FreedomCAR Partnership

2003

Highlights of Technical Accomplishments

Table of Contents

Preamble

This report contains brief summaries of key accomplishments of the FreedomCAR program for 2003. FreedomCAR is a Partnership between the U.S. Department of Energy and the U.S. Council for Automotive Research (USCAR) member companies DaimlerChrysler Corporation, Ford Motor Company, and General Motors Corporation, which maintain critical research and development resources in the United States to advance energy efficiency in the future U.S. vehicle fleet.

The current document highlights specific accomplishments that the FreedomCAR Partners recognize as significant milestones or breakthroughs achieved in 2003. In each case, they represent the culmination of many months or years of research.

2003 Significant Technical Achievements

- Durable, Low Cost Fuel Cell Catalysts
- Hydrogen Storage: Higher Pressure Tanks
- Hydrogen Storage: Cryo-Compressed Tank
- High Voltage Power Module Meets Performance and Cost Targets
- Lithium-Ion Battery Cost Reduced
- Charge Stratification to Improve HCCI Combustion Efficiency
- Lower Temperature Diesel Combustion
- Lightweight Aluminum Metal Matrix Composite Casting
- Lightweight Magnesium Cast in Structural Application

2003 Significant Progress

- Durability Gains in Fuel Cell Membranes
- Offset Impact of Air Impurities on Fuel Cells
- Hydrogen Storage: High-Capacity Metal Hydrides
- Abuse Tolerant Lithium-Ion Cathode
- Lithium-Ion Electrolyte Model for Low Temperatures
- Lithium-Ion Battery Thermal Run-Away Mechanism
- Sensors for Closed-Loop Diesel Engine Control
- Advanced Fuel Cell Membrane Electrolyte
- Benchmarking of High-Temperature Fuel Cell Membranes and Catalysts

2003 Critical Test Protocols & Nat'l Lab Facilities

- 42 Volt Battery Test Manual
- Fuel Cell Water Flow for StartUp Diagnostics
- Faster Qualification of Lightweight Polymer Composites
- Test Machine for Automotive Crashworthiness

This report is also available on the USCAR Web site at www.uscar.org/freedomcar.

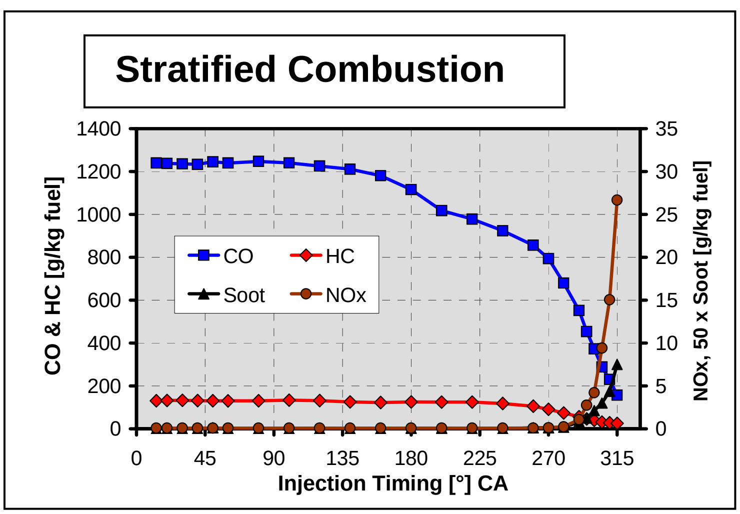
2003 FreedomCAR Highlight

Charge Stratification to Improve HCCI Combustion Efficiency

Spark-ignited gasoline internal combustion engines power most of the vehicles sold in the United States and the world. These engines offer low cost and meet very low emissions standards. However, these engines are typically less efficient than their diesel counterparts.

In recent years, the automotive industry has been exploring Homogeneous Charge Compression Ignition (HCCI) combustion to improve the efficiency of those engines to rival that of diesel engines. HCCI uses compression heating (i.e. no spark) to ignite a lean, homogeneous mixture of fuel and air. This mixture combusts without a high-temperature flame front, which results in low NOx emissions. However, stable HCCI operation is difficult to control at high- and low-load limits. Operating below the low-load limit results in poor combustion efficiency as well as high CO and HC emissions, and could prevent HCCI operation at idle.

FreedomCAR research conducted at Sandia National Laboratories investigated the mechanism by which variations in injection timing affect the stability and emissions at low-load operation. These studies concluded that late direct injection of fuel at approximately 290 degrees of crank angle (290^{o}CA where Top Dead Center is 360^{o}) increases charge stratification, which improves combustion stability and efficiency, and reduces CO and HC emissions (see graph below). Higher charge stratification locally increases combustion temperature to a point where combustion is sustained and the chemistry converting CO to CO_2 occurs with minimal increase in NOx. Using this strategy, HCCI engines can be designed to operate at lower loads than were previously possible.



2003 FreedomCAR Highlight

Lower Temperature Diesel Combustion

Sandia National Laboratories

Diesel engines offer a significant improvement in efficiency over current gasoline engines. However, traditional diesel combustion (21% oxygen) progresses through rich and high-temperature, stoichiometric modes which produce soot and NOx, respectively. Therefore, emissions regulatory compliance is difficult. Advanced low temperature combustion (LTC) methods offer approaches to engine design that could meet emissions requirements while maintaining diesel-like efficiency.

The mechanisms of new LTC methods are now being unraveled using unique optical diagnostics at the Sandia Combustion Research Facility. One approach reported as a 2002 accomplishment couples small (50-μm) injector nozzles with high levels of energy-absorbing diluents (cooled exhaust gas recirculation, EGR). Typically, as EGR is added, soot increases; however, there was no soot formation as EGR was increased using small nozzles. The small-orifice/EGR emission trends are caused by an increasing lift-off length with increasing EGR (i.e., decreasing oxygen—see images). This maintains a fuel/oxygen mixture in the flame zone that inhibits soot formation while the EGR cools the combustion process, reducing NOx.

Further developments in 2003 use reduced ambient temperature to produce LTC by increasing the lift-off length without needing to rely on EGR. The extended "lift-off" creates a fuel-lean mixture with a low flame temperature, avoiding NOx and soot formation. This mechanism offers a path to LTC without using high levels of EGR (which creates drivability issues) or fuel premixing (which creates control issues).

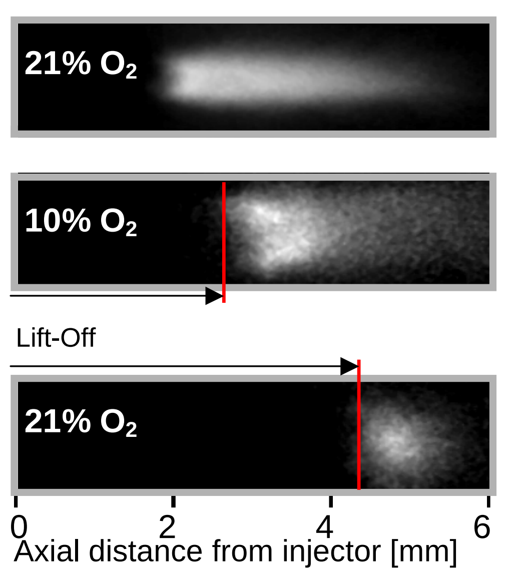
The discoveries offer pathways to low soot/NOx combustion with heat release that can be controlled by the fuel injection rate. Unlike other LTC methods under consideration, this approach makes engine control less difficult. The challenge now is to develop engines using these LTC mechanisms.

