitation, wind velocity, etc.), and vehicle dynamics. This data will be utilized to generate real-world duty cycles that can be utilized as a common basis for comparing vehicle technology performance, and will contribute to the development of the DOE-sponsored Powertrain Systems Analysis Toolkit. A field-operational test with a reduced set of performance measures will be initiated in late-Spring/early Summer 2006 utilizing a fleet of up to ten class-8 tractor-trailers operating in their normal long-haul vocation.

Fuel Cell R&D

Fuel cell research projects underway at ORNL include:

- Microstructure Characterization of PEM Fuel Cells (this was the top DOE laboratory program this year and is currently supporting nearly all fuel cell OEMs to determine degradation mechanisms in their cells and stacks).
- Cost-Effective Metallic Bipolar Plates Through Innovative Control of Surface Chemistry (program demonstrated viability of metallic plates in fuel cells. Plates have run for more than 5,000 hrs in stack tests).
- Compact Carbon-based radiators for Fuel Cell Power Systems (woven carbon fiber radiators).

- Development of a Robust Fiber-Optic Temperature Sensor for Fuel Cell Monitoring (developing optical fiber based sensors for temperature and humidity measurements in stacks).
- Selective Catalytic Oxidation of Hydrogen Sulfide (this project has successfully developed a catalyst that can reduce H_2S and COS levels in fuels to the parts per billion level. Removes sulfur species by oxidation forming solid sulfur-emissionless process avoids SO_2 which can lead to acid rain).
- High-Temperature PEM Membrane Development (have incorporated nanocrystalline inorganic materials into Nafion which have resulted in increased proton conductivity and stable performance at 120 °C–40 °C higher than its current use temperature).
- Successful Technology Transfer: ORNL developed a fibrous carbon composite bipolar plate and have licensed the technology to Porvair, who is currently scaling-up a process to makes tens of thousands of plates per year.

Demonstration Project

The National Transportation Research Center (NTRC) has in operation a UTC phosphoric acid fuel cell to provide heating, cooling, and electricity to a building. It is currently supplying up to half of the building's power supply. Hydrogen is generated from an on-site natural gas steam reformer and a SEMCO desiccant wheel recovers energy (heating or cooling) and controls humidity from exhaust air.

Hydrogen Production & Delivery

ORNL is the lead laboratory in developing delivery technologies:

- Work is ongoing in both metallic and polymeric materials for pipelines, failure mechanisms, welding, and materials understanding. Additional work is ongoing in tribology to understand hydrogen effects in turbomachinery (compressors) and other moving devices.
- ORNL is playing a leading role in developing a strategic model (HYTRANS) to determine scenarios for a transition from our current NG infrastructure to a hydrogen-based economy.
- ORNL is recognized as a leader in the development of hydrogen purification and separation technologies. Ongoing projects include microporous membranes, ceramic proton conducting membranes, polymeric proton conducting membranes, and metallic membrane materials.
- One last area of significant development and interest is in Development of Efficient and Robust Algal H_2 Production Systems. An ORNL researcher has developed a genetically engineered algae that under anaerobic conditions is able to produce hydrogen. They have recently been able to grow a new version of this algae and are on the way to solving four of the five major mechanistic issues limiting algae's ability to produce large quantities of H_2.

Our society's power and energy demand is met largely through the combustion of fossil fuels. The world economy relies upon on a limited resource; trends suggest that global energy use is expected to double in the coming decades. At the same time, concerns about the effects of anthropogenic carbon dioxide and criteria pollutants and about energy security continue to mount. Meeting our energy needs in a sustainable manner is an historic challenge that will cause us to diverge from the pattern of the last couple of centuries. Storage and conversion of energy becomes increasingly relevant as we move toward greater reliance on renewable energy sources. Fuel cells are an efficient means to convert chemical energy into electrical energy with little or no emissions. Fuel cells are therefore expected to be an important energy technology for the future.

Savannah River National Laboratory—Aiken, South Carolina

The Savannah River National Laboratory (SRNL) has a long-standing history of hydrogen technology development and deployment. SRNL has more than 90 scientists and engineers dedicated to hydrogen research and is recognized as a world-class leader in the development of safe handling systems for hydrogen. CTE, then known as SCAT, worked with SRNL in 1993 on one of the first fuel cell bus demonstrations in the U.S.

SRNL has comprehensive capabilities in the area of hydrogen effects on materials and selection of materials and components for pressurized hydrogen systems. This work includes fundamental studies and applied research for the development and improvement of hydrogen production, handling, and storage system materials. SRNL also has extensive experience in the development and start-up of hydrogen process systems. The development of these systems requires the application of na-

tional codes and standards to insure safety margins comply with established consensus levels. SRNL staff is actively involved in the development of new national standards for hydrogen storage vessels and leakage management methodologies for hydrogen systems.

SENTECH, Inc.—Bethesda, Maryland

SENTECH, Inc. is a small, energy and environmental consulting firm which specializes in energy efficient technologies, renewable energy technologies, and advanced transportation technologies. They assist Federal, state and private sector clients by providing a full spectrum of technology management services, including strategy development and program execution; technical assistance; economic, regulatory and market analysis; and project development. SENTECH also provides the critical element of refining the tangible and intangible benefits of these clean energy options. They develop strategies for communicating such benefits to stakeholders.

SENTECH is a successful graduate of the 8(a) program and is grateful for the foundation it provided as the company established itself. Today the company is comprised of more than 45 professional staff and maintains offices in Bethesda, Maryland and Knoxville, Tennessee. SENTECH takes great pride in being able to sustain its growth independently.

SENTECH is very pleased to be a member of the Center for Transportation and the Environment (CTE), and are grateful to CTE for identifying potential opportunities and more importantly assisting us in forming strong teams to respond to those opportunities. The diverse membership of CTE provides a great opportunity to assemble the different capabilities that are often needed to respond to complex projects rapidly and efficiently. Currently, SENTECH is participating with CTE and its members in competing for the fuel cell bus demonstration projects that will likely be funded through the Department of Transportation (DOT).

SENTECH's core business involves providing technical, management and communication/outreach services to Federal agencies. Their primary client is the Office of Energy Efficiency and Renewable Energy (EERE) of the U.S. Department of Energy (DOE). SENTECH provides technical and management support to several of the EERE programs in renewable energy, hydrogen and fuel cell systems, advanced transportation systems, and energy efficiency. SENTECH also has contracts with the Oak Ridge National Laboratory and the National Renewable Energy Laboratory through which they provide technical assistance to national laboratories. SENTECH's Federal business is not restricted to DOE. The company also provides communication and outreach services to EPA's ENERGY STAR™ Program and has worked with USAID in providing technical assistance to recipient countries in electric utility restructuring and in developing and implementing energy efficiency projects.

SENTECH's business model assumes that clean energy technologies developed with Federal funding support will ultimately be implemented mainly through the leadership at the state level. With this in mind, SENTECH has been aggressively building relationships with the states. A few years back, the State of Hawaii contracted with SENTECH to develop a roadmap addressing how the state could to use its renewable resources and play a role in a hydrogen economy. SENTECH has continued its partnership with the state since then and today is assisting the state in developing partnerships with both large and small industries and demonstrating clean energy technologies in the state. SENTECH's state activities currently include energy efficiency projects in Maryland, technology due diligence for the State of Massachusetts, and hydrogen road mapping for the State of Texas and the Commonwealth of Virginia.

SENTECH holds extensive knowledge regarding DOE programs and has developed in-depth experience in multiple industry sectors. Senior managers each have decades of experience with DOE, and their experiences with industry provides a plethora of knowledge important to the private sector as it develops and commercializes new clean energy technologies. SENTECH provides services to private companies ranging from technical due diligence in mergers and acquisitions to market research and project management. This is a small part of SENTECH's business currently but is expected to grow rapidly in the future as many of the new technologies being developed today become commercial.

In conclusion, SENTECH is a consulting firm focusing exclusively on energy efficiency and clean energy technologies for both stationary and transportation applications. The company continues to see rapid growth in business with its Federal, state and private sector clients. Their credibility and growth comes from the high quality of the staff and the systems level approach taken when solving clients' problems. SENTECH's business provides a link between technology development and commercialization. Their staff must understand the technology, policy/regulatory issues, and

markets. SENTECH maintains a multi-disciplinary staff with a variety of expertise but recognizes that, as a small company in today's complex global markets, it is difficult to encompass all of the needed expertise in-house. Teaming with other firms with complimentary capabilities is therefore critical to SENTECH, and membership in CTE helps immensely in identifying those partners.

Hawaii Center for Advanced Transportation Technologies—Honolulu, Hawaii

CTE has recently established a relationship with the State of Hawaii to partner in the Department of Transportation's National Fuel Cell Bus Program. Our interest is based on Hawaii's ongoing initiatives and needs in advanced energy technologies, specifically in the development of fuel cell technologies and hydrogen infrastructure with a goal to establish a hydrogen-based economy.

