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New Jersey Fuel Cell Hybrid Electric Vehicle (New Jersey Genesis)

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16. Abstract

The intent of this project was the retrofit of a donated aluminum Ford Mercury Sable with an electric drive train, fuel cell power system, advanced battery pack, and a hydrogen generator to do a preliminary demonstration of the technology. Currently there are several high profile electric vehicles and hybrids now commercially available through numerous automotive manufacturers. Many of these manufacturers are now evaluating hydrogen as a source of fuel to power future vehicles. The mechanism to process the hydrogen into a usable from of energy for these mobile applications is the fuel cell. The New Jersey Department of Transportation (NJDOT) has contracted with the Center for Advanced Infrastructure & Transportation (CAIT) at Rutgers University to conduct an advanced clean vehicle development program known as the New Jersey Fuel Cell Hybrid Electric Vehicle (New Jersey Genesis) Project. The program is a multi-party partnership of governmental, private, and academic institutions in the State of New Jersey collectively known as Team New Jersey. The New Jersey team is engaged currently in the development of a prototype vehicle incorporating an advanced fuel cell and using a novel method of hydrogen storage. Hydrogen will be generated, stored, and transported in the form of a 20 percent solution of sodium Borohydride in water. In the vehicle, the sodium borohydride solution will be passed over a catalyst to generate gaseous hydrogen. The hydrogen gas is then cooled, dried, and used to power the fuel cell. Since the hydrogen is produced on-board only a small amount of hydrogen gas will be present in the vehicle at any given time between the catalyst reactor and the fuel cell, thus reducing storage problems. There are many important issues still to be resolved and refined, thus this work should be considered a preliminary study. As such, this vehicle has little chance of being used a the final prototype for a practical vehicle, a unusable rear seat and little trunk space would not be user acceptable, thus more engineering is necessary. At the time this report was written, at the end of 1.5 years of development work, a fully functional integrated system had not yet been demonstrated.

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ABSTRACT

The intent of this project was the retrofit of a donated aluminum Ford Mercury Sable with an electric drive train, fuel cell power system, advanced battery pack, and a hydrogen generator to do a preliminary demonstration of the technology. Currently there are several high profile electric vehicles and hybrids now commercially available through numerous automotive manufacturers. Many of these manufacturers are now evaluating hydrogen as a source of fuel to power future vehicles. The mechanism to process the hydrogen into a usable from of energy for these mobile applications is the fuel cell. The New Jersey Department of Transportation (NJDOT) has contracted with the Center for Advanced Infrastructure & Transportation (CAIT) at Rutgers University to conduct an advanced clean vehicle development program known as the New Jersey Fuel Cell Hybrid Electric Vehicle (New Jersey Genesis) Project. The program is a multi-party partnership of governmental, private, and academic institutions in the State of New Jersey collectively known as Team New Jersey. The New Jersey team is engaged currently in the development of a prototype vehicle incorporating an advanced fuel cell and using a novel method of hydrogen storage. Hydrogen will be generated, stored, and transported in the form of a 20 percent solution of sodium Borohydride in water. In the vehicle, the sodium borohydride solution will be passed over a catalyst to generate gaseous hydrogen. The hydrogen gas is then cooled, dried, and used to power the fuel cell. Since the hydrogen is produced on-board only a small amount of hydrogen gas will be present in the vehicle at any given time between the catalyst reactor and the fuel cell, thus reducing storage problems. There are many important issues still to be resolved and refined, thus this work should be considered a preliminary study. As such, this vehicle has little chance of being used a the final prototype for a practical vehicle, a unusable rear seat and little trunk space would not be user acceptable, thus more engineering is necessary. At the time this report was written, at the end of 1.5 years of development work, a fully functional integrated system had not yet been demonstrated.

