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EXECUTIVE SUMMARY

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 programs, 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.

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. The SFCC will provide seed funding for multiple 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.

In addition to advanced technology R&D, CTE is recognized nationally for its expertise in the design, measurement, and evaluation of transportation demand management (TDM) programs. CTE is currently under contract to provide management and administrative services to the Association for Commuter Transportation (ACT), an 800+ member international organization promoting commute alternatives. CTE also developed and continues to manage a nationally recognized research and measurement program on behalf of the Georgia Department of Transportation. The program provides strategic direction and evaluates the effectiveness of TDM programs in the Atlanta region. CTE is also doing TDM evaluation for the state of Arizona and in Missoula, Montana.

The Transportation Sector - Defining the Energy Problem

The transportation sector accounts for a significant portion of energy and petroleum consumption in this country. With a growing focus on the United States' dependence on foreign petroleum supplies, it is imperative to develop and utilize alternative transportation technologies to help reduce energy consumption.

Petroleum Consumption

- U.S. consumption of petroleum accounts for 20.5 million barrels per day or 24.9% of world consumption (2004)
- Net imports as a percentage of U.S. petroleum consumption: 59.8% (2005)
- Transportation share of U.S. petroleum consumption: 66.8% (2005)
- Transportation share of U.S. energy consumption: 28.0% (2005)
- The latest study conducted by the National Defense Council Foundation puts a price of $49 billion dollars/year for the defense of oil in the Middle East (2003).
- In calendar year 2005, the U.S. trade deficit in goods totaled nearly $782 billion, with nearly half (47.5%) attributed to transportation-related activities (petroleum (29.3%) and vehicles, engines, and parts (18.2%)).
- 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% of vehicle miles traveled in 2003.
- Heavy-duty trucks represent only 2.7% of trucks in use but consume 21.6% 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.

The Transportation Sector – Solutions through Technology

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

Exemplary projects are listed below. This is by no means a comprehensive list of our members or our members' projects but serves as a good sample of some of the activity occurring in the Southeastern United States.

Flywheel Battery Technology

University of Texas – Austin, Texas
Test Devices, Hudson, Massachusetts

Flywheel batteries store energy mechanically. They provide a smaller, more reliable replacement to batteries systems and they have significantly longer usable lives. CTE recently demonstrated a flywheel with a cycle life of more than 100,000 cycles! Flywheels are ideal components for hybrid electric vehicles because they offer high power output and high cycle life. They have tremendous potential as an enabling technology for fuel cells, which are relatively low power, high-energy devices.

Flywheel battery technology advantages:

- Low cycle life cost, lasts the life of the vehicle;
- High recovery level of braking energy (70%);
- Permit down-sized engine yielding more fuel efficiency and reduced emissions;
- Preferred energy storage for fuel cell vehicles which may significantly extend fuel cell service life;
- Europe leads in application experience, but it can be overcome with a U.S. effort; and
- We are at a cusp of the technology evolution. The actions in the next few years will likely determine whether the manufacturing jobs in this emerging technology are in the U.S. or predominately in Europe.

Computer Controlled Active Suspension System

University of Texas – Austin, Texas

Computer controlled active suspension can be integrated into a heavy-duty fuel cell vehicle to minimize shock and vibration, thereby possibly extending the life of the fuel cell, while also providing improved rider comfort. Possible excessive bus roll, from the weight of the roof-mounted hydrogen storage will be controlled by the active suspension.

Current passive suspension systems can only offer a compromise between ride and handling and cannot address the need for reduced vibration on a fuel cell bus. The University of

Texas at Austin – Center for Electromechanics' (UT-CEM) active suspension system continually responds to sensors and adjusts the forces at each wheel to optimize ride under all operational conditions. The system is controlled by an electronic control unit, which manages the ride height of the vehicle including adjustments to raise or lower (kneel) the bus at bus stops to allow easier ingress and egress. Under previous efforts, UT-CEM has adapted the patented suspension technology to provide a complete active suspension system including actuators, power electronics, and controls for a prototype transit bus along with a wide variety of wheeled and tracked military vehicles. Testing of these vehicles has demonstrated greatly improved roll control, handling, and the ability to manage aberrations in road conditions (large bumps and potholes) when compared to identical vehicles with passive suspension systems.

Hybrid Electric Drive Systems

SK International – Athens, Georgia
DRS Technologies - Huntsville, Alabama
EVamerica – Chattanooga, Tennessee

SK International designed a drive system and worked with CTE to demonstrate it on a 35-foot, 30,000-pound prototype transit bus that achieved 17.5 miles per gallon in a test conducted by our research partner ATTI in Chattanooga, Tennessee. A bus this size averages approximately six to eight miles per gallon in typical applications.