The Hawaii Center for Advanced Transportation Technologies (HCATT) is a program of the High Technology Development Corporation (HTDC), an agency of the State of Hawaii. Its mission is to focus on energizing the transportation technologies industry in Hawaii to support military and commercial applications and improve economic competitiveness. Under previous U.S. Departments of Defense and Transportation programs, HCATT partnered local companies with Mainland companies to develop advanced transportation technologies for both military and commercial applications.

In 2001, HCATT began a partnership with the Advanced Power Technology Office (APTO) at Robins Air Force Base (AFB). Through HCATT, APTO established a National Demonstration Center at Hickam AFB to facilitate demonstration and validation of the latest fuel efficient and environmentally-compliant technologies for use in Air Force support equipment, Basic Expeditionary Airfield Resources (BEAR), and ground vehicle fleets. This program is focused on development and evaluation of advanced transportation technologies and supporting infrastructure with both military and commercial applications for eventual production and acquisition. Initially, the program evaluated light- and heavy-duty electric drive vehicles and battery charging systems. The current goals of the National Demonstration Center include the introduction of fuel cell technology, development and evaluation of fuel cell-powered vehicles and support equipment, determination of hydrogen infrastructure requirements, and development of deployable hydrogen refueling stations. In partnership with power management technology developer Enova Systems, and hydrogen and fuel cell technology developer Hydrogenics Corporation, HCATT delivered a fuel cell/battery-powered hybrid electric 30-foot flight crew shuttle bus in 2004, and followed with a fuel cell/battery powered hybrid electric step van in 2005. The bus was the first fuel cell vehicle in both Hawaii and the Air Force.

More recently, HCATT partnered with HydraFLX Systems to design and develop a modular, deployable hydrogen fueling station for transport on a flatbed truck or tactical aircraft to any location in the world. The station consists of three modules: a fuel processor; a pressure management system; and a pressure storage module. Each module is configured to fit on a standard aircraft pallet. This station will serve as a model for the rest of the Air Force for building deployable systems to meet future contingency operations. These initiatives at Hickam lead both the State of Hawaii and the Air Force in the application of fuel cell vehicles and hydrogen infrastructure.

HCATT will continue to expand the fuel cell vehicle fleet and infrastructure at Hickam AFB, to demonstrate and validate technologies for future Air Force procurement. Future vehicles and equipment include:

- Fuel cell/battery-powered MB–4 Tow Tractor.
- Fuel cell powered-light cart using metal hydride storage technology.
- Fuel cell augmented-flight line maintenance support vehicle.
- Lithium battery-powered pick-up truck.
- Lithium battery-powered step van.
- Hybrid electric dump truck.
- Plug-in parallel hybrid electric step van with continuously variable transmission.

The U.S. Department of Energy (DOE) and its National Renewable Energy Laboratory are participating in the Hickam bus evaluation as part of DOE's Hydrogen, Fuel Cells and Infrastructure Technologies (HFCIT) Program. This Program integrates activities in hydrogen production, storage, and delivery with transportation and stationary fuel cell activities. The ultimate goal is a future in which hydrogen energy and fuel cell power are clean, abundant, reliable, and affordable and are an integral part of all sectors of the economy in all regions of the U.S.

The Hickam AFB bus evaluation is one of several HFCIT projects that support the research and development of highly efficient, low- or zero-emission fuel cell power systems, which serve as alternatives to internal combustion engines. The U.S. Department of Transportation is also supporting this project through the Federal Transit Administration's Hydrogen and Fuel Cell Bus Initiative.

Hawaii Fuel Cell Test Facility

The Hawaii Natural Energy Institute (HNEI) of the University of Hawaii in collaboration with industrial partners has developed the Hawaii Fuel Cell Test Facility (HFCTF). This 4,000 square foot facility, opened for business in April 2003. It houses six fuel cell test stands including three stands designed for full size single cells or short stacks and one specifically designed for high-speed dynamic testing as the first step toward Hardware-in-the-Loop and rapid prototyping capabilities. With support from the Office of Naval Research, DOE, and industry, efforts at this facility include testing of advance-membrane materials and component materials, and characterization of the effects of fuel and air impurities on fuel cell performance and durability. The results of this work will help fuel cell developers design higher performance, more durable devices. Hardware for testing is currently provided by several major fuel cell developers. In 2006, this facility will be expanded to allow testing of stacks up to 5 kW, including cyclic testing consistent with transportation applications. In light of the fact that fuel cells still are not as durable as they need to be, testing as is done at the HFCTF is of value to both government and private sector organizations involved in fuel cell development.

Hawaii Renewable Hydrogen Economy

As noted above, Hawaii, like other states, is developing public-private partnerships to facilitate the deployment of alternative energy technologies, specifically for fuel cell applications and the pursuit of a hydrogen-based economy. The State of Hawaii is strongly committed to the development of these technologies as is evidenced by recent legislation to establish a renewable hydrogen program to manage the state's transition to a renewable hydrogen economy. This legislative initiative also includes the establishment of a hydrogen investment capital special fund to provide seed capital for and venture capital investments in private sector and Federal projects for research, development, testing, and implementation of the Hawaii renewable hydrogen program.

The program will design, implement, and administer activities that include:

(1) Strategic partnerships for research, development, testing, and deployment of renewable hydrogen technologies;

(2) Engineering and economic evaluations of Hawaii's potential for renewable hydrogen use and near-term project opportunities for the state's renewable energy resources;

(3) Electric grid reliability and security projects that will enable the integration of a substantial increase of electricity from renewable energy resources on the Island of Hawaii;

(4) Hydrogen demonstration projects, including infrastructure for the production, storage, and refueling of hydrogen vehicles;

(5) A statewide hydrogen economy public education and outreach plan focusing on the Island of Hawaii, to be developed in coordination with Hawaii's public education institutions;

(6) Promotion of Hawaii's renewable hydrogen resources to potential partners and investors;

(7) A plan, for implementation during the years 2007 to 2010, to more fully deploy hydrogen technologies and infrastructure capable of supporting the Island of Hawaii's energy needs, including:

(a) Expanded installation of hydrogen production facilities;

(b) Development of integrated energy systems, including hydrogen vehicles;

(c) Construction of additional hydrogen refueling stations; and

(d) Promotion of building design and construction that fully incorporates clean energy assets, including reliance on hydrogen-fueled energy generation;

(8) A plan, for implementation during the years 2010 to 2020, to transition the Island of Hawaii to a hydrogen-fueled economy and to extend the application of the plan throughout the state; and

(9) Evaluation of policy recommendations to:

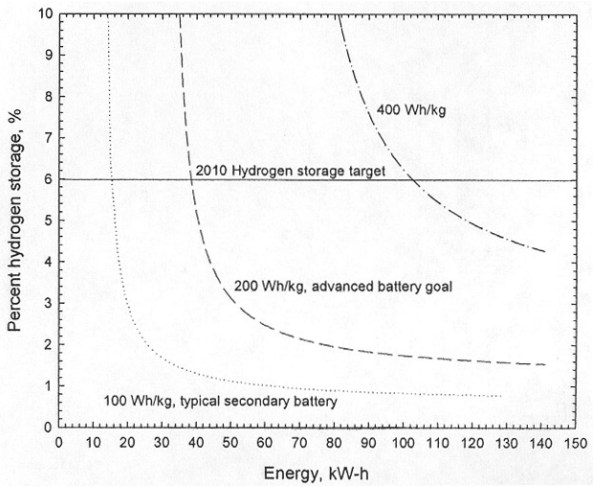
(a) Encourage the adoption of hydrogen-fueled vehicles;

(b) Continually fund the hydrogen investment capital special fund; and

(c) Support investment in hydrogen infrastructure, including production, storage, and dispensing facilities.

Center for Innovative Battery and Fuel Cell Technologies—Georgia Institute of Technology, Atlanta, Georgia

Hydrogen and electricity are the only carbon-free energy carriers under serious consideration. Therefore, for transportation applications in a future hydrogen economy, the key competition to fuel cells will be batteries. The source of hydrogen for a fuel-cell system may be from the electrolysis of water using energy from nuclear power or a renewable source, thermolysis or photolysis of water, or from a reformed hydrocarbon fuel. The fuel cell stack, pumps, blowers, etc. along with a hydrogen-storage system are an energy-storage system equivalent to a battery. The battery will be more efficient in converting electrical energy into chemical and back, achieving round-trip efficiencies of 80 percent or more. However, rechargeable batteries have a specific energy of about 100–120 Wh/kg with a long-term goal of 200 Wh/kg, and typical vehicle requirement of near 300 Wh/kg. The key advantage for the fuel-cell system will be greater energy density, which translates directly to better range. This comparison is shown in Figure 1 for a 100 kW fuel cell assuming 0.65 kW/kg (DOE 2010 goal). More than likely the vehicle system will be a hybrid—the extent of hybridization and specific system architecture will depend on the relative successes in improving hydrogen storage, reducing fuel-cell costs, and in increasing the energy density of secondary batteries.



So which approach will be successful? The two most difficult barriers are improving the energy density of batteries (EV) or improving the hydrogen storage (FCV). Both are challenges of comparable difficulty. In both cases, researchers must select from elements on the periodic table. Today most of the emphasis is on fuel cells and a better balance between batteries and fuel cells is needed.