INTRODUCTION

Those Team New Jersey partners having design responsibility designed the New Jersey Genesis vehicle cooperatively in late 1999 and early 2000. The platform for the vehicle is a prototype all-aluminum Mercury Sable donated by Ford Motor Company. The motor and drive train that was chosen for the vehicle is a Solectria 78 kilowatt AC induction electric motor operating at 324 volts (nominal) and a Solectria transmission matched to the motor. Power for the motor comes from a 15 kilowatt-hour nickel-metal hydride battery pack. A 11.7 kilowatt Proton Exchange Membrane (PEM) fuel cell was designed and built to recharge the battery pack. Hydrogen fuel for the fuel cell is provided by a Hydrogen-On-Demand™ system using sodium borohydride as a storage medium for hydrogen; hydrogen gas is generated by the passage of a solution over a catalyst. The Genesis vehicle was first modified with many lightweight and efficient parts, including special wheels, and seats. The motor and drive train, controls, new wiring, and the fuel cell system were installed in the vehicle and integrated. Throughout the design and planning, and the construction of the Genesis, students from a myriad of schools played an active role in various aspects of the work. Rutgers University is currently aligning the necessary resources to complete the vehicle and make it ready for operation. At the time this report was written the project vehicle required repairs to the brake system and battery box as well as rewiring and installation of the batteries and hydrogen generator system including necessary testing and safety enhancements as indicated in Appendix 2. As a secondary project the New Jersey Venturer was rehabilitated for the 2000 Tour de Sol by Team New Jersey. The primary focus of the teams efforts were on the Genesis, but it was felt there was still much we could learn from our original prototype vehicle.

PROJECT GOALS[1]:

Below please find the original project goals outlined in the original proposal to NJDOT.

1. Demonstrate the integrated hydrogen generator and fuel cell systems and subsystems as a viable alternative to reforming technology.
2. Produce a full size 4 door fuel cell electric vehicle with the goal of 1000+ mile range in a single refuel of non-flammable liquid fuel.
3. Vehicle will be designed as to optimize vehicle weight using lightweight materials and advanced technologies.
4. Vehicle will have full passenger and cargo capacity.
5. Vehicle shall have comparable speed, handling, and acceleration to its gasoline counterpart.
6. Vehicle will have zero emissions and use a renewable fuel.
7. Technology created for this project will be transferable to other industrial applications.
8. The partnership of government, universities, and industry created by this project will continue to generate educational, economic and environmental benefits for the next century.
9. Re-enter the 1999 NJ Venturer in the 2000 Tour de Sol.

Due to design constraints many of these goals have been modified to optimize other components of the system. The two most significant modifications are: Firstly, it was anticipated to maintain full passenger and cargo capacity. However the trunk space was forgone to primarily make more room and provide adequate ventilation for the hydrogen generation system. Later during a vehicle redesign the back seat area was utilized to provide additional room for the batteries, there was a safety need to separate the potentially “wet” chemical systems from the high voltage battery pack. The good news is that the redesigned vehicle should be safer for two reasons the weight is more equally distributed thus producing better stability and handling plus it has regained some of its lost trunk cargo space. However, without several actual crash tests (which is unrealistic for this project) or a comprehensive dynamic computer simulation run by a certified facility (which is too expensive for this type of program) there is little else that can be done to validate the crash worthiness of the vehicle due to changing so many structural components and the removal of the engine. It was determined in order to maximize safety, that this chemical reaction should be isolated from the passenger compartment. Secondly, the range was reduced from 1,000 miles to approximately an expected design yield of 450 miles on a single refuel. The original 1,000 mile goal was partially set to outperform the commercially available Honda Insight which has a range of 700 miles on single refuel. The Genesis vehicle has not been completed and this mileage has not been field-tested.

PROJECT DESCRIPTION

To meet the project goals the work was divided into several tasks. The individual tasks are as follows:

1. Design and develop an advanced fuel cell / electric hybrid vehicle using hydrogen as a fuel, and utilizing sodium borohydride as a storage medium for hydrogen.
2. Produce an operational prototype vehicle – the New Jersey Genesis – and ready it for driving on public roads.
3. Make minor improvements to the New Jersey Venturer – Team New Jersey's fuel cell / electric hybrid vehicle from the 1999 program – and ready it for the 2000 Tour de Sol.
4. Technology Transfer - Educate the public regarding the benefits of the new clean vehicle technologies represented by Genesis and Venturer, and provide opportunities for students to learn and gain hands-on experience in an advanced technology development environment.