Images of OH Chemiluminescence

Normal Combustion (Diesel engine)
- **Ambient 1000 K; Flame 2700 K**
- **Note: flame temperature >2200 K produces NOx**

LTC with reduced O_2/High EGR (2002 work)
- **Ambient 1000 K; Flame 1980 K**
- **Flame lift-off increases with added EGR reducing soot formation after ignition but impairing performance**

LTC with reduced ambient temperature (2003)
- **Ambient 850 K; Flame 2070 K**
- **Greater flame lift-off for reduced soot formation**
- **Requires little or no EGR**



2003 FreedomCAR Highlight

Promising Work in Progress

Sensors for Closed-Loop Diesel Engine Control

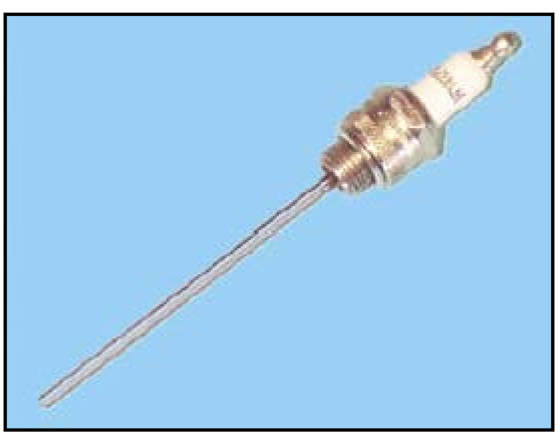
Honeywell and Univ of Minnesota

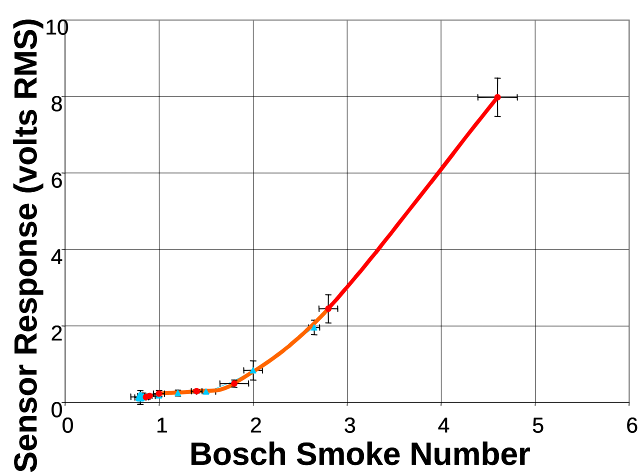
CIDI (compression ignition direct injection, or diesel) engines provide a significant opportunity for improved fuel efficiency if Tier 2 emissions standards for NOx and particulate matter (PM) can be met. This will require both reduced engine-out emissions and improved post-engine emission control systems.

Research has indicated that PM is higher during engine transients where the current state of knowledge supports less optimized control of engine fueling due to the multitude and complexity of transient conditions. One way to improve fueling during engine transients is through improved closed loop control of the engine operation. This would require extremely rapid and accurate sensing of PM emissions and the ability to adjust fueling rates accordingly. The goal of the PM sensor development work is to develop a sensor that is suitable for closed loop control of a diesel engine. The PM sensor needs to be low cost, robust under harsh environments, and manufacturable in high volumes.

A prototype PM sensor has now been developed and tested. This sensor is packaged in the shell of a spark plug for easier construction and installation. It was tested for over 100 hours in the exhaust stream of different engines without degradation. The sensor output correlates with traditional measurements and demonstrates the required temporal resolution. Further development and eventual production of this sensor could enable improved control of diesel combustion.

As this technology is commercialized, it will enable improved control over combustion with a sensor that is robust and cost effective.





2003 FreedomCAR Highlight

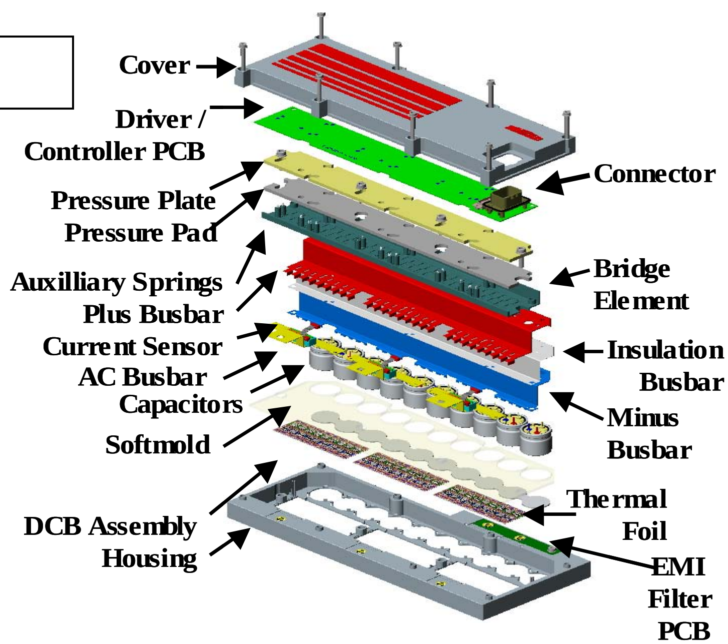
High Voltage Power Module Achieves Performance & Cost Targets

Semikron

Previously, hybrid and fuel cell vehicles have required three or four separate electronic modules to manage three key functions: (1) conversion of DC power (from batteries or fuel cells) to AC power required to drive the electric motor; (2) conversion of AC power back to DC to charge batteries in generator mode and (3) smoothing (conditioning) of the operating current during high power switching. Light, compact, energy-efficient and low-cost power modules are required for widespread, affordable vehicle use. To those ends, the challenge has been the integration of multiple functions into a single Automotive Integrated Power Module (AIPM) tailored specifically for automotive applications to reduce the overall cost and size while improving durability and performance.

Last year, a prototype 42 volt AIPM was demonstrated. During 2003, the design of the integrated AIPM was scaled up from a design that supported 42 volt system (primarily for operation of electrical accessories) to a 450 volt system design that is suitable for operation of a hybrid or fuel cell vehicle. The scaled-up version can achieve the cost, weight, volume, and system efficiency targets established for the AIPM. The module is now ready for the application specific engineering that could lead to commercialization. Efforts are also continuing to address higher temperature operating requirements for the FreedomCAR program.

450 V. AIPM



2003 FreedomCAR Highlight

Technical Resource

42V Battery Test Manual Issued

Idaho National Environmental and Engineering Laboratory

As more electronic applications have been added to vehicles, battery demands have increased. Mild hybrid vehicle applications place additional performance requirements on these battery technologies. One emerging system that automotive manufacturers feel address these issues is the application of 42-volt battery systems. Standardized test and evaluation procedures, performance specifications, and cost goals are needed to further the development of batteries for 42-volt systems.

Idaho National Environmental and Engineering Laboratory published a comprehensive 42V battery test manual including:

- **Performance and price goals for Start-Stop, Mild Hybrid Electric Vehicle (M-HEV), and Power-assist Hybrid Electric Vehicle (P-HEV) 42V batteries**
- **Life cycle profiles for all applications**
- **Unique test methods appropriate to 42V battery usage**
- **Cycle and calendar life test procedures**
- **Data analysis and reporting instructions**

The establishment of a comprehensive test protocol will allow benchmark testing of commercially available 42V battery systems, including products from Japan Storage Battery and SAFT America. Selected 42V energy storage goals are shown in the table below. The complete test manual and 42V battery goals are available on the USCAR website.