Tremendous progress has been made in the development of low-temperature fuel cells. Two noteworthy advancements were the introduction of perfluorinated ionomer membrane and the improvement of electrode structures that increase catalyst utilization. At the same time, numerous incremental improvements have been made. Nonetheless, it is clear that present technology falls far short of the ultimate requirements, and significant effort in fundamental understanding is warranted.

The key barriers for PEM fuel cells for transportation applications are cost and durability. The approach taken at Georgia Tech has been to focus on durability. This strategy is particularly relevant to the heavy-duty transportation segment. Any transportation application is going to require many hundreds of thousands of power cycles and thousands of start/stops. These transients exacerbate many of the failure mechanisms. Further, for heavy-duty vehicles the operational life (40,000 hours) is much higher than for automobiles (5,000 hours). Since the fuel cell is a large fraction of the vehicle cost, durability and reliability of the cell stacks is critical.

From a detailed understanding of the mechanisms and root causes of failure two approaches are taken at Georgia Tech. The first is a system solution. By careful de-

sign of the system architecture and control strategy of a hybrid system, for example, some degradation mechanisms can be mitigated. The second approach, the development of new materials, is more elegant but also much more difficult.

The major failure mechanisms that are being worked are (1) degradation of the membrane separator materials, (2) stability of precious metal catalysts, and (3) corrosion of carbon support materials. We are also working on hybrid systems to understand better how the power management and control strategies affect the life of the fuel-cell stack and batteries.

Another barrier for fuel cells for transportation is their low temperature of operation. Just like today's internal combustion engines, a significant amount of heat must be rejected to the atmosphere. The low temperature of operation (80 °C) increases the size of the radiator. It is estimated by the auto companies that an operating temperature of 120 °C is needed to maintain the same radiator size as for ICEs. However, present ionomer membranes don't work well at these temperatures. This is another area that is being investigated at Georgia Tech (supported by Toyota). Professor Meilin Liu's group is developing new membrane materials (triazoles) that show promise at elevated temperatures.

EVamerica—Chattanooga, Tennessee

EVamerica is CTE's newest member. They are embarking on the electric and hybrid electric shuttle bus market, starting with 22-foot buses. EVamerica is an example of how entrepreneurial operations are starting up throughout the United States to address our energy needs through clean transportation technologies.

EVamerica was founded as a Limited Liability Company on March 16, 2006, to own the assets, provide space, management staff, and employees, to design, develop, manufacture and assemble electric and hybrid electric medium to heavy-duty vehicles. The company was publicly announced by Congressman Zack Wamp, 3rd District Representative of Tennessee at the Tennessee Valley Corridor 2006 National Summit in Chattanooga, Tennessee on June 1st.

EVamerica will become the premier designer, developer and manufacturer/assembler of electric and hybrid electric medium- to heavy-duty vehicles in the United States. Additionally, the company will offer hybrid systems for installation in other manufacturer's vehicle's through the integration of S.K. International into EVamerica as the Power and Propulsion Division of the company.

The company will employ individuals with a strong knowledge of the electric and hybrid-electric vehicle industry, a clear understanding of the benefits and challenges of advanced technology vehicles, and experience in public transportation; the initial market for EVamerica.

The organization has begun by developing 22-foot electric buses with the latest and best technology comparable to those already operating in Chattanooga, Tennessee. The company will grow, *in a controlled and systematic process,* to develop three or four more variations of the 22-foot design that will include the use of auxiliary power units for hybridization. The company will also be developing a family of designs that can be powered with a number of electric power systems and hybrid electric systems from internal combustion engines to hydrogen fuel cells.

Conclusions

As energy consumption and dependence on foreign petroleum supplies becomes a more critical concern in our society, the U.S. must continue to address potential solutions. The transportation sector offers opportunities for significant advances in technological solutions, resulting in significant benefits to the market and to the environment. The U.S. is poised to become the worldwide leader in the clean transportation technology arena. The work conducted through the Center for Transportation and the Environment and its members demonstrates the capabilities and potential for moving the U.S. to the forefront of electric, hybrid electric, and fuel cell vehicle development.

To make the United States a leader in the clean transportation market, it will require a commitment on the part of the U.S. Government to support more than just pure research. We must invest heavily in getting products out of university laboratories and onto our streets. We must invest in prototype development, market appraisal, and manufacturing analyses. We must take advantage of the tremendous potential that lies outside of the major automobile manufacturers and energy suppliers. We must increase funding to encourage collaborative efforts between government, universities and industry, including incentives for smaller companies to partner with universities to capture the potential for innovation within each. We must focus more on the heavy-duty vehicle market, not only for its impact on petroleum use, but because the bus market in particular offers the best test bed for new transportation technologies.

The Center for Transportation and the Environment works to establish the needed industrial-university-government consortia to bridge the gap between basic research and commercialization and to bring the best transportation research ideas to market.

We look forward to working with the Senate Subcommittee on Technology, Innovation, and Competitiveness from both a public policy and a technology research and demonstration perspective as we pursue energy independence for the United States and cleaner air for our citizens.

Senator ENSIGN. I want to thank all of you. I think this is an exciting hearing. You know, I would love all of America to be able to hear some of the exciting new developments that are being made around the country, especially in the private sector in some of these applied technologies. In addition, I think that the folks here today are representing some of the most exciting things happening out there in the marketplace.

I want to explore some of the issues discussed today in a little further detail. I also want all witnesses to feel free to comment on something that I ask about. But I want to start with Dr. Gotcher. Dr. Gotcher, you were talking earlier about ion battery technology and one of the problems that we have heard with some of these new technologies—whether they are hybrids or electric cars—is the degradation of the batteries. With a lot of these technologies we have to examine how long these things last. Today, we understand approximately how long a petroleum-powered car lasts today. We also know how long power plants last. I'm going to try to get each one of you to address, as best you can, the lifespan of the products that you are offering. Do we have any of the research on some of the products that you are developing? Can you discuss your research on how that makes it more viable to the marketplace.

Dr. Gotcher, could you start with the ion battery technology and discuss some of the advances that you have made that will help make battery technology more viable?

Dr. GOTCHER. I'd love to answer that question.

First, today's battery technology, are lead-acid batteries for starting, lighting, and ignition, and mainly nickel metal hydride batteries that used in HEV, or hybrid electric vehicles. The lead-acid battery has a typical life of 3 to 5 years, and nickel metal hydride batteries used in HEV, the expected life is 5 to 7 years. Now, in both cases, the life of the battery is substantially less than the life-design of an automobile.

Now, we've been focusing on lithium-ion batteries——

Senator ENSIGN. In your answer, please also address, if you would, how a battery degrades over time. It isn't that a battery just all of a sudden quits working. It degrades over time, correct?

Dr. GOTCHER. That's correct.

Senator ENSIGN. So a battery loses "X" percent of capacity per year.

Dr. GOTCHER. That's correct. It does lose capacity, and its design capability and capacity deteriorates over time.

The batteries that we've been focusing on are lithium-ion batteries, which today are not used in vehicles, primarily because as the lithium-ion battery grows in size, its safety hazard becomes unmanageable. And that's the primary reason that lithium-ion batteries are not used in vehicles today, which is why we've placed so much emphasis on the safety testing of the Altairnano battery.

And, to date, in every single test we've run, when our batteries have failed, they fail safely, in large format. And so, with the Altairnano battery one of the major reasons for not using lithium-ion battery material in vehicles has been addressed by the materials selection and the use of nanomaterials.

Second, with respect to lifetime, typical batteries will have a few hundred cycles of charge and discharge. Typically, they're limited at about 500 to maybe as many as 900 cycles. Our batteries have been tested, both in our facilities and third-party facilities, and have obtained 9,000 cycles of charge and recharge at 20C rates, which means charging the battery in 3 minutes. So, we believe that the design-life of our batteries approximates 15 years, which is clearly within the design spec of automotive cars. So, we feel that——

Senator ENSIGN. OK, how much have these batteries degraded in that 15 years?

Dr. GOTCHER. In 15 years, our—well, in the 9,000 cycles—end-of-life is measured, within the battery industry, at 80 percent of first-charge capacity. So, after 15 years of life, 9,000 cycles of charge and discharge, we'll still have 80 percent of the battery's capacity remaining in the battery pack.

Senator ENSIGN. And if the battery was used in a car, how many miles would the car be able to travel?

Dr. GOTCHER. The range of an automobile depends on the size of the battery, the amount of energy stored in the battery. And we believe that we'll be able to have ranges of 250 to 300 miles in a reasonably sized battery pack. The number of charge cycles indicates: How many times do you recharge the battery after you've depleted that energy? And so, from several different perspectives, our battery technology appears to have the safety features, the recharge cycle-life, which also includes calendar life, as well as the range, to make an electric vehicle or an alternative energy vehicle behave much like an internal combustion engine-driven car. It'll have a range of 300 miles. It'll be able to be recharged in 6 or 8 minutes, which is typically the amount of time that it takes to refuel a gasoline-powered vehicle. And it'll, importantly, have a lifetime comparable to today's cars; you'll expect the powertrain, based on a battery-powered car, to last as long as an internal combustion engine.