The Genesis vehicle was designed cooperatively in late 1999 and early 2000 by those Team New Jersey partners having design responsibility, see Appendix 1 for a description of each partners responsibilities. The platform for the vehicle is a prototype all-aluminum Mercury Sable donated by Ford Motor Co. The 1998 Venturer had poor acceleration and pick-up, therefore it was determined to build the Genesis with a stronger more powerful motor. The motor and drive train that was chosen for the vehicle is a Solectria 78 kilowatt AC induction electric motor operating at 324 volts (nominal) and a Solectria transmission matched to the motor. However a larger motor also means increased power demand. Power for the motor comes from a 15 kilowatt-hour nickel-metal hydride battery pack. Two PEM fuel cells producing 11.7 kilowatts were designed and built to recharge the battery pack. Thus far reformers are large, heavy, and operate at high temperatures. They also have complex chemical reactions, therefore at this time they are unrealistic for vehicle applications. A hydrogen generator in comparison to a reformer can be significantly smaller with only one main chemical reaction occurring. Hydrogen fuel for the fuel cell is therefore provided by a Hydrogen-On-Demand™ system using sodium borohydride as a storage medium for hydrogen. The hydrogen generation system could potentially be used in the heating, power generation, mobile communications, and many other stationary and mobile industry applications. The vehicle was first modified with many lightweight and efficient parts, including special wheels and seats. The motor and drive train, controls, new wiring, and the fuel cell system were installed in the vehicle and integrated. Throughout the design and planning, and the construction of the New Jersey Genesis, students from the schools mentioned in - Project Partners and Sponsors played an active role in all aspects of the work. While the hydrogen storage and generation system was being installed an incident occurred which lead to the destruction of approximately half the batteries of the battery pack, please see Appendix 2 - NJ Genesis Safety/Function Audit Report for details of this accident. This occurred two weeks before the start of the 2000 American Tour de Sol competition, at a time when considerable work and testing was still left on the vehicle. Many systems including the hydrogen generator were not completely installed, nor was the vehicle integration complete, so with such a major set back the Genesis vehicle was unable to compete. Work on the Genesis vehicle resumed after the Tour de Sol competition, and the vehicle is currently under development, testing, and being readied for operation. The New Jersey Venturer had minor rehabilitation work done prior to the 2000 Tour de Sol while work on the Genesis was taking place.

TECHNICAL AND EDUCATIONAL ACCOMPLISHMENTS

There were several objectives in the 2000 work program for the New Jersey Genesis Project. The objectives were:

Task 1 - Design and develop an advanced fuel cell / electric hybrid vehicle using hydrogen as a fuel, and utilizing sodium borohydride as a storage medium for hydrogen.

Advanced Fuel Cell / Hydrogen Generator Development

Hydrogen-powered vehicles hold great promise as a path to clean transportation technology. "Hydrogen has the highest mass energy density of any fuel: 120 MJ/kg (LHV) 144 MJ/kg (HHV)[1]" and has the potential to be produced by renewable fuels. When used as a fuel in a fuel cell powered vehicle, virtually the only emission from the reaction is pure water. However, there are significant barriers to the introduction of hydrogen as a transportation fuel. The 2000 work program for the New Jersey Genesis Project aimed to address some of those problems and develop solutions for them. The generator was improved by addressing Millennium Cell's proprietary catalyst systems which include both chemical substrate and method of manufacture. The current generator is performing as designed for the Genesis system. Improvements to the catalyst chamber and catalyst medium in general are continuing at Millennium Cell.

Fuel Cells Background and Theory

A Proton Exchange Membrane Fuel Cell (PEMFC) is a device that electrochemically combines hydrogen and oxygen to produce electricity and pure water. There are no other side-products or emissions produced. Pure oxygen is required for fuel cells used in outer space; but in most terrestrial applications the oxygen is supplied to the cathode by flowing air through the cell. In Genesis, pure hydrogen will be generated on-board by a liquid hydride technology developed for this project. The hydrogen is consumed at the rate required by the electrical load. In this way a fuel cell is different from batteries. A battery must be recharged each time it uses the electrical charge that was stored in it, but a fuel cell will continue to generate electricity as long as hydrogen and oxygen are supplied to its cells[2].

The first problem is that even though fuel cells are a highly efficient and clean method for converting hydrogen to electric power, they require refinement and further development. A goal of the 2000 work program for the New Jersey Genesis Project was to make improvements in PEM fuel cell weight, volume, efficiency, reliability, and life expectancy. These tasks were undertaken primarily by H-Power Corporation, shown in Figure 1 is a test stand where fuel cell stacks are tested and developed.