42 Volt Energy Storage Goals	Start – Stop	M – HEV	P – HEV
Available Energy (Wh @ 3 kW)	250	300	700
Calendar Life (Yrs)	15	15	15
Maximum System Weight (kg)	10	25	35
Maximum System Volume (Liters)	9	20	28
Selling Price ($/System @ 100k/yr)	150	260	360
Operating Temperature Range (^{0}C)	-30 to +52	-30 to +52	-30 to +52

2003 FreedomCAR Highlight

Promising Work in Progress

Abuse Tolerant Li-Ion Cathode

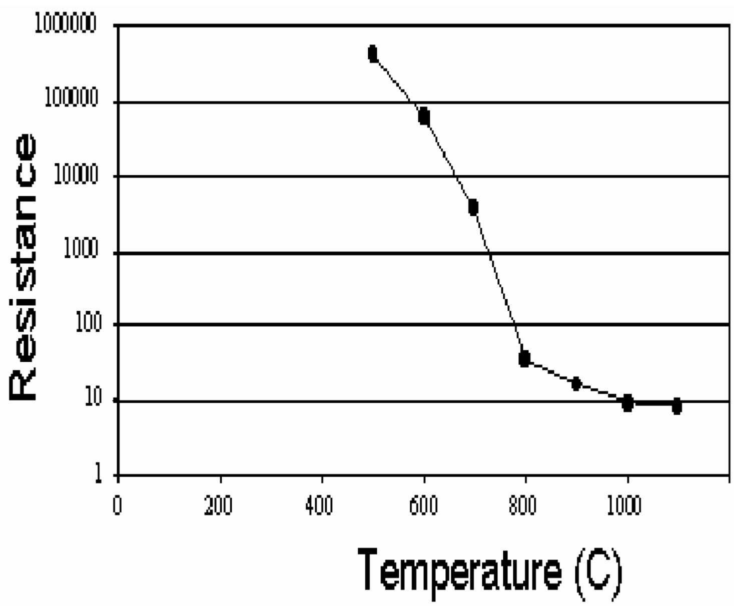
Lawrence Berkeley National Laboratory

Li-Ion batteries are being developed for high power hybrid applications to reduce battery weight. The remaining challenges are cost, abuse tolerance, and low-temperature performance. One critical challenge is the thermal stability of the battery components.

Lawrence Berkeley National Laboratory has investigated an insulator material with inherent thermal stability, LiFePO4, for use as a cathode in Li-ion batteries with potentially improved thermal abuse tolerance. They demonstrated that residual carbon in the LiFePO4 material has a large effect in determining the electrochemical performance of batteries using this cathode material.

New synthesis routes are being pursued to produce cathodes made of LiFePO4 with appropriate amounts of carbon to optimize battery performance and improve abuse tolerance.

Electronic Resistance of Pyrolyzed Carbons Depends on the Temperature



2003 FreedomCAR Highlight

Promising Work in Progress

Li-Ion Battery Thermal Run-Away Mechanism

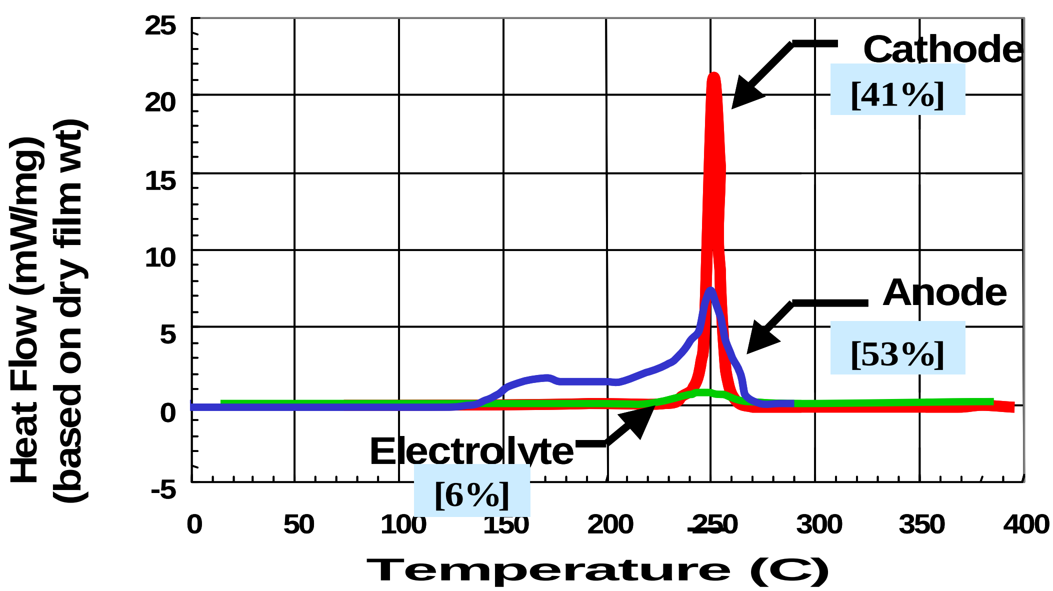
Sandia National Laboratory

Li-Ion batteries are being developed for high power hybrid applications to reduce battery weight. The remaining challenges are cost, abuse tolerance, and low-temperature performance. In order to improve abuse tolerance, it is desirable to prevent a potential thermal run-away from overcharging or in certain short-circuit scenarios and crush tests.

The chemical mechanisms that cause a thermal run-away event have now been elucidated by Sandia National Laboratories. As the cell heats up, the breakdown of the protective layer on the anode surface allows solvent reduction to begin. The anode is the major source of heat until exothermic oxidative cathode/ electrolyte reactions occur at higher temperature. The anode contributed over half of the heat generated, but the cathode had the highest heating rate.

Improvement in abuse tolerance can be achieved either through the incorporation of more stable electrode materials or by the use of additives which produce more stable protective layers. This detailed understanding of the sources of heat during thermal run-away events will allow developers to improve battery chemistries for abuse tolerance.

Percentage Contributions to Heat Flow



2003 FreedomCAR Highlight

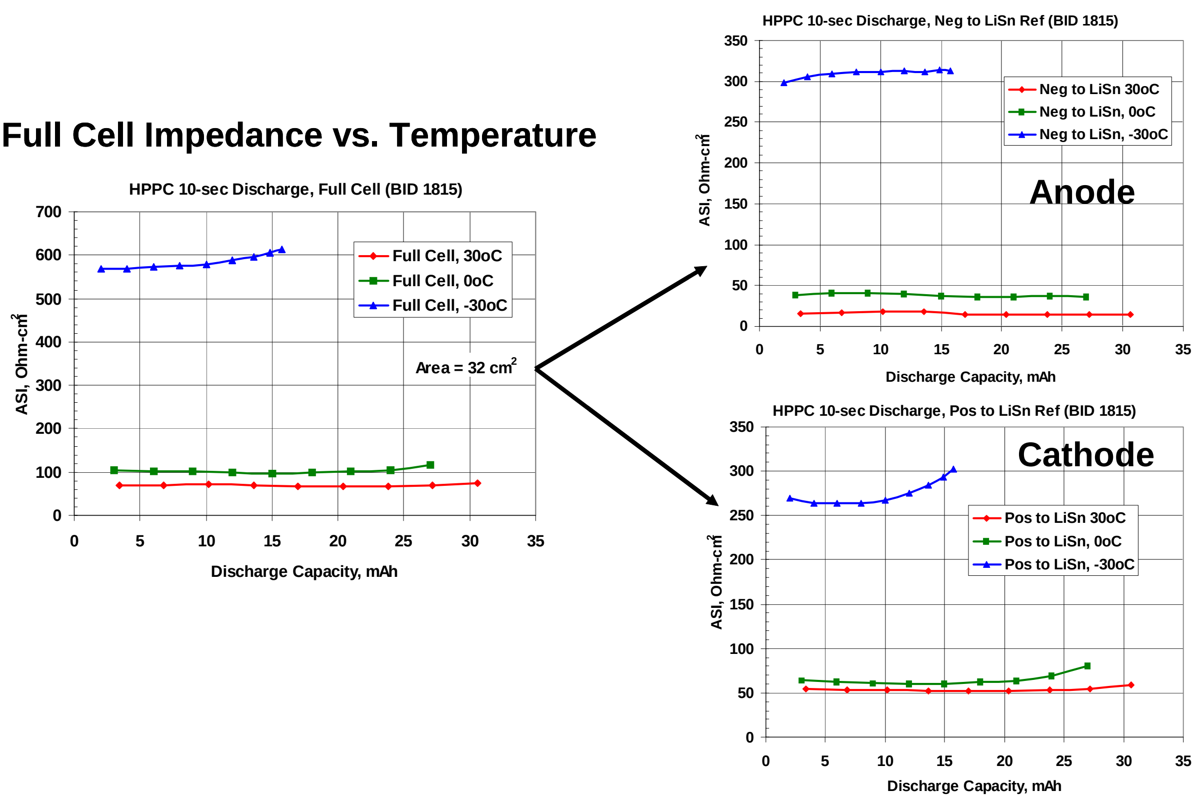
Promising Work in Progress
Li-Ion Electrolyte Model for Low-Temperatures