Senator ENSIGN. And you would be able to charge these electric vehicles at home or at a charging station?

Dr. GOTCHER. That's correct. It will take a little longer at home, only because the voltage available typically in a home is lower.

Senator ENSIGN. OK.

Dr. GOTCHER. And so, the length of time to a full charge is a function of the amount of power that you can deliver to the battery. It can take the power very rapidly.

Senator ENSIGN. Right. I was just thinking, if you had fuel cells or if you had an intelligent energy management product like Mr. Corsell's company manufactures, at nighttime you could take power off the grid at different times to maximize efficiency and hook it up with an electric vehicle. You could really start playing with some of these various devices and become very energy efficient.

We can just go down the line, if you want. I invite all witnesses to make comments if you would along this line of questioning.

Dr. PRELI. I can comment on the durability of fuel cells. The most successful case of fuel cells right now is in the stationary market. We've produced over 250 of these 200-kilowatt fuel cells, and they're in the field. The highest-time unit in the field in the customer's hand has now surpassed 60,000 hours. Our goal is 80,000 hours, which is approximately 10 years of continuous runtime. So, great progress has been made in that arena.

In the auto market, the life requirement is only 5,000 hours. The average internal combustion engine in your car only really needs to run for about 5,000 hours, but it's a much more difficult mission. At UTC, in the laboratory, we've achieved those results: greater than 5,000 hours—in fact, greater than 13,000 hours. In the field, though, the DOE infrastructure program is starting to prove capabilities of fuel cells in the hands of customers, so we'll get a lot more information over the next couple of years. But we're confident that today we're at least in the 1,500- to 2,000-hour range. And, shortly, we'll be able to achieve the 5,000 hours.

Transit buses require a lifetime of about 25,000 to 30,000 hours. And, again, it's a fairly difficult mission. However, you're allowed more space than you are in an automobile in a transit bus, so we can put in design features to extend the life. We currently offer buses with at least a 4,000-hour lifetime on the fuel cell system, and that soon will be ratcheted up to 10,000 hours. So, we're making good progress meeting those goals, as well.

Senator ENSIGN. Thank you.

Dr. SRIDHAR. I think you hit upon a very important question. When you go from the centralized powerplant on the grid to many of these technologies that you're talking about here today, you're suddenly changing the way you buy energy. Rather than buy electric as a commodity, you're buying an appliance that sits at your place that's supposed to meet that need. So, the way you look at the economics changes. Rather than buy a commodity at that price at that point in time, in addition to some commodity like fuel that you may buy that way, you're also buying the initial fixed-cost appliance, and it's the total cost of ownership that matters. And then, the total cost of ownership, maintenance, beginning-of-life to end-of-life performance all become very important aspects of the economics.

It took 100 years of evolution before which now we are seeing every 100,000 miles we can change the spark plug. It didn't happen overnight, even though there was no inherent physics associated with it. It was cost, engineering evolution.

In any of these new technologies, if you want to get to the grid price point in terms of economics, achieving the kind of lifetimes that you heard about the fuel cell will be very, very difficult. It'll be very difficult in most of these technologies, initially. If you're very aggressive on cost, something's going to give. That's inherent. And so, the question is: Is it a predictable maintenance, as opposed to an unpredictable maintenance? Can you make it very serviceable and make it very cheap? Can you monitor it constantly, so it's opaque to the customer? Even before they know that they need to have it serviced, it's in the maintenance contract, you can go fix it.

This is the way that we are looking at this technology, as a complete economic situation.

Our guess is, for the economical fuel cells, a 5-year lifetime or 60,000 hours in a stationary fuel cell, you will be able to get a very good total cost of ownership. And that number is not a magic number. It's that total cost of ownership versus grid power. What is your payback period? If the payback period is 3 years or less, it's a very attractive buy. If it is anything more, it's not. So, there is no magic number to the life. It is more the economics. But for what we are doing, we think it's about 5 years. We think our initial products will not have that. But our model will be able to sustain that. Our guarantees will be able to sustain that. That's how we are approaching it.

Senator ENSIGN. Mr. Werner, as you address this question, too, could you maybe comment on how something like Mr. Corsell's product could decrease the payback period of time on your products?

Mr. WERNER. Sure. And this question really plays to solar power's strengths. Today, we ship hundreds of systems. And you can buy one in Nevada that we'll warrant for 25 years. So, we'll sell a system, and if it drifts in power rating more than 10 percent, we'll replace the system. So, you get a payback of 9 years, which means you have 16 years of profitable cash-flow. And that's the product that we sell today.

So, fundamentally, the challenge is, how do you innovate and continue to support a 25-year warranty, because it's kind of hard to test for 25 years. It would be a long development cycle. So, a lot of our innovation is in terms of accelerated testing. So, as we pull cost out of the end product, we need to be able to test that new product quickly, so we can introduce it into the field and still have the 25-year warranty.

Now, in terms of using Mr. Corsell's product, the power costs a lot more, depending on when it's generated. So, if you can optimize the use of solar, which happens to pretty much match when power costs the most, but when you can level the use of a building or a residence, then you can optimize the use of that peak power generation. So, I have a system on my house, and I generate more power than I use in the summer, and less than I use in the winter, and so in the summer I have excess power, and his product would help the utility use that excess power effectively. So, there are a number of ways of using the power when it costs the most, and balancing the grid.

Senator ENSIGN. Thank you.

Mr. Corsell?

Mr. CORSELL. This is all about economics and payback period and the tremendous implications of moving from a model where you are essentially renting power from the electric power grid, and moving toward distributed clean generation. It makes rational sense for storage to go along with that. GridPoint is not a producer of storage technologies. Of course, we purchase batteries from other companies and are constantly looking for better batteries. But like SunPower, which I do believe makes the world's greatest solar modules, we are in the consumer marketplace. The same dealer in Nevada that sells Mr. Werner's product will sell ours. And the

issues that we have to address are cost and physical footprint—how many kilowatt hours of storage are you getting in how large a physical space? People only have so much room in their homes. Weight is a big issue. When you get down to installation, taking a system like this through a doorway and down stairs to a basement, there are all sorts of practical issues.

Senator ENSIGN. Do most of your products get installed indoors or outdoors?

Mr. CORSELL. Indoors. In basements, garages or storerooms. And so, there are all these issues that come down to how robust the storage is, how many times can you discharge it, how long will it last? GridPoint, of course, as an appliance provider, has to warranty and stand behind the performance of the entire device, so our on-board computing power is significant. With advances in storage technology, we will be able to deliver much greater value to our customers by leveraging that storage intelligently, the same way users will benefit from further advances in the efficiency of Mr. Werner's solar panels. But the cost of storage technology has to be driven down. We use telecom-grade deep-discharge VLRA batteries right now. I've seen more impressive technologies both in and out of the lab, but price performance is the principal issue. Solar panels face the same challenge—the economics are attractive in California, they are more attractive in New Jersey or Austin, Texas, where there are high subsidies, and they are not attractive in Kentucky. Eventually, the regulatory environment and improved economics will drive adoption of intelligent turnkey systems that encompass generation, storage, and local control at a reasonable cost with a payback period that consumers will accept. Otherwise, people just won't buy it, and—although it's wonderful when the Government promotes clean technology, we, like SunPower, believe that our success depends upon competition in the consumer marketplace.

Senator ENSIGN. Thank you. Just a little observation—if the nanotechnology ion batteries that Dr. Gotcher is talking about meet the costs—you guys may want to get together.

[Laughter.]

Senator ENSIGN. Dr. Taylor?

Dr. TAYLOR. Wave power stations, have a projected lifetime of 30 years. A conventional coal-burning power station has a lifetime of about 25. The reason why we can project a lifetime of 30 years is that the basic unit, the PowerBuoy™, is encased inside a device somewhat like a navigation buoy. And NOAA, for example, has a regular maintenance program on their navigation buoys, which will be the same program that we will use. This program requires, every 4 years, each buoy is taken out of the water, the algae and the barnacles are scraped off, and it's repainted and put back in. The smart part of the system that does the conversion of the mechanical motion of the waves into electricity is encased inside a watertight compartment filled with dry nitrogen. We, therefore, expect that the maintenance will be—every second time the buoy is taken out of the water (*i.e.,* every eight years), there will be maintenance on the parts inside the buoy.

So, overall, the lifetime of the wave power station, we believe, is 30 years. Utility partners who have looked at it with us agree that

that is probably right. Obviously, the maintenance cost is built into the total cost of the energy. Because it is a modular system, a power station consists of an array of buoys, making it easy to take each buoy out separately. And so, if you have a field of 50 buoys, you take one out, you only have a decrease of 2 percent while you're doing the maintenance. And it gets even easier than that, because the small tugboat that takes the buoy out to the site will take a refurbished one out, and it just will be a quick exchange over a short period of time.

Senator ENSIGN. Mr. Raudebaugh, do you want to comment? Because I think that your organization is looking at all these private technologies and what the government is doing from the outside. Could you provide an outside perspective on some of the things that we have been talking about?