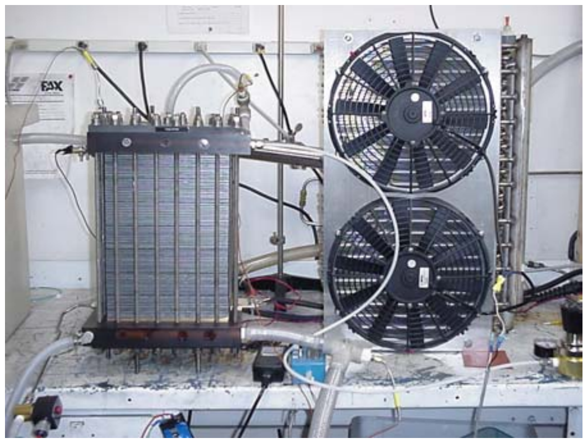


Figure 1 High-power fuel cell test stand at H-Power.

Fuel Cell Description

The fuel cell stacks are graphite stacks with plastic end caps, a design change that lowered fuel cell weight by nearly half over the previous years technology in New Jersey Venturer. In the Venturer the fuel cell was steel intensive, components like the plates, end caps, and the tie rods were all steel. One concern in using the steel plates was that the humidification and the fuel cell cooling systems both used de-ionized water, which can corrode steel. Therefore the Genesis stacks were produced using graphite plates. The graphite does not corrode or react with the de-ionized water. However graphite is generally more brittle, more expensive, and more variable in strength and thickness than the steel counterparts. The end caps of the fuel cells were also replaced with plastic. There are several reasons why this was done, the plastic caps are lighter and cheaper than steel. Also the plastic is easier to machine, the caps need to have the manifolds, tie rod holes, cooling loops, hydrogen feed line, and humidified air feed line machined into the cap. By using high strength plastic to withstand the torque of the tie rods the cost and weight of the end caps were significantly reduced in comparison to steel caps. The tie rods were replaced with titanium, this was done to reduce the weight of the stacks. Steel is approximately 75 percent heavier than titanium. Since titanium is stronger than steel, in theory the diameter of the tie rods could also have been reduced further reducing the weigh but the plastic end caps had already been manufactured and purchased. Based on actual use and lessons learned in the 1999 Venturer project, the Genesis fuel cells were built to improve overall electrical efficiency.

The NJ Venturer was equipped with a 64 cell, 4.2 kW fuel cell; whereas the NJ Genesis was outfitted with two (2) 100 cell 5.85 kW fuel cell stacks wired in series. The unregulated voltage varies from 120 to 200 VDC, because the voltage of the individual cells is proportional to the electrical load (0.6 to 1.0 V/Cell). The individual cells are "stacked" in series so the voltages add to provide the higher voltages needed by the drive motor and other ancilliary devices. A DC/DC converter regulates the variable voltage to a steady DC input to an inverter that transforms it to AC. In the NJ Genesis the traction motor and the air compressor operate on AC; all other components operate on the regulated 12 and 24 VDC power.

In a fuel cell if the membranes become too wet, a condition referred to as 'flooding' occurs. The 'flooded' state will prohibit the reactant gases, mainly the oxygen from reaching the catalyst. As excess moisture accumulates in the stack the number of reactions decrease because is cannot perform hydrogen reduction. Consequently the stack will no longer be able to produce electricity efficiently[3]. The residual water from must be periodically purged from the cell, in the Venturer project the fuel cell system used a four-channel flow manifold for the purge. It was believed that the stack had dead areas where water was not being fully purged or that the channels did not provide a quick enough water removal system. Since flooding decreases the efficiency of the reactions within the stack this was considered a major concern. Therefore a sixteen-channel manifold was used for the fuel cells in the Genesis project. The hydrogen-side of the cells are pressurized with pure hydrogen and are periodically purged to remove any product water that may accumulate. The average flow rate of the hydrogen was 4.9 SCFM and both the air and hydrogen were pressurized to 6 psi. This has resulted in good laboratory results where the stack efficiency does not fluctuate as much as before.