Reducing the cost and enhancing the performance of high-power batteries required for hybrid electric vehicles (HEVs) continues to be a challenge. One of the major limitations of Li-Ion systems is their reduced performance at low temperatures.

The DOE Advanced Technology Development (ATD) program at the DOE National Laboratories has determined that both the anode and cathode contribute significantly to the huge cell impedance rise associated with operation at -30°C. The magnitude of this impedance rise cannot be explained by the reduction in electrolyte conductivity alone. A model of electrolyte behavior, including its low-temperature behavior, was developed to help understand the phenomena that limit low-temperature performance. The model can handle electrolyte systems containing up to 10 different solvents and can perform thousands of conductivity calculations to determine the optimum solvent composition for a given temperature and salt concentration. Parameters for 10 common Li-Ion solvents and 3 salts have been measured and entered into the database for model validation. This model is being refined to further aid in understanding the low-temperature performance issues and to help in the development of battery chemistries with enhanced low-temperature performance. Preliminary results indicate that the model accurately predicts electrolyte behavior.

Data from cells employing reference electrodes show that the impedance rise associated with low-temperature operation is shared evenly by the anode and the cathode.

Full Cell Impedance vs. Temperature



2003 FreedomCAR Highlight

Li-Ion HEV Battery Cost Reduced

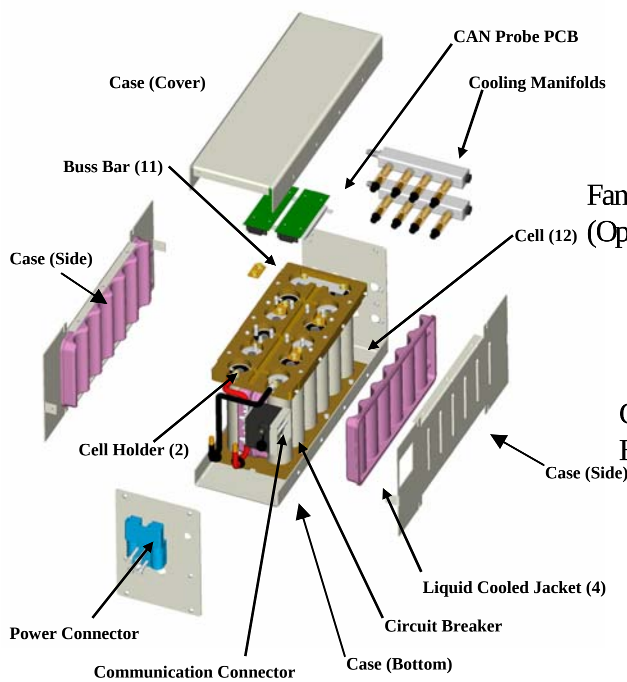
Saft America

Cost reduction and performance improvements remain key challenges for application of Li-Ion batteries to power-assist hybrid electric vehicles.

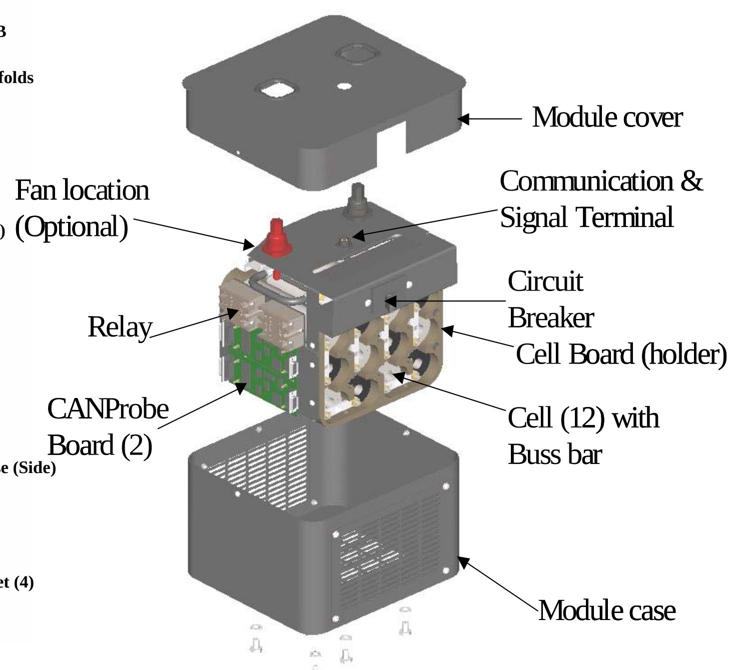
This year, the SAFT program demonstrated a cost reduction of 20% in Li-Ion battery technology. The cost reduction was achieved primarily by development of a new lower cost, air-cooled high power cell design. The new design allowed for a reduction in the number of cells required to satisfy the FreedomCAR power-assist HEV battery goals. In addition, a low-cost separator (used between the anode and the cathode inside the cell) and new carbon material were identified that could reduce the cost by an additional 16%. The result is a projected high volume 25kW Li-Ion HEV battery cost approaching $35/kW. This compares favorably to the present NiMH battery cost of at least $50/kW. At the same time, system weight was reduced by 12%, and system volume was reduced by 6%.

Testing by the Idaho National Engineering and Environmental Laboratory (INEEL) at the cell, 42V module, and battery levels confirmed that the SAFT technology meets power, energy, efficiency, cycle life, calendar life, and cold cranking requirements for the power-assist hybrid electric vehicle application. Remaining performance challenges are cost and wider temperature operating range.

Future work will focus on improving abuse tolerance through new electrode materials and more robust cell designs.