Mr. RAUDEBAUGH. Sure. Well, from a vehicle market perspective, as alluded to earlier, that market has been around for 80, 90, 100 years, and I don't know if there's been a more capital-intensive market in the world than the worldwide automotive market. So, it's very tough to compete, given that they've got an 80-year headstart and millions of times as much capital as we have on that electric vehicle side or the hybrid electric vehicle side. But we have advantages. Electric motors are much more efficient than an internal combustion engine is. Electric motors are a much better fit for a vehicle. What we have to do is, we have to get our products into the marketplace, because—the reason they're so good is, they've been in the marketplace, they've gotten feedback from all over the world on what works, what doesn't work. And I talked earlier about doing prototypes. We need to do prototypes. Five-thousand hours in a lab is impressive, but if we don't build a prototype, how will we know how it does in the field in an automotive duty cycle or even a transit bus duty cycle, a transit bus duty cycle is much easier, because you have central refueling space and weight is not as much of an issue. The transit bus market is large, I think there are 80,000 out there, about 6,000 sold a year. Eighty percent of those are paid by the Federal Government, by the FTA. So, it's an excellent place for the government to bring these new technologies to the marketplace and to get the experience we need.

One of the technologies I mentioned earlier, flywheel battery, is a mechanical battery. So, we have talked about batteries that do well to get 5,000–9,000 cycles over their lifetime. We've done tests on a flywheel battery that did 106,000 cycles, which is—far exceeds the lifetime of a vehicle. And we had to quit testing, because we ran out of money to keep testing it. But, basically, as a mechanical battery, it works as long as the vehicle works, and then some. Now, you can't power a vehicle on a flywheel. It's a high-power, low-energy device. But if you put a flywheel in conjunction with a fuel cell, and the flywheel does the acceleration for the fuel cell, then the duty cycle for the fuel cell is much easier. If you put it in conjunction with lithium-ion batteries, and you take the acceleration part out of the duty cycle for those batteries, they're—they will last longer, and you put less batteries onboard, because they have to provide the nominal power, not all the power to accelerate.

So, these type of technologies are what are improved when you build prototypes, and what the fuel cell manufacturers find out,

and what the battery manufacturers find out, is, maybe, given that you have an electrical system, the duty cycle for an automobile or a bus isn't that bad, because there are so many enabling technologies that will help you make the system work.

Senator ENSIGN. I would like to make one comment; when we talk about some of the technologies that we are discussing today, many folks mention—as I did in my opening statement, the millions of barrels a day that we consume as petroleum products. Some of the technologies we're talking about today involve stationary power, some involve automotive power, but it would seem to me that, even with the battery technologies we're talking about here, when you combine the stationary with automotive or portable power—whether they're the fuel cells, the hybrids, or whatever, especially if you can charge them at home and you can use some of the products that you're using at off-peak times we can become less dependent on foreign oil, even through the stationary market. And the technologies that we have been talking about today, I think, are very exciting, and we have not even touched on the environmental benefits of all of these things. One of the problems that they are confronting in China right now is that—because they have very high sulfur fuels, there are a lot of complaints not only with traffic, but with the increased air pollution. Air pollution is very, very bad in China, particularly in urban centers. If you've been to China for any period of time, you feel such pollution in your collar. They use a lot of coal, but even now they are starting to get a lot of the sulfur problems that we have dealt with in this country. And China just does not have the economics yet to be able to change the refining capacity to lower sulfur types of fuel.

So, I think the progress that has been made on alternative energy technologies in the United States is very exciting. I agree with some of the suggestions that have been made by this panel about the government's role. From my perspective, we subsidize petroleum and the auto industry in a lot of different ways, not just, necessarily with tax credits, like what we do to encourage the development of these new technologies. Consider, how much money do we spend with our military right now to make sure that oil flows to America? And we have exploration tax credits. We even have some things in our tax code that keeps that petroleum coming.

The reality is that we will be dependent on petroleum products for quite some time. We all agree on that point. But how can we decrease that over time, especially as demand for energy in China is increasing, we had better be decreasing our use of petroleum products, or the cost of using such products is going to continue to skyrocket. I believe, as this committee and subcommittee, especially, is focused on the competitiveness aspects of America—the less dependent we can be on petroleum products, in general, I think that the more competitive we are going to be as our economy evolves and as our demands—in computing power, etc., increase. If we can satisfy some of those energy needs with a lot of what you all are doing, and other technologies that are out there, I believe that will put us in a better position in the global marketplace to be competitive. So, I'm very excited about some of the things that you all are doing here, and I want to encourage you to not only continue to pursue some of the things that you are doing, but also to

give us the feedback that we need here at the Federal level. We could probably do a hearing per week on this topic for the next 50 weeks and barely scratch the surface of what is going on out there. But these kinds of hearings that bring the issues up and help educate some of us that are policymakers up here, I think, are very important.

Maybe we can just spend a couple of minutes talking about one of the things that I hear from my colleagues. When we are talking about some of these new technologies, and we see op-eds sometimes written that state that the promise of solar technology, for instance, "Oh, it's right around the corner." Some of these technologies—wind, wave technology, and battery technologies—have demonstrated advances. In fact we have seen advances in all of these technologies, But the issue of commercial viability remains and that is why I've spent some time on that. Maybe each of you could take 30 seconds on it, to answer the critics who would say that, "America is just basically wasting this money that we're going to be investing in new alternative energy technologies—whether it's tax credits, whether it's subsidies, whatever it is, we're going to be wasting some of our money into the future, because the promises have been there, but these technologies still can't compete."

Dr. GOTCHER. The competitiveness issue, or the price performance issue, is really a key challenge for businesses when they're bringing a new technology to market. As was said earlier by the panel, the playing field isn't really level. The in-place or entrenched technology has years of engineering and cost-reduction efforts, and it's been fine-tuned over a number of years. So, the challenge for a small company, like Altairnano, as we bring this new battery technology to market, is to pick the first battleplace in the market very carefully. And we need to pick a small opportunity, where we can exploit the advantages of the technology and where the marketplace is willing to pay for that improved performance. And I think that's, frankly, one of the reasons why so many new technologies don't succeed commercially. It's not because of the technology challenges. The technology works. It's the economic equation, price/performance. And when you have a large company that has been competing for a number of years, and they have significant market share, they have a lot of weapons to bring to the battle in the marketplace. And so, that first battle is really important. And I think we're trying to be very clear about where our entry point to that market will be, and the strategies that we use, trying to exploit the performance of our technology, which means we're going to try to exploit the weakness of the entrenched technology. But it's a tough battle, and it's not a level playing field.

Dr. PRELI. My thoughts are along the same lines. I think, first, what you need to do is look at the payoff we're trying to achieve. If you first look at, for example, an internal combustion engine or a diesel engine, versus a fuel cell or wind or solar, you'd say, "Well, it's a tough economic proposition at first. Once you have volume, you can get there." So, I think you have to look past that into what the true payoff is. And you've touched upon it. We don't really pay the true cost of oil and petroleum to provide power. You mentioned military costs, but you didn't mention healthcare costs. It's hard to attribute exactly how much of our healthcare costs result from en-

vironmental effects, but I think we all are, more and more, agreeing that it's significant, and we're also concerned about climate change in the future. These costs are not added to the price of a gallon of gasoline. The motivation really is the ultimate payoff. And if you agree that these technologies will get you to where you want to be, then what you're really doing is incentivizing and providing a means to grow the volumes so the technologies can stand on their own.

In the end, they'll not only be very economically-viable, but probably more so than a lot of the mechanical components we use today, and fuel cells will also provide these additional benefits that you've mentioned.

Senator ENSIGN. OK.

K.R.?

Dr. SRIDHAR. Senator Ensign, if you look at just stationary power generation in the world, it's roughly a $2 trillion market, growing at about a 10-percent rate. And, given that we can't meet the global electricity needs, as it's being projected, with a few billion people coming out of abject poverty to even lower middle class, we know that the existing solutions, as they go, are not going to scale, they're not sustainable. So, the market pull is enormous. So, be it a small start-up like us, Ion America, or be it the large guys, like United Technologies or General Electric, there's no reason for Federal dollars to go into R&D to be able to do this. The market opportunity is so large. If we believe something can work, we don't need R&D dollars. By putting R&D dollars into any of these things, at the industry level—I'm not talking about academia and national labs—at the industry level, we're trying to pick winners and losers, and I don't think we should be doing that. That's not the role of the Federal Government. However, if you take established industries and look what the government has done in the past, which has been very successful, you build a backbone for them to grow. If it is the Internet and everything that we look at, it is the ARPANET. And, you know, that was put in by the government. It was the highways, it was the transmission/distribution infrastructure. For this particular industry, it is going to be going from feasible, demonstrable projects to commercialization, that chasm. Because without the economies-of-scale, you can't get to cost. That is the place to help. So, the government as an early adopter is the single best place that the government can put its money.

And you should be technology agnostic. You must say, "These are the criteria. It is efficiency, it is emissions, it is dependence on oil," and keep raising that bar so we go do that. I think that's the best help we can get.

Senator ENSIGN. I wish there was another Senator here, because I have to step out just for a moment to take a phone call. I will be right back. So, if you could just hold on, because I would like to finish this discussion. OK? Thank you.