The original ballpark figure of how much power would be produced by the fuel cells was estimated at 14kW. This figure was based on the fact that the individual cells can produce 0.6 to 1.0 V/cell, thus if each stack produces a maximum of 1.0 V/cell, has 100 cells, running at 90 amps, and there are two stacks the net power would be about 18,000 watts. If we further refine this design to account for the heat losses within the fuel cell of about 50 percent we find that the actual expected net output of the fuel cell should be about 9 kW. If the system were to really produce 9 kW this would be more than double the NJ Venturer fuel cell system of 4.2kW. Thus for design purposes a conservative 10 kW was used in a rough design of the systems. The actual power output of the fuel cells was unknown until after the bench testing of the fuel cells. A summary load versus voltage and power graph is shown in Figure 2 and Figure 3. At 90 amps stack one is running at 64.4 V with an output of 5,797 watts. Stack two at 90 amps is running at 65.5 V and 5,895 watts. Therefore the estimated 14 kW fuel cell output is actually 11.7 kW based on the bench test results. Since the 9 kW output was really only a rough target this 2.7 kW increase was not unexpected.

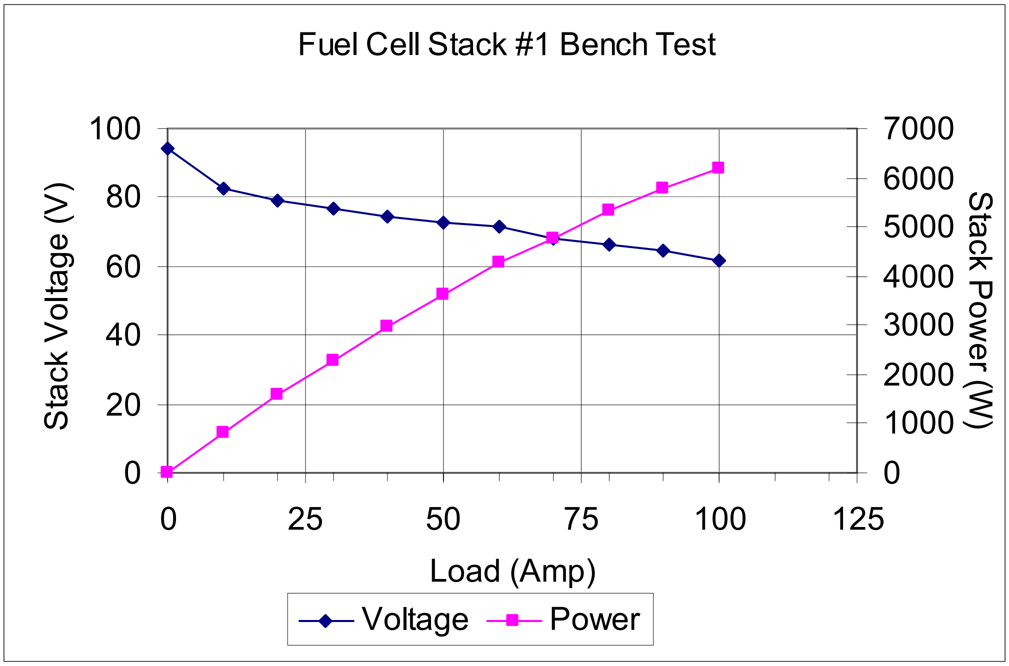


Figure 2 Bench test results of the fuel cell stack number two at H-Power.