Liquid-cooled



Air-cooled

2003 FreedomCAR Highlight

Advanced Fuel Cell Membrane Electrolyte

Dupont/De Nora North America

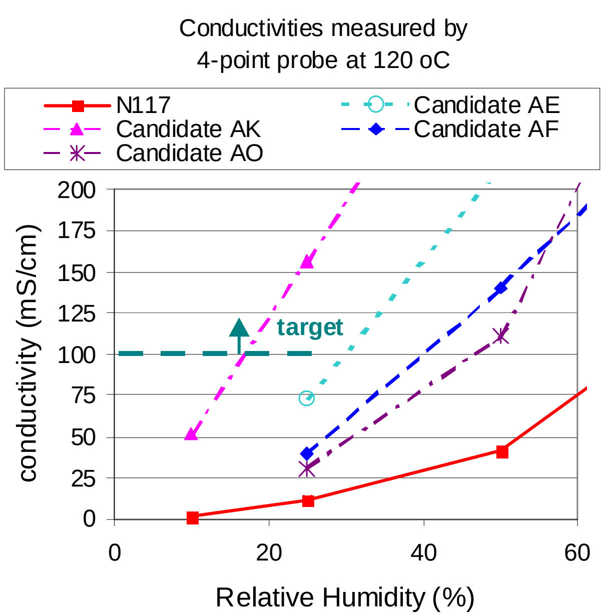
The Membrane-Electrode Assembly (MEA) is the working heart of a fuel cell. High hydrogen-ion conductivity through the membrane is essential for energy efficiency.

Today's membrane materials perform adequately at 80°C with humidified gas flows. But if MEAs could operate at 120°C and less than 25% relative humidity (RH), the efficiency of radiators managing the waste heat would improve, and that would allow the use of smaller, conventionally-sized vehicle radiators.

At present, the size of radiators that can fit into vehicles limits the fuel cell power output on hot days (greater than 40^0C). Since the conductivity of a membrane generally decreases with lower RH, it has not been clear *if it is physically possible* to devise a membrane material with the needed hydrogen ion conductivity at RH of 25% or less.

A new polymer electrolyte material has demonstrated the required hydrogen-ion conductivity. Subsequent development for thermal and mechanical stability will proceed with potential demonstration of acceptable high temperature membrane performance next year.

Demonstrated High-Temperature Membrane Electrolyte



Hydrogen ion conductivity at 120°C of newly-synthesized polymer electrolyte materials as a function of relative humidity. Baseline material is N117.

2003 FreedomCAR Highlight

New Information Resource

Benchmarking of High-Temperature Fuel Cell Membranes and Catalysts

United Technologies Fuel Cells

Standardized laboratory testing of new membrane and catalyst materials developed at leading universities was conducted to determine the degree to which they meet the full range of vehicle requirements, and thereby to guide further development.

At present, radiator size is a design constraint limiting sustained full power output of fuel cells on hot days. High temperature fuel cell membranes operating up to 120°C would allow radiators to be more efficient in thermal management, and thereby allow for more conventionally-sized radiators in fuel cell vehicles. High temperature membranes would have to operate at low relative humidity to realize a net size advantage. Conductivity testing of candidate high-temperature membrane electrolyte materials showed that all membranes required at least 50% relative humidity, well above the 25% relative humidity target.

New cathode catalysts are needed to reduce loadings of expensive platinum while meeting efficiency and durability targets. Newly developed Pt-alloy catalysts achieved nearly a three-fold improvement in specific activity compared to platinum alone (on an area basis, see below). Higher activity translates into reduced Pt and lower cost for fuel cells. One alloy demonstrated stability against corrosion during accelerated testing emulating stressful portions of the automotive duty cycle.

Catalyst	Activity (uA/cm^2)
$Pt_{50}Ir_{25}Co_{25}$	115
$Pt_{75}Ni_{25}$	112
$Pt_{75}Co_{25}$	120
Pt	44

Summary of platinum binary and ternary catalyst systems developed. Activity measures the current (power) generated for a given electrode size.

2003 FreedomCAR Highlight

Promising Work in Progress

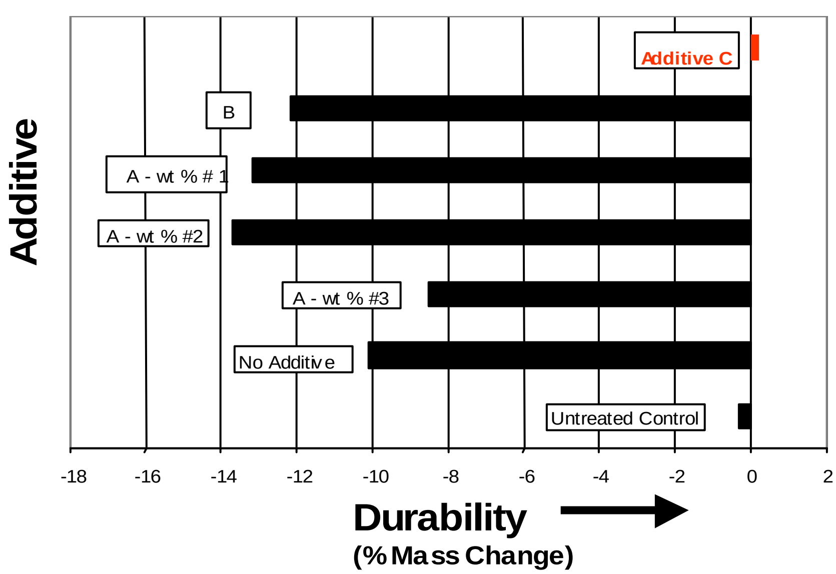
Durability Gains in Fuel Cell Membranes

3M

The performance of state-of-the-art PEM fuel cells meets many of the requirements for light-duty vehicle applications, but the need to achieve durability over the life-cycle of the vehicle is driving an increasing proportion of fuel cell development efforts. Durability of the membrane-electrode system is a key challenge.

A membrane additive has been developed to dramatically prevent weight loss during peroxide exposure, which is the primary mode of perfluorinated membrane chemical degradation. This is a critical first step to developing durable membrane electrode assemblies. Performance tests to verify the robustness of this result for assorted fuel cell designs remain to be accomplished. Also, comprehensive tests to verify other membrane requirements are underway.

In addition, a new polymer electrolyte material has been formulated and shown in preliminary testing to increase durability under conditions of high-temperature and low relative humidity.



2003 FreedomCAR Highlight

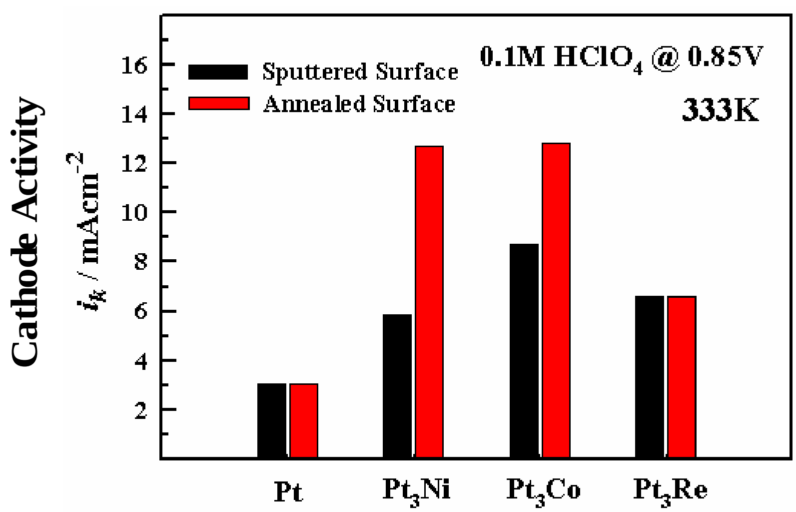
Durable, Low Cost Fuel Cell Catalysts

Lawrence Berkeley National Laboratory

Platinum (Pt) used as an electrocatalyst in fuel cell electrodes is a significant fraction of the total system cost. Alloying non-noble metals with platinum has been known for quite a few years as a way to significantly increase the catalytic activity of each surface Pt atom, and thereby provide a path to using less Pt and reducing cost. But the alloys have been subject to corrosion that cuts fuel cell power over time.