[Recess]

Senator ENSIGN. Sorry.

Mr. Werner?

Mr. WERNER. OK. So, once again, I think solar is in a good situation here. First of all, what I would say is, SunPower is the fastest-growing technology company for the last five quarters, in terms of

revenue growth, so solar is real, and even in North America. But when you look outside of—or when you look at the economic-viability, I don't think it's a question of "When"—I'm sorry—I don't think it's a question of "if," I think it's a question of "when" and "who." When, as in the next 5 years, in the next 10 years? And, who, is it going to be, American companies, or is it going to be Germany or Japan? Those are the other leading countries. And, just briefly, how do you get economically-viable—let me use our company as an example. We convert more sunlight to power than anybody in the world. Today we convert 20 percent of the sunlight that hits our product into power. We can get that up to 25 percent. So, in just that one measure, 20 to 25 percent, we can lower the cost of solar power by 25 percent. All of the value changes divided by the number of watts you produce, just by one metric, one innovation metric, which is what we excel at, we can pull 25 percent of the cost out. And we estimate we need 40 percent of the cost to go mainstream to address the $1 or $2 trillion electricity market. So, on one innovation factor, we get over halfway there. And, of course, as you scale, then you get manufacturing efficiencies, and you get more than the balance. So, it's not a question of "if" you'll be—"if" solar goes mainstream, it's a question of "when" and "who." And with a predictable market, of course, we hope that'll be an American company—namely, us.

Senator ENSIGN. Mr. Corsell?

Mr. CORSELL. Senator, three quick points. First, on the technology. Obviously, we would all agree here that the technology is real. The issues we're facing have to do with market adoption and existing methods of producing energy and consuming energy, and how we compete on a price/performance basis. As we have seen with the solar industry of late, and the rise in hybrid cars, these technologies have penetrated the market, and are now beginning to benefit from cost reductions at large volumes of production.

On the issue of energy itself, we have an entrenched power generation infrastructure that has a negative environmental impact. And I think everyone on this panel is here, in large measure, because we care about clean energy. If we're going to accord value to the fact that energy produced from solar panels is clean, where energy produced from a coal plant is substantially less so, it only makes economic sense to allow that cost to surface so that customers deal with it. If you subvent the price of dirty power so that the customer has no economic incentive to choose clean power, then we, as a society, are saying, "There is no value to having reduced air pollution."

Finally, a lot of this has to do with information and educating the customer. And that's why GridPoint focuses on the information component. Our systems provide customers with visibility, for the first time, to say, "Here's what I'm spending per month on each appliance." That opaque electric bill, which is going up all across the country—it's driving people nuts, it's something they have to pay, just like taxes, and they don't really understand it. We provide a window through GridPoint Central, which is our online web portal, into how that money is being spent. We say, "Here is the actual economic benefit of those solar panels you've put on your house, in real dollars." We say, you know, "Power doesn't really cost the

same throughout the day. Here are the decisions we're making to purchase you less power when it's expensive and more power when it's cheap." And that education component is significant, because as people realize that there's something they can do to take control of their energy situation, they begin to think, "Well, you know, maybe I should invest in solar panels, now that I see how much they can save me." You know, "Maybe I should allow the system to run my clothes dryer at night, or run my pool pump when utility rates are cheapest."

So, just going to market-based pricing for utilities makes a whole lot of sense, because if you place customers in a framework where they have to pay different prices for power based on the underlying economic and environmental considerations, they'll adopt technology to make those choices all on their own. But if you subvent the true costs—you mentioned the cost of military supporting the existing oil economy—when you have a system like we have now, people aren't forced to deal with those costs directly. And if they're not forced to pay the price, they're going to have less incentive to adopt these new technologies. We believe that education and transparency are critical for customers to chose conservation with minimum government support.

Dr. TAYLOR. I'd agree with several of the other panelists in their comments about the need to get into volume manufacturing of one's renewable technology. In our case, we believe that in the next 3 years we should be able to have 50 megawatts of wave power systems in the ocean; and we believe, once we've got to that level of manufacturing, our economics will come down to the point that we're competitive against fossil fuel such as oil at $30 a barrel. So, I think this crossover, in our case, will occur, and, for all the other renewable technologies, will occur quicker, just because of the market forces in the oil industry and also the coal industry.

One interesting metric that perhaps is unique about what we're doing is that if you have an oil lease of a million barrels of oil, that million barrels of oil if used in a oil-burning power station, will produce 100 megawatts in 1 year. Compare that with taking 100 acres of surface area, literally a drop in the bucket, as it were, on the—given the size of the ocean—but 100 acres of surface area where there's good wave energy will produce 100 megawatts per year, but it will keep producing it forever. So, you can say—you can draw a direct relationship between the amount of wave energy that's out there, versus the barrels of oil that we are rapidly depleting around the world.

Mr. RAUDEBAUGH. I'm going to speak to the transportation, and primarily automotive market, again. And trying to get into that market's tough, because our automobiles work. They work well, obviously. And gasoline, even at $3 a gallon is cheap. But what is the advantage for electric vehicles, battery vehicles, hybrid vehicles, fuel cell vehicles? The advantage is efficiency. We're more efficient. The internal combustion engine, when converting the potential energy in a gallon of gas to power is about 25-percent efficient, at best. Fuel cells—and if I'm low—correct me, but a PEM fuel cell can achieve in the 40- to 50-percent range of converting potential energy in hydrogen to motive power. An electric vehicle can convert in the neighborhood of 80 to 90 percent of the potential energy in

batteries to power. And because we're more efficient, that means our operating costs are lower. So, when gas is $1 a gallon, lower operating costs don't make a lot of difference. And as gas continues to rise, those operating margins become more significant—that delta becomes bigger and bigger, and there's more of a market. And that's why hybrids are starting to jump into the market now.

Our disadvantage is volume manufacturing, period. In 1994, my boss at the time went and visited with Chrysler, to talk about electric vehicles and before they took him into the conference room, where they had encased in glass, a 3.3-liter Mitsubishi engine that they put in their minivan at the time, and they said, "Our cost at volume on that engine is less than $700." If you were to try to build one of those engines in the numbers that we're building fuel cells, which are, ten at a time when we're lucky, you would be looking at hundreds of thousands of dollars to design the engine, machine the parts, and do it, but it—in a volume manufacturing situation, you just really can't jump into the market until your operating advantage becomes great enough that people will pay a premium to get you there. And you find niche markets to try to get your volume up, which—we've talked about the bus market, the heavy-duty vehicle market as an example of how we can do that.

And one thing we know is, as demand for petroleum continues to increase faster than supply is available, at some point—we don't know when, everybody would probably have a prediction that's different—but, at some point, worldwide oil production will level off and start decreasing. Whether that's 5 years away or 20 years away, when that happens, the market will explode. Our operating-cost advantage will be huge.

So, the question is, what have you done between now and then? If it's 5 years away or if it's 10 years away, is it going to be the European market, is it going to be the Japanese market that's going to invest the capital, some winners, some losers, in these technologies, so that we're ready for that day, so that when that happens, and all of a sudden $3 a gallon looks dirt cheap, are we going to be ready?

So, you've got to invest money in these technologies. You've got to find niche markets for them. The heavy-duty vehicle market is what we are suggesting you invest in. You've got to get prototype vehicles out there, so that they can get the volume up, so, when this operating advantage becomes big enough, the market will be there, and we'll have success, and we'll have clean-burning, more-efficient vehicles on the road.

Senator ENSIGN. I have more questions than we have time today. And if I could submit to each one of you the rest of the questions that we have, if you could get back to us, so that we can have those for the record and be able to go through those, I would appreciate it.

I have truly enjoyed this panel, and appreciate you all being here. I think this has been very valuable, and I look forward, also, to reading some of the written responses to the questions. They're fairly detailed, and that's the reason we don't have—you know, each one of the answers will probably take 20 minutes. So, I'd appreciate if you could get back to us. But I really appreciate each

one of you being here and taking the time out to spend some time with us.

Thank you. And this hearing's adjourned.

[Whereupon, at 11:45 a.m., the hearing was adjourned.]

A P P E N D I X

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN ENSIGN TO ALAN J. GOTCHER, PH.D.

Question 1. Lithium ion battery technology has revolutionized the portable device market. Deploying the technology to the automotive industry, however, is a large-scale undertaking. One challenge, faced by large automakers incorporating hybrid technology into their production mix, is that they are looking for a battery company to deliver a finished integrated system, not just the component pieces. How is Altair Nanotechnologies poised to address the demands of automobile companies, like Toyota and Honda, as they begin to market new hybrid technologies?

Answer. The current state of lithium-ion battery technology, as used in the portable device market (*e.g.,* cell phones) has inherent safety, longevity, and performance issues that inhibit its direct application in the large size and format configurations required by the automotive industry. Altairnano' s lithium titanate spinel technology has successfully addressed these issues and offers economically- and technically-viable solutions that are ideal for large format applications, both automotive and stationary market applications. (See Dr. Gotcher's testimony to the Senate.)