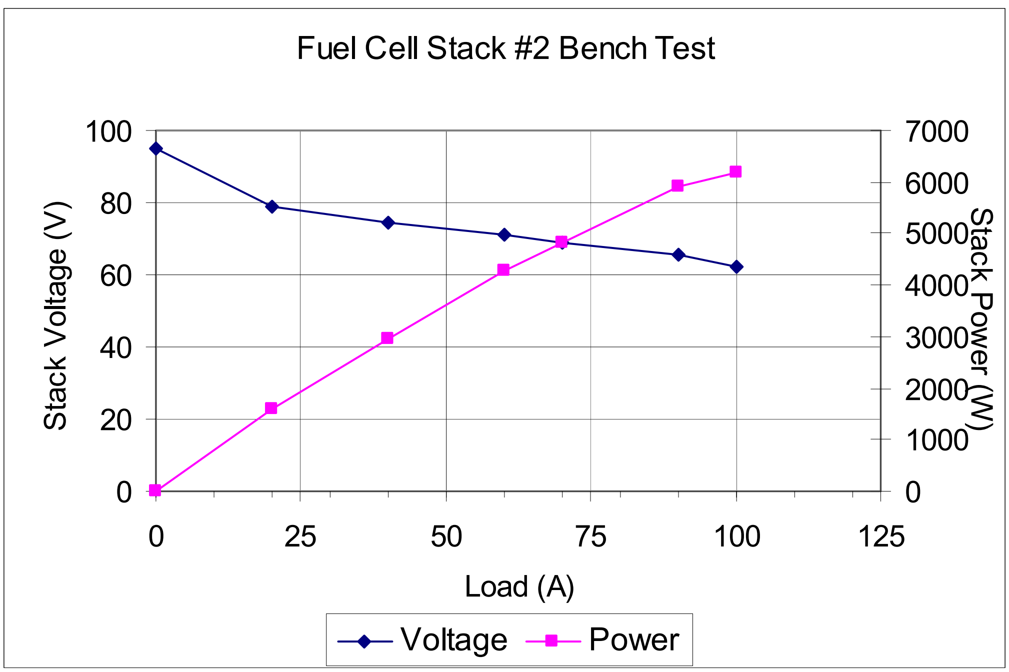


Figure 3 Bench test results of the fuel cell stack number two at H Power.

Several other fuel cell advancements have been made for the Genesis project. The vehicle is equipped with two fuel cells both of which are larger than the one previously used in the Venturer. However, several subsystems have been combined to reduce redundancy in the vehicle, instead of having true parallel system components such as air blowers, controllers, humidifiers, and heat exchangers they have been increased in size and the fuel cells linked in a series system. For example only one blower is used for both stacks. Also a new custom built fully automated controller monitors all fuel cell functions as well as optimizing flow rates and purge cycles thus increasing overall system efficiency. The control board is a critical component and is responsible for varying the speed of the air compressor as the load on the car's motor changes and for continuously performing safety checks of the voltage and temperature of the fuel cell stacks. Data is recorded on-board the vehicle for detailed analysis later. A comparison of the Fuel Cell Systems is shown in Table 1.

Table 1 Comparison Fuel Cell Systems.

	Previous Generation used in the NJ Venturer Vehicle	**Next Generation used in the NJ Genesis Vehicle**
Purge Valves	1	4
End Caps	Stainless Steel	Plastic
Rods holding stacks together	Stainless Steel	Titanium
Flow Channels	4	16
How Many Fuel Cells	1	2, in series
Total kilowatts	4.2 kW	11.7 kW
How Many Cells	64	100 per stack
Stack Controllers	1	1, running both stacks
Blowers	1	1 for both stacks
Hydrogen Source/Generation	Tank Storage	Sodium borohydride
Hydrogen Storage	12 tanks in backseat	1 tank in trunk

Finally light weight materials have been used to not only reduce the weight of the fuel cell stacks but also the size. The original design of the fuel cells used many stainless steel components. The fuel cell stainless steel rods and end plates were replaced with titanium rods and plastic end plates. The net weight savings per fuel cell stack was approximately 50 pounds. The result of the upgrades is that each fuel cell stack is now 10" X 12" X 24" and weighs only 75 pounds. The fully assembled integrated system easily fits within the large engine compartment of the Mercury Sable.

Hydrogen-On-Demand™ Development at Millennium Cell, Inc.

Hydrogen as a fuel has disadvantages in the area of transportation and distribution. Hydrogen gas has a very low volumetric energy density. Previous solutions to this problem, including high-pressure storage, storage using metal hydride adsorption[4], and liquefaction, all have significant drawbacks. Researchers have spent considerable effort to identify a method to overcome the safety, weight, and volumetric limitations of these storage mechanisms for vehicles. At this time these methods of storage fail to solve the mobile vehicle storage problem adequately and are all undergoing major research developments[5,6].

The premise of the project required the use of a catalyst enhanced storage process. It was proposed that the vehicle utilize sodium borohydride as a medium for the storage, transportation, and generation of hydrogen gas, see Appendix 3 for Material Safety Data Sheet (MSDS) information. The stoichiometric hydrolysis reaction of sodium borohydride ($NaBH_4$) can generate 4 mols of H_2 gas per mol of $NaBH_4$.[7] Sodium borohydride powder is stable in dry air, but will undergo hydrolysis with acidic or neutral pH water to generate hydrogen gas. Sodium borohydride is incompatible chemically with heat, strong oxidizing agents, chemically active metals, acids, and will react with water. See Appendix 4 – Commercially Available Sodium Borohydride Product Information for more information on sodium borohydride powders available from Rohm and Haas. The Rohm and Haas literature has summarized the properties, handling, and disposal of sodium borohydride powder. The powder form of sodium borohydride is considered flammable as the hydrogen generated from hydrolysis or thermal decomposition will ignite in the presence of free flame.