New annealed "skin" electrodes have been formed with pure Pt surface monolayers created over the highly active Pt-alloys. The enhanced activity of the "skin" electrode has now been conclusively measured and shown to be more active than the bulk alloy. Also, measurements now establish that the "skin" layer survives unchanged in corrosive conditions similar to those encountered in fuel cell operation.

Test results suggest that the pathway to even more active, yet durable and less costly Pt-alloy catalysts may lie through the promotion of corrosion-resistant all-Pt skin *surface* layers, rather than through seeking alloys with the highest *bulk* stability.



Pt-alloy systems with (annealed) and without (sputtered) all-Pt surface "skin" layers, compared to pure Pt

2003 FreedomCAR Highlight

Promising Work In Progress

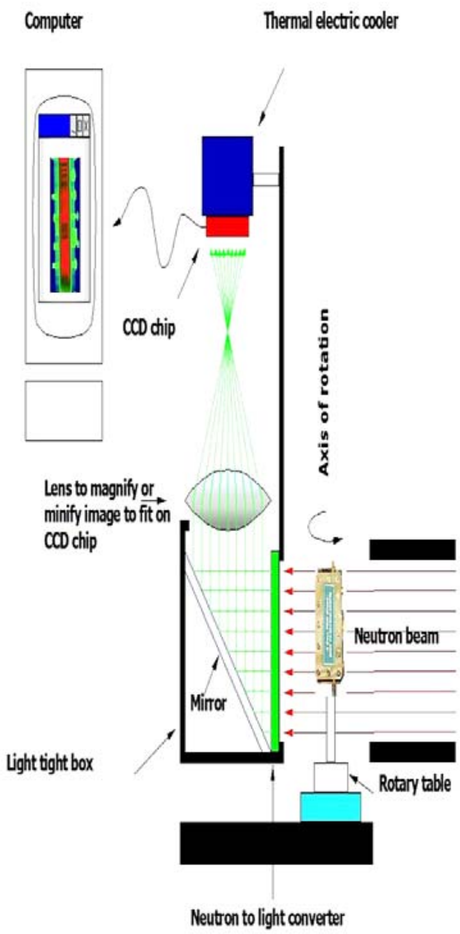
Fuel Cell Water Flow for StartUp Diagnostics

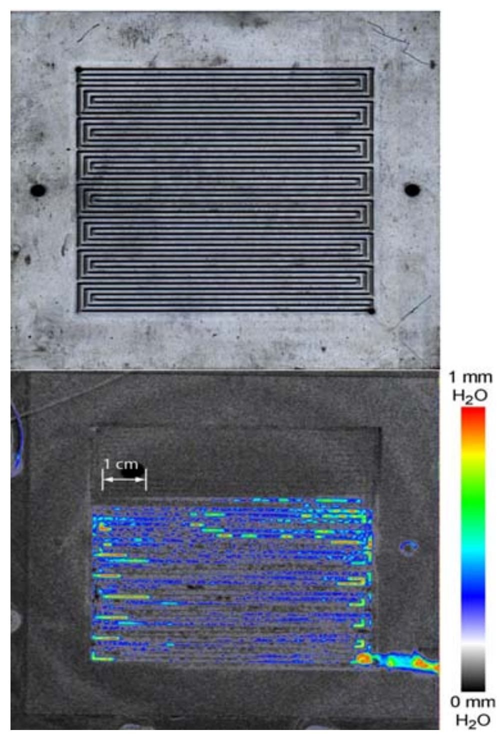
National Institute for Standards and Technology

A key challenge to rapid start of fuel cells in cold conditions is avoidance of water freezing in flow channels. Design modifications require precise and accurate diagnosis of water transport issues. Previously, neutron scattering in two dimensions was adapted to provide real time, non-destructive direct evidence of water transport in the interior of a PEM fuel cell.

The neutron imaging is now being advanced to provide faster (30 fps) water measurements in three dimensions so that water transport across from the bipolar plate flow channels, diffusion media, electrodes and membrane will be revealed for optimized cell design.

The non-destructive techniques developed in this project can be useful in testing models of water transport mechanisms in fuel cells during actual operation. This in turn can be a helpful tool in the understanding of catalyst behavior and hydration state and in the design of optimized flow channels. The tool can also help to understand fuel utilization and water balance in the individual cells.





2003 FreedomCAR Highlight

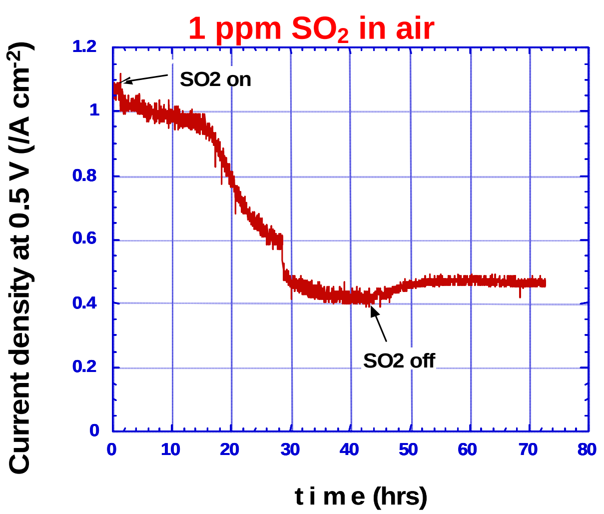
Promising Work in Progress

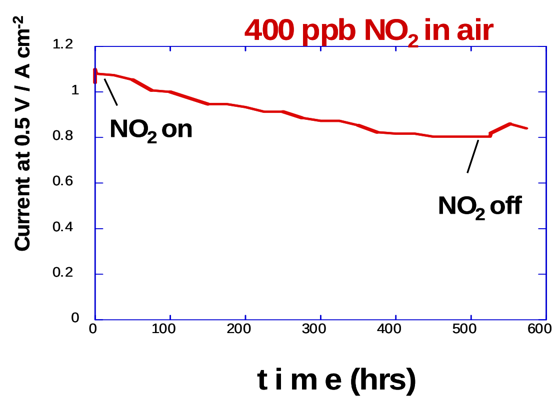
Offset Impact of Air Impurities on Fuel Cells

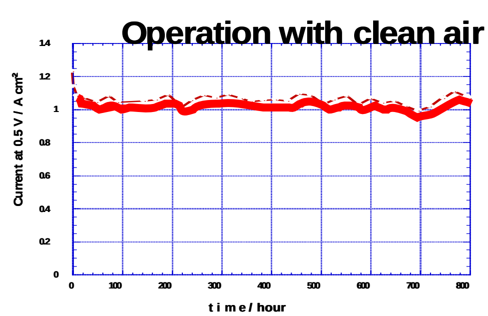
Los Alamos National Laboratory

Fuel cell researchers have quantified losses in the activity of cathode catalysts exposed to SO_2 and NO_2. Without countermeasures, these exposures could result in significant loss of power output, energy efficiency, and durability.

The discovery prompted an investigation, under a separate Cooperative Development Agreement, of air filters to mitigate the issue before extensive vehicle testing ensues. Preliminary testing of a chemical filter system shows effective protection, but filter capacity, maximum space velocity and outlet concentrations remain to be determined.