DRS Technologies worked with CTE to design and build a prototype military hybrid electric High Mobility Multipurpose Wheeled Vehicle (HMMWV) that demonstrated twice the power/performance of a traditional HMMWV, while simultaneously achieving twice the fuel economy of a traditional HMMWV.

EVamerica is CTE's newest member. They are embarking on the electric and hybrid electric shuttle bus market, starting with 22' 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.

Hydrogen and Fuel Cells for Transportation Systems

Stennis Space Center - Mississippi
University of Alabama at Birmingham
General Hydrogen - Gallatin, Tennessee
Oak Ridge National Lab - Oak Ridge, Tennessee
Savannah River National Lab - South Carolina
SENTECH, Inc. - Bethesda, Maryland
Hawaii Center for Advanced Transportation Technologies - Honolulu, Hawaii
Center for Innovative Battery and Fuel Cell Technologies - Georgia Tech - Atlanta, Georgia

Stennis Space Center is working with CTE to install a hydrogen refueling station. Stennis does rocket engine testing for NASA and is one of the largest users of hydrogen in the United States. One of NASA's priorities is to transfer technology into the commercial marketplace and Stennis staff has industry leading knowledge of how to store and transport hydrogen.

The University of Alabama at Birmingham (UAB) is working with CTE and bus and fuel cell manufacturers to design, build, and demonstrate fuel cell powered buses in the Southeast. UAB is also working with Argonne National Labs to test hydrogen-fueled vehicles and assess the infrastructure requirements for a hydrogen economy.

General Hydrogen is working with CTE on a demonstration project using a fuel cell pack as a drop-in replacement for conventional lead acid batteries in electric forklifts (800,000 in the U.S. alone). The fuel cell power packs triple runtime performance of the lead acid pack they replace. General Hydrogen is also working with CTE on designing a fuel cell pack as a drop-in replacement for a battery pack in an electric shuttle bus in Chattanooga, Tennessee.

Oak Ridge National Laboratory (ORNL) and the National Transportation Research Center (NTRC) is working with CTE on several transportation related projects, including the development of strategic plans for the road mapping of hydrogen infrastructure and fuel cells for the State of Texas and for Atlantic Station, a brown-field redevelopment project in Atlanta, Georgia. The NTRC is a window to transportation research programs at ORNL and the University of Tennessee . NTRC offers one of the most diverse concentrations of transportation researchers in the United States.

Savannah River National Laboratory (SRNL) is working with CTE as a safety consultant on several fuel cell bus programs. The Savannah River National Laboratory, previously the Savannah River Site, has a long-standing history of hydrogen technology development and deployment. SRNL has more than 90 scientists and engineers dedicated to hydrogen research and it is recognized as a world-class leader in the development of safe handling systems for hydrogen.

SENTECH Inc. is working with CTE on hydrogen road mapping for the State of Texas. SENTECH, Inc. is a small energy and environmental consulting firm specializing in energy efficient technologies, renewable energy technologies, and advanced transportation technologies. Their 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. Department of Energy (DOE).

Hawaii Center for Advanced Transportation Technologies (HCATT) is partnering with CTE in the Department of Transportation's National Fuel Cell Bus Program and is working with CTE on a seed project as part of the SFCC. HCATT's 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 Center for Innovative Battery and Fuel Cell Technologies at Georgia Tech is working with CTE in support of the Department of Transportation's National Fuel Cell Bus Program and the development of strategic plans for the road mapping of hydrogen infrastructure and fuel cells for the State of Texas and for Atlantic Station, a brown-field redevelopment project in Atlanta, Georgia. Georgia Tech is also addressing key barriers for PEM fuel cells for transportation applications. Two critical barriers are cost and durability. Georgia Tech is focusing on durability. This strategy is particularly relevant to the heavy-duty transportation segment.

Introducing Clean Transportation Technologies to the Marketplace

There is a tremendous opportunity for alternative energy technologies in the U.S. 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 towards energy independence.

1. Bridge the Gap between Basic Research and Commercialization

Michigan Congressman Vern Ehlers described the gap between Basic Research and Commercialization in the United States as the "Valley of Death". 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. 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 for the research laboratory. These two forces are widening the valley.

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. CTE plays its most important role in bringing research ideas to market.

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. These 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.

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 of 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 are 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.

The FTA is not always viewed as the ideal place to spend research dollars. This perception needs to change. 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.

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 of units, 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 researches must be 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. Lastly, prototypes allow the end user to work closely with the researchers and component suppliers to ensure the final product meets market demands.

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 United States 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.

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 $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 programs, 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% 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%, and provided 30kW 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 brown-field redevelopment site in Midtown Atlanta.

<u>Chattanooga Fuel Cell Bus Demonstration</u> - 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.