Altairnano is rapidly validating the use of nanomaterials in EV, HEV and PHEV applications, in conjunction with various automotive component partners, while ramping up the production capability for these materials, securing battery cell production capacity and installing battery module and battery pack capacity, in order to make them readily available as soon as the vehicle manufactures design and set production schedules for their EV/HEV/PHEV vehicles. Given that OEM vehicle design programs take a minimum of two to 4 years to implement new component technology, Altairnano has taken the necessary steps create the awareness and to make the technology and products available to the major global OEMs through well established contacts and relationships.

Altairnano has the total transportation market in view, and the company recognizes that it will take many alliances and partnerships to organize the supply chain that will be necessary for the automotive supplier network to provide finished, integrated systems. Altairnano's business development staff has established numerous contacts and relationships to be prepared to initiate its part of the supply chain when the OEMs are ready to make the transition. That said, however, the timing and pace of market introduction and the relative speed of market penetration by EV/HEV/PHEV vehicles will be determined by the automotive companies, public transportation polices, and international energy markets. Altairnano's ability to initiate capital investment and resource development for making their new lithium-based batteries for automotive applications will depend entirely upon the decisions of downstream automobile manufacturers, government policymakers, and those who buy vehicles.

Question 2. Unmanned aerial vehicles (UAVs) have become a very important component in both the global war on terror and in the efforts to secure our Nation's borders. Improving the performance of a UAV could determine the success of a mission, like the one used to track and kill Abu Musab al-Zarqawi in June of this year. Can companies like Altair Nanotechnologies, develop technology fast enough, and at a large enough scale, to meet the quickly evolving needs of our industries—including our military and homeland security needs?

Answer. Many people have argued that *only* small, highly innovative companies—such as Altairnano—can move quickly enough, and can push research and development sufficiently "outside the box," to effectively meet emerging or only recently anticipated threats and opportunities. Using the UAV example, Altairnano's new nano-battery technology, based upon nano-lithium titanate spinel, could prove both lightweight enough and long-endurance enough to permit small, field-portable UAVs to fly for many hours without landing for fuel, and then to be fully recharged (from a light truck or field generator) and returned to flight duty within minutes. Such capability would provide an infantry unit or a reconnaissance patrol with virtually

constant "eye in the sky" capability to survey the terrain around within miles. Larger size UAVs, flying for hours on end, could function constantly to locate and track enemy movements, surveil fixed positions or suspected hideouts, or attack with munitions repeatedly as necessary over the course of many hours. Moreover, being driven by an electric motor, the noise emitted by an electric UAV would be minimal, adding a stealth component to its attributes.

Altairnano has also been performing R&D, in partnership with Western Michigan University, to develop nanosensors that are capable of detecting chemical, biological or radiological agents or explosives materials from a distance. Our nanosensors, which are being prototyped and uniquely are virtually free of false-positive reactions, are designed to be embedded in or attached to Altairnano's titanium nanocrystals, providing the sensors with tremendous physical protection and longevity. In one application being considered, these sensors could be applied to the skin of a UAV to act as a "phased array sensor" that could detect and locate the source of a wide range of hazardous or dangerous chem./bio/rad agents, even when those agents are present in the air in only minute quantities.

In both these examples, Altairnano's materials are, or will be when in full production, cost-effective and economically-competitive with less capable alternatives. The real question for small companies like ours is whether we can attract sufficient capital investment to graduate from being innovators to being large-scale producers of materials and products. That is difficult, because institutional investors generally insist on seeing product-line revenues from a company *before* they will make investments. It becomes a chicken-and-egg situation. Help from the Federal Government, such as the EPACT 2005 authorization for loan-guarantees to companies seeking to manufacture products embodying new energy generation technologies or technologies for greater energy efficiency, is absolutely critical. Yet the Energy Department's program to provide those guarantees, which is just now being rolled out, is woefully inadequate in the size of its funding pool to make more than a tiny drop in the country's need for capital that is available for highly innovative, quick turnaround, fast start-up new technological opportunities.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN ENSIGN TO DR. FRANCIS R. PRELI, JR.

Question 1. In your testimony, you state that, "Deployment of fuel cell vehicles powered by renewable sources of hydrogen can break our dependence on imported oil and at the same time take transportation out of the environmental debate." You add, however, that, "fuel cell vehicles for private use in meaningful quantities are a decade away." Please elaborate on why this is so?

Answer. Three key issues need to be addressed in order to enable the full-scale deployment of fuel cell vehicles for personal transportation: (1) Technology readiness of the fuel cell power plant that must be able to operate with the same robustness and in the same environments as today's vehicles, (2) Hydrogen storage capacities that currently are not sufficient and require further development, and (3) Hydrogen infrastructure that must be built to allow convenient fueling of the vehicles. Great progress is being made with respect to technology readiness of the fuel cell, but much more work is required to adequately address the hydrogen storage issues. The infrastructure issues do not present a large technology challenge but will require significant investment over a period of time to build the fueling stations.

We believe municipal transit buses represent the nearest-term transportation opportunity for deployment of fuel cell vehicles. The three barriers to developing the personal vehicle market mentioned above are not as significant for transit buses. For example, more space is available on the bus for the fuel cell and the hydrogen storage and the buses are routinely fueled from a single location, alleviating the need for big investments in hydrogen infrastructure. Today, the main barriers to deployment of fuel cell technology in the bus market are cost and durability. Cost issues are volume dependent and great progress is being made in fuel cell durability, so large scale deployment of buses could begin more quickly with the support of the public and private sector.

Question 2. Do you feel that any state and/or Federal regulations make it unreasonably difficult for fuel cell technology to compete with more established energy providers?

Answer. Regulations sometime hamper the deployment of stationary fuel cells due to the variety of state regulations relating to grid interconnect and restrictions on utility ownership of distributed generation equipment at the customer facility. Also, high standby connect charges for customers that choose to produce their own power can sometimes negate an otherwise attractive value proposition. So far, state/Fed-

eral regulations have not hampered the bus and automotive markets. In fact, California's Zero Emission Bus mandate has been a positive force in the development and commercialization of fuel cell technology for this specific market.

Question 3. In your testimony, you discuss how fuel cells can improve the Hurricane Katrina reconstruction efforts. As we enter anther hurricane season, how do you think fuel cells should be used to help populations recover from the destructive powers of nature?

Answer. Stationary fuel cells currently operate primarily on natural gas. Generally, the natural gas grid remains intact during a hurricane. In the cases where the natural gas grid is disrupted, the damage is usually much less severe than the damage to the electrical grid. So these stationary power plants could remain operational, for example at hospitals, fire and police stations and emergency shelters even after a severe hurricane. Fuel cells have a relatively small footprint and low noise, which allows them to be installed within buildings to further maximize their ability to provide continuous power in the event of flooding.

Another use of fuel cells for disaster relief would be to drive fuel cell powered buses to critical buildings after a storm. UTC Power has a contract with DOD to validate the capability of our PureMotion™ fuel cell bus power plant to export power to the electric grid or other critical infrastructure. The fuel cell electricity, normally used to power the bus, could be used to provide these key buildings with power until the grid is restored. The bus power plant can continue to provide power as long as hydrogen is available. The hydrogen could be delivered along with the bus or the buses could rotate duty until the crisis passes.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN ENSIGN TO DR. K.R. SRIDHAR

Question 1. In your testimony you mention that to facilitate the adoption of new, innovative energy technologies, the Federal Government, "needs to ensure a level playing field between new energy technologies and legacy petroleum-based solutions." Please elaborate on the factors that you think make the playing field between new energy technologies and legacy petroleum-based solutions unequal.

Answer. The legacy petroleum-based industries benefit from the combination and accumulation of decades of Federal assistance. Federal support comes in the form of direct subsidies, beneficial tax incentives, and other legislative and regulatory assistance. The Federal aid that the utilities and oil and gas companies receive dwarfs the amount of support that has gone to alternative energy technology research, development and deployment over the years. Subsequently, an uneven playing field has been created resulting in an uphill battle for new technologies trying to provide viable alternatives to the incumbent utility, oil and gas industries.

In 2000, the U.S. Government Accounting Office released a report comparing the petroleum tax incentives with the incentives provided to the ethanol industry (GAO/RCED–00–301 R—*Tax Incentives for Petroleum and Ethanol Fuel*). This report states that the largest component of Federal support for the petroleum industry comes in the form of allowing an arcane accounting procedure that allows oil and gas producers to depreciate capital investments as a percentage of revenue rather than in relation to actual costs. This has amounted to a tax break of $82 billion dollars over 32 years. In addition to allowing this unique accounting procedure, the GAO lists over $50 billion in tax incentives and subsidies that the petroleum industry has received over the years. The GAO compared the over $130 billion in Federal support for the petroleum industry to the approximately $11 billion that the ethanol industry has received to highlight the uneven playing field as it relates to biofuels.

In addition, the 2005 EPAct further exacerbates the discrepancy between the Federal Government's support for the incumbent oil and gas industries relative to alternative energy technologies. The Joint Committee on Taxation reported to Congress about the extent of subsidies contained in the law (*http://www.house.gov/jct/x-59-05.pdf*). That report concludes that of the $11.525 billion in the 2005 EPAct, close to $8 billion goes to the electric utilities and the oil and gas industries.