2003 FreedomCAR Highlight

Hydrogen Storage: Cryo-Compressed Tank

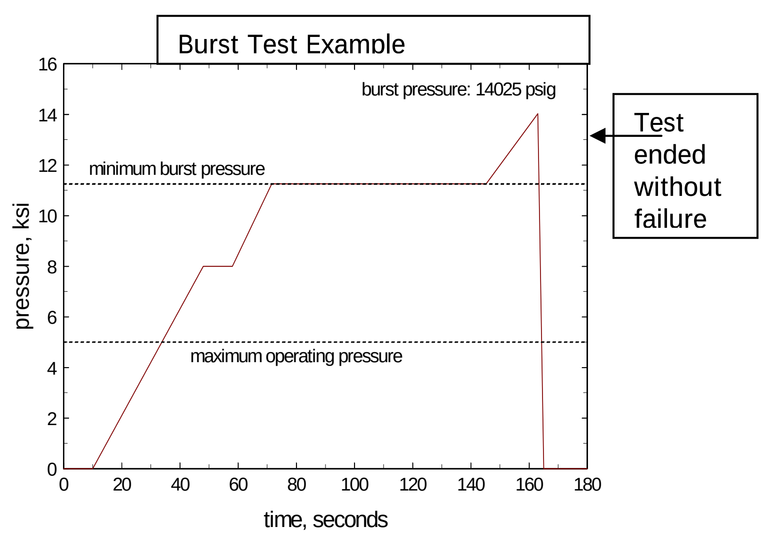
Lawrence Livermore National Laboratory

The ability to store enough hydrogen fuel to power a vehicle for significant miles of driving between refueling has become a key challenge to achieving hydrogen fueled transportation. Storage system energy densities of at least 1.5kWhr/L, which are targeted for 2010, are not achievable by today's 5000-psi compressed hydrogen gas tanks.

A novel 5000 psi cryo-compressed tank that can be operated at cryogenic temperature (about 80 to 100 Kelvin) with no performance losses has been designed and tested. This design incorporates an insulated hydrogen pressure vessel which has the flexibility of being fueled with either liquid hydrogen or compressed hydrogen. Insulated hydrogen pressure vessels can be more compact than ambient-temperature pressure vessels, require less energy than liquefaction and have less evaporative loss than liquid hydrogen tanks. Cryogenic operation does not reduce the performance of the carbon fiber pressure vessel subjected to cryogenic temperature cycling and burst testing: cryogenic temperature cycling tests a container's design and materials; burst test evaluates a container's initial strength and resistance to degradation over time.

Based on analytical projections of the prototype cryo-compressed tank, the system has an estimated system volumetric and gravimetric capacity of 1.1 kWh/kg and 1.6 kWh/liter, respectively. These capacities are 70% and 80%, respectively of the 2010 FreedomCAR goals.

Test pressure vessel was instrumented with strain gages to measure the effect of stresses.



2003 FreedomCAR Highlight

Promising Work in Progress

Hydrogen Storage: High-Capacity Metal Hydrides

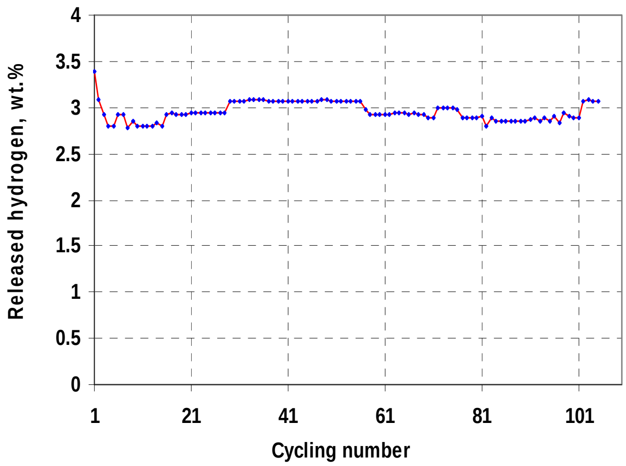
Sandia National Laboratory, Savannah River Nat'l Lab, University of Hawaii

The ability to store enough hydrogen fuel to power a vehicle for significant miles of driving between refueling has become a key challenge to achieving hydrogen fueled transportation. Storage system energy densities of at least 1.5kWhr/L, which are targeted for 2010, are not achievable in today's 5000-psi compressed hydrogen gas tanks.

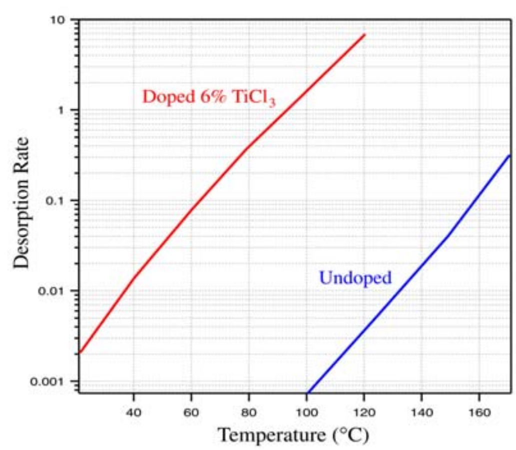
Preliminary progress has been achieved with doped (i.e., chemically modified) sodium alanates, a class of metal hydrides with a high capacity to store hydrogen and to survive multiple rapid refuelings. While sodium alanates can not satisfy the 2010 performance targets, they are serving as a learning platform to guide the design of more advanced metal hydrides to meet the 2010 performance targets.

Specific accomplishments include preparation of modified formulations to release more hydrogen to the fuel cell system at a faster rate. Also, techniques were developed to remove by-products from doped $NaAlH_4$: possibly the key to designing a 6 wt % reversible material. Durability was improved for multiple refuelings at 110 cycles with 3 wt% reversible capacity at 120°C, and testing is in process at 40 cycles with greater than 4 wt% reversible capacity at 150°C with titanium-doped sodium alanates. Experiments found that the rate of hydrogen release from titanium-doped alanates is comparable in formulations with greater hydrogen storage.

TI-DOPED SODIUM ALANATE: 3 WT% REVERSIBLE HYDROGEN STORAGE CAPACITY



DESORPTION RATE IMPROVED WITH DOPED ALANATES



2003 FreedomCAR Highlight

Hydrogen Storage: Higher Pressure Tanks

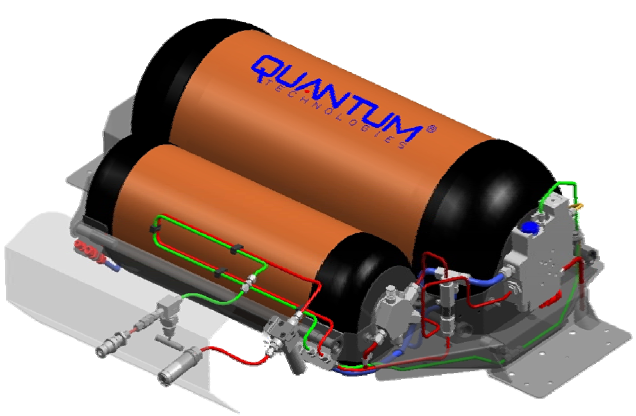
Quantum Technologies

The ability to store enough hydrogen fuel to power a vehicle for significant miles of driving between refueling has become a key challenge to achieving hydrogen fueled transportation. Storage system energy densities of at least 1.5kWhr/L, which are targeted for 2010, are more than are available in today's 5000-psi compressed hydrogen gas tanks.

A 10,000-psi high-pressure tank has been designed and validated in fatigue testing for the targeted 45,000 pressure cycles at ambient temperature. This is a 10-fold improvement in cycles from 2002. Pressure cycling is used to evaluate a container's durability to fatigue failures from cyclic loads imposed on the tank during refueling over its entire service life. In addition, these tanks successfully demonstrated fast-fill times of about 3 minutes.