<u>Texas DOT Strategic Hydrogen Infrastructure and Vehicle Plan</u> - 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.

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

<u>Development of Hydrogen Fuel Cell Airport Tow Tractor</u> - 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.

<u>Stennis Space Center (SSC) Hydrogen Refueling Station</u> - 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 seven 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% of total energy consumption. Of the 28% of the total energy consumption that is used by the transportation sector, more than 96% 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% of the world's population, the U.S. uses more than 25% 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% of its oil and today the U.S. imports 56% 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% 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% (2005)
- Net imports as a percentage of U.S. petroleum consumption: 59.8% (2005)
- U.S. consumption of petroleum is 20.5 million barrels per day or 24.9% of world consumption (2004)
- Transportation share of U.S. petroleum consumption: 66.8% (2005)
- Transportation share of U.S. energy consumption: 28.0% (2005)
- Petroleum share of transportation energy consumption: 96.4% (2005)
- Transportation energy use by mode (2003):
  - Light-duty vehicles (cars, light trucks, motorcycles): 61.5 %
  - Medium- and heavy-duty trucks and buses: 19.7%
  - Non-highway (including air, rail, water, pipeline): 18.8%

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%) attributed to transportation-related activities (petroleum (29.3%) and vehicles, engines, and parts (18.2%)).
- 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% of vehicle miles traveled in 2003.
- Heavy-duty trucks represent only 2.7% of trucks in use but consume 21.6% 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.

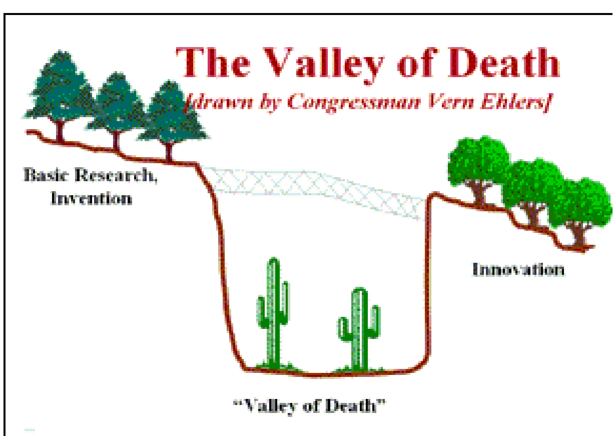
It is in our national interest to do more to facilitate appropriate research and technology transfer of these promising technologies to introduce them into the marketplace. The following are four areas where more emphasis should be placed as we move down the path towards energy independence.

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 bi-lateral 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% of our energy use and about 97% 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 of 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 are paid for by the Federal Government, through the Federal Transit Administration (FTA). If the U.S. government want 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 researches 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. Lastly, 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% - 20% 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% 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% 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% while the parallel hybrid system can achieve around 15-20% 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% 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% 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% of the total propulsion system cost while the lead-acid batteries account for only 10%.

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 the 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 kWatts 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 kWatts 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 kWatt generator but converted to hybrid drive it will be capable of producing approximately 225 kWatts 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%. 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% 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 power 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 .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 three seconds. This integrated power system is projected to be 80% 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 kWatts of power while on the move and firing this advanced directed energy weapon.

Using hybrid vehicles for provisioning of electric power, there are a 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 enhance 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 construction 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 US 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 runtimes 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-foot 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 two to three 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 runtime performance. An average forklift lead-acid battery only lasts four to six 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%.

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 stations 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 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 5000 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 120C – 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 towards 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 startup of hydrogen process systems. The development of these systems requires the application of national 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 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 5kW, 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.*

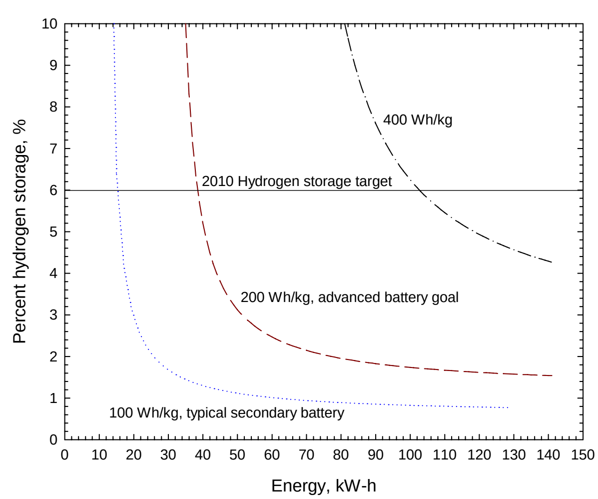


Figure 1.

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 (5000 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 design 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 need 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.

EV*america* 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.

EV*america* 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 **EV*america*** 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 **EV*america.***

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 on 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 United States 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.

APPENDIX – CONTACTS

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