Most recently, the Federal Government waived approximately $7 billion in royalty payments to encourage the petroleum companies to drill in the Gulf of Mexico. All the while, the companies receiving these billions of dollars of aid are reporting unprecedented earnings to Wall Street.

Furthermore, the billions of dollars in direct and indirect support that the Federal Government provides the legacy petroleum industry does not even begin to address the ancillary costs we bear for buttressing our continued dependence on foreign oil. The hidden costs we pay to subsidize the petroleum companies come from the mili-

tary costs associated with socio-political instability, as well as the unmonetized air pollution costs that come from the combustion of fossil fuels.

Meanwhile, the International Energy Agency estimates that less than $30 billion has collectively been spent *internationally* on renewable energy RD&D over the 30 years from 1974–2003 (Renewable Energy: RD&D Priorities, Insights from IEA Technology Programmes). That international figure pales in comparison to the subsidies the U.S. Federal Government pays to the petroleum industry. If just a portion of the United States Federal support for the legacy petroleum industries was dedicated to promoting renewable energy, it could help level the playing field and lead to significant advancement toward the goal of ending our Nation's addition to oil.

Question 2. You mention in your testimony that your company, "can trace its roots to the Federal Government's commitment to innovation." Do you think that the Federal Government's continued investment in basic research will help the development of your industry?

Answer. The United States Federal Government needs to promote innovation in alternative energy by working with industry to help foster and commercialize innovative energy solutions with the same sense of national purpose that we had when working on the mission to the moon a generation ago. The Apollo mission was driven by political necessity, commitment of leadership, strong public support, and the need to demonstrate technical prowess and superiority. A similar convergence of factors is at play today in the energy arena. The stakes are energy security and independence, sustainable growth, environmental impact, quality-of-life, and economic leadership.

But what is the best way for the Federal Government to help the development of this industry? How should precious Federal dollars be spent to commercialize clean energy technologies? Providing basic research funding to academia is important to foster innovation and to nurture the young American scientists who we will rely upon to succeed in the twenty-first century. University research is very important to promote American competitiveness. However, I do not believe that the Federal Government should invest in specific technology development; it is not the government's role to pick winning and losing technologies in the research and development stage. Private capital is flowing into clean energy and the private sector is already dedicating funds to support promising technology development. Now that the clean energy technology sector has become the third largest recipient of private venture capital investment dollars, tax payer dollars should not be allocated to clean-tech R&D.

Instead, the Federal Government needs to be an early adopter and a leader in purchasing viable-innovative energy technologies.

Venture capital investment dollars can usher new technologies up through the product development and testing stages, but the U.S. Government needs to commit to help American clean-tech companies cross the chasm and become commercially-viable substitutes for traditional petroleum-based electricity generation. The major challenge for this industry is to evolve from feasible, demonstrable projects to commercial products that are cost-competitive with the grid. Without economies-of-scale, clean energy technologies will struggle to achieve the cost reductions that will enable them to compete. In order to achieve wide-scale adoption in the United States, viable alternative energy solutions need a temporary benefactor.

The Federal Government needs to exert its buying power to signal its commitment to ending our Nation's addiction to oil. Although it means that the Federal Government will sometimes need to pay "pre-production" prices for some emerging energy technologies, it will signal a willingness to share the risk with the innovators and entrepreneurs for the benefit of national security. In order to foster innovation and encourage new solutions to our energy problems, the U.S. Government needs to lead by example and flex its consumer muscle.

The Federal Government is the single largest consumer of energy in the country, consuming almost one quadrillion BTUs of energy annually and spending over $200 billion on products and services. That fact gives it a lot of power and a lot of influence over the energy sector. A lot more influence perhaps than legislation ever could. The power of the almighty dollar is strong.

While basic academic research is fundamental to promoting American innovation, the single best place that the government can spend Federal dollars to promote the development of the clean energy industry is to be an early adopter of clean energy technologies.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN ENSIGN TO THOMAS H. WERNER

Question 1. In your testimony, you note that private sector investment is increasingly driving your company's technology advances and scale-up. Please elaborate on why this is so, especially in an industry that has traditionally obtained major support from the Federal Government and state governments.

Answer. The solar manufacturing capital investment is not directly supported by U.S. state and Federal rebate and tax credit programs. Capital costs per manufacturing line run in the $25–$50 MM range within plants containing 4–10 manufacturing lines. Thus, in order to invest in new capacity, hundreds of millions of dollars of capital are required. SunPower, and a dozen other major publicly-traded solar manufacturers, are now able to raise money in the equity and debt markets to fund this level of investment, a situation that did not exist 5 years ago. The ability of public companies to raise capital is tied to the emergence of stable, long-term market development policies in states across the U.S., the Federal investment tax credit and other countries' programs in Europe and Asia.

Question 2. In your testimony, you discuss the fact that SunPower is, "the fastest growing U.S.-based, publicly-traded technology company in terms of revenue growth over the last 5 quarters." Please elaborate on how your domestic success is linked to the overall development of the global solar market?

Answer. SunPower's financial market success is directly tied to investors' confidence that that U.S. state and Federal market development policies, aimed as dropping the installed cost of solar systems to customers, and similar programs in other countries, are sufficient in duration and scale to bridge the solar market to price parity with retail electric rates. These programs are proliferating around the world and demonstrating success in creating the demand that is drawing capital into the industry to rapidly scale manufacturing additions to drop costs.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN ENSIGN TO DR. GEORGE W. TAYLOR

Question 1. In your testimony, you indicate that wave energy is the most concentrated form of renewable energy and can be transmitted to on-shore power grids via underwater cable. How far inland is it feasible to transmit wave energy? What is the potential power generation?

Answer. The energy from any power station, including a wave power station, can in theory be transmitted any distance by high voltage transmission lines (*i.e.,* the grid). However the cost of long-distance lines makes it uneconomic to use long lines. The shorter the distance between the power station and the location of the users of the electricity the smaller the transmission costs for the electricity. In the USA, and also in many other countries, wave energy has the intrinsic advantage that more than 50 percent of the population live within 50 miles of the coast. Thus wave power stations will be located very close to where the electricity will be consumed. As a result transmission costs to connect the wave power station to the on-shore grid will be minimum.

The potential for wave power is enormous. It has been calculated that wave power in the oceans of the world could produce two Tera Watts of electricity. This is twice the world's current usage. The British Government has calculated that wave power could produce 20 percent of the UK's electricity needs. California, Oregon, Washington State, Hawaii and Alaska and some of the northeastern states of the USA have excellent wave energy resources capable of producing a large portion of their electrical power needs.

Question 2. One of the challenges cited with wave technology is the reliance on a certain level of wave activity to generate energy. How has the technology developed by your company overcome this hurdle? Does the supply feed the grid at a continuous rate, regardless of real-time generation? Does the technology require a location with consistent wave generation?

Answer. Of all the types of renewable power, wave power comes closest to being able to produce base load power generated by conventional fossil fueled power stations. Unlike wind or solar power, wave power is very predictable and consistent. It is possible to know hours and even days in advance from satellite photography what the wave power and hence the amount of electricity that will be generated by a wave power station.

The OPT PowerBuoy™ is designed to produce electricity efficiently and economically from waves in the range 1 to 4 meters in height and for periods from 3 to 20 seconds. This is achieved with OPT's patented technology, which is able to tune the

system automatically to varying wave conditions. There are many sites 1 to 3 miles off the U.S. coastlines that have waves with amplitudes and periods that are in the ranges listed above. These potential sites for wave power stations typically are capable of producing and feeding into the grid electrical power 90 percent of the time. The non-productive 10 percent of the time takes into account the calm periods (less than 1 meter waves) and storm waves (greater than 4 meter waves). An OPT Wave Power Station would have a load factor of between 30 and 45 percent depending on the specific site. By comparison the comparable numbers for wind are 25 to 35 percent and for solar 10 to 20 percent.

Question 3. Another challenge associated with wave technology is the construction of devices that can withstand Mother Nature. Previously deployed designs have suffered interrupted activity due to broken welding or snapped mooring lines. How has the PowerBuoy™ developed by Ocean Power Technologies met this challenge: to remain sustainable without creating a device that is too overbuilt to harness the energy from the waves?

Answer. Since Ocean Power Technologies (OPT) began operations in 1994, it has focused on the design of wave power conversion systems that can survive the enormous forces that occur in the ocean during storms and hurricanes and at the same time can be built economically.

OPT's design approach has been to utilize a buoy like structure to house its wave energy conversion system. Buoys are a well proven and ocean tested devices, that the U.S. Coast Guard and other maritime authorities have shown can, if properly maintained, have a 40-year life.

The OPT PowerBuoy™ is designed to automatically "lock-down" when the waves exceed 4 meters and to survive storm waves of up to 20 meters in height and then to automatically begin operating again when the waves return to 4 meters.

OPT began ocean testing its PowerBuoys™ off the coast of New Jersey in 1997. Since then it has undertaken many tests of its PowerBuoys™ in both the Atlantic and the Pacific Oceans. The tests have shown that OPT's PowerBuoys™ can successfully survive hurricane and winter storms.

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