Based on preliminary data, this 10,000 psi tank design is close to meeting the 2010 performance goals. However, the cost targets remain a challenge.

Parameter	2005	2010	2015	Status
Specific Energy (kWh/kg)	1.5	2	3	1.9
Energy Density (kWh/L)	1.2	1.5	2.7	1.3
Cost ($/kWh)	6	4	2	16
Refueling Rate (Kg H_2/min)	.5	1.5	2	1



2003 FreedomCAR Highlight

Light-Weight Aluminum Metal Matrix Composite Casting Hits Performance & Cost Targets

Pacific Northwest National Laboratory

The demand for better fuel economy is a major reason to reduce vehicle mass. In principle, the substitution of aluminum metal matrix composite material for steel components provides a significant opportunity to reduce vehicle mass in a number of automotive applications.

Aluminum metal matrix composites (MMCs) possess both light weight and high wear-resistance characteristics, making them desirable for a number of body, chassis and powertrain applications, provided performance and cost objectives can be reached. A brake rotor was selected as a demonstration piece for this project to show that the low-cost material developed in the initial phase of this project is viable for use in a challenging application that has potential for substantial mass savings.

The thermal and structural properties of new low-cost MMC materials have now been evaluated and found to be acceptable. Also, a cost model for the low-cost MMC material showing that $1/lb is feasible at pilot scale volume was validated.

To demonstrate the material's potential, prototype full-scale, fully reinforced brake rotors were produced by a squeeze casting method. This method was selected as being the most economical of the several innovative shape casting methods that were evaluated.

Computer simulations and brake dynamometer tests show that it is possible to achieve acceptable performance for either front or rear brakes of a mid-size sedan using the new low-cost aluminum MMCs. The novel brake rotor design enhances dissipation of the heat generated during braking and prevents excessive temperature increase.

Innovative Brake Rotor Geometry for Aluminum MMC Material

2003 FreedomCAR Highlight

Light-Weight Magnesium Cast in Structural Application: Engine Cradle

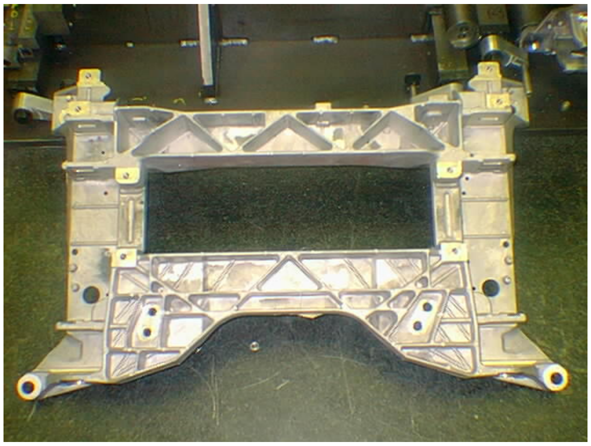
USAMP: Automotive Metals Division

The demand for better fuel economy is a major reason to reduce vehicle mass. Thus aluminum, because of its lower density, has gradually been replacing steel in some automotive applications. The density of magnesium is even lower (by a third) than that of aluminum and has the potential for even greater weight reduction. However, the knowledge base for, and expertise in the use of, magnesium alloys is far less advanced than for aluminum. Previously, magnesium castings were used only where loads were low.

Now the capability to cast magnesium for application in a front engine cradle has been developed. In particular, the design, manufacturability and durability of a magnesium substitute for the present cast aluminum cradle to be used on the 2006 Chevrolet Corvette has been examined. Prototype magnesium castings achieved the target mass savings of 35% less than the current cast aluminum production part (10.3 kg versus 15.8 kg).

CAE modeling indicates that the mass savings do not compromise cradle performance. Some parameters were in fact better for the magnesium, than for the aluminum, cradle. And solutions have been identified to deal with joining and protective coating issues.

The potential benefits include not only better fuel economy but also improved vehicle handling and performance.



Prototype Magnesium Front Engine Cradle Casting

2003 FreedomCAR Highlight

New Device Allows Faster Qualification of Light-weight Polymer Composites

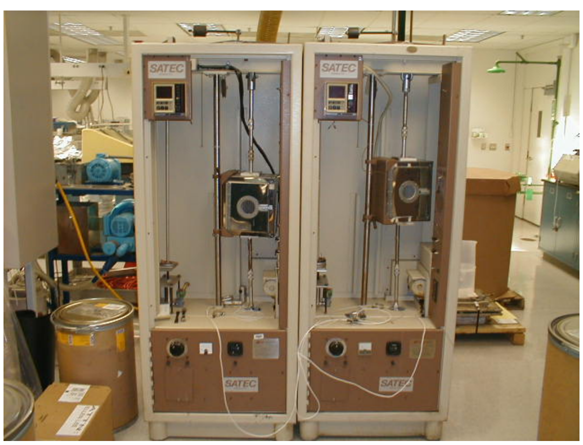
Automotive Composites Consortium

The demand for better fuel economy is a major reason to reduce vehicle mass. In principle, substitution of polymer composite material for the steels traditionally used for structural load-bearing applications can potentially reduce the component mass by half while retaining structural strength. However, these materials may "creep" (deform under load over time) in harsh environments, such as elevated temperatures. The potential for a material to creep needs to be determined so that appropriate creep-resistant materials can be selected.

Conventional test machines ("dead-weight creep frames") are expensive and occupy significant space. A new very compact, low-cost ($900 compared to $30,000 for a dead weight machine), portable test fixture has been developed to accurately measure the creep of structural composites under various automotive environments.

With this new fixture, data necessary for the accurate design of structural composite components can now be taken far more conveniently, including in vehicles if desired, without any loss in accuracy.

The fixtures are already being used by the automotive industry to provide more rapid development, and hence wider applications, of light-weight polymer composite alternatives for vehicle parts.



Conventional Fixtures (2 rigs, side by side)

New, Compact Fixtures (data processor plus 8 rigs)

2003 FreedomCAR Highlight

Test Machine for Automotive Crashworthiness

Oak Ridge Nat'l Laboratory & United States Automotive Materials Partnership: Automotive Composites Consortium

A direct way to improve fuel economy is by reduction of vehicle mass. There is therefore interest in replacing conventional materials such as cast iron and steel with lighter weight alternative materials, such as polymer composites, aluminum, and advanced high strength steels. However, in crash situations the performance of many of these materials is deformation rate sensitive, i.e., dependent upon the speeds involved in the crash. The ability to accurately model their behavior and performance in a crash is critical if these alternative lightweight materials are to be adopted.

During an impact the velocity throughout the event is constantly changing. However, conventional impact test methods (drop tower and impact sled) provide data primarily at speeds above 5 m/s, where energy absorption is large. Such data differ significantly from those generated from quasi-static measurements and there has been a need to bridge this gap in order to understand material performance during the entire event. This has now been achieved with the design and installation of the Test Machine for Automotive Crashworthiness (TMAC) for intermediate rate crush studies. The machine has demonstrated its unique ability to conduct controlled, progressive crush experiments at constant velocities in the intermediate range (0-8 m/s) and at high force levels (0-267 kN). The machine's performance exceeds the original velocity (<5 m/s) and velocity uniformity (±10%) specifications.

TMAC with Specimens Before and After Crush Test

Previously unobtainable crush measurements can now be used to improve the accuracy of predictive crash performance models and simulations. This will aid in the design of light-weight materials that perform better in crash conditions.