The most likely route of exposure to sodium borohydride powder is via skin contact, therefore lab protective gear is recommended including goggles and face shield, lab coat and apron, vent hood, etc. for an exact description and safety precautions of sodium borohydride in the powder form (please see Appendix 3 for MSDS information). The acute dermal LD50 of sodium Borohydride is 4-8 g/kg [9] (equivalent to 272 to 544 g for a 150 lb person). At present time sodium borohydride has not been evaluated for safety as a motor vehicle fuel source. The current cost of sodium borohydride is $40/kg however if it were to become more widely used for hydrogen production, its cost would reduce and it could become economically competitive with fossil fuels and thus feasible for use in transportation[7].

Over time, non-stabilized solutions of sodium borohydride will decompose and off-gas hydrogen. This rapid reaction makes raw sodium borohydride an infeasible fuel solution, and continuous production of hydrogen gas is a safety issue. Alkaline solutions of sodium hydroxide are stable[8 and 9] as the rate of the hydrolysis reaction is slowed with increasing pH. In fact, a solution of sodium borohydride and sodium hydroxide is commercially available for use in the paper industry and is stable for months. Concentrations as low as 1 percent sodium hydroxide are enough to prevent hydrolysis and to allow the use of aqueous sodium borohydride as a viable fuel solution. For use in the Hydrogen-On-Demand™ generator, a 20 percent by weight solution of sodium borohydride is stabilized by 1 percent by weight sodium hydroxide. Therefore the fuel composition by weight is 20 percent sodium borohydride ($NaBH_4$), one percent sodium hydroxide stabilizer, and 79 percent water. As hydrogen generation only occurs in the presence of selected catalysts, hydrogen generation rates can be controlled, storage efficiencies of hydrogen are high, and hydrogen can be generated at a wide range of temperatures[7]. It should be noted that the solution is still corrosive and potentially hazardous, though nonflammable, and must be handled accordingly. At this concentration, the system should be capable of supplying between 120 to 150 L/min of hydrogen at about 100 psi. In Figure 4 it can be seen that there is an initial spike of about 150 L/min in hydrogen generation during the start-up of the generator. After about five minutes the reaction becomes more uniform and hydrogen production levels out at about 130L/min until the flow of sodium borohydride solution is ceased.

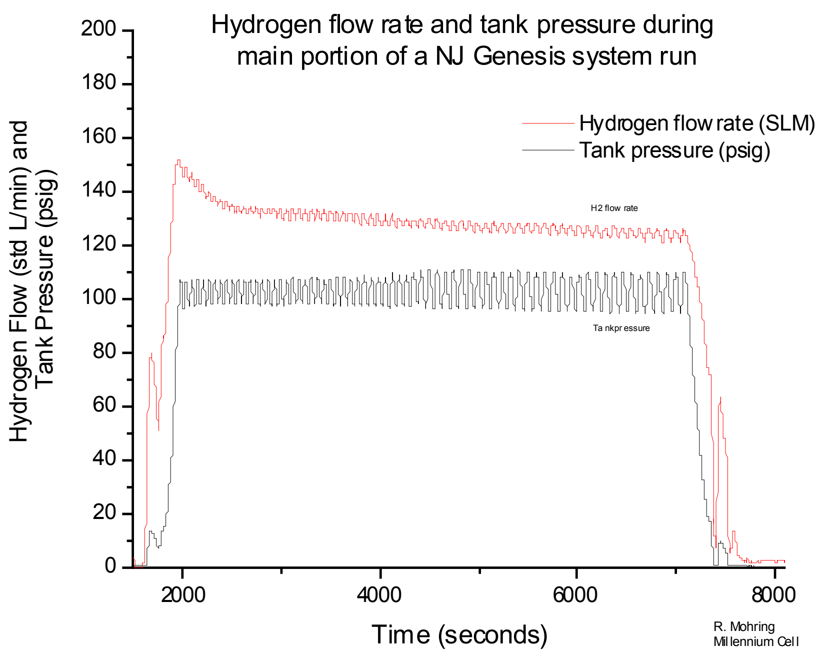


Figure 4 Initial hydrogen generation flow rate experiments utilizing the Hydrogen-On-Demand™ generator for the NJ Genesis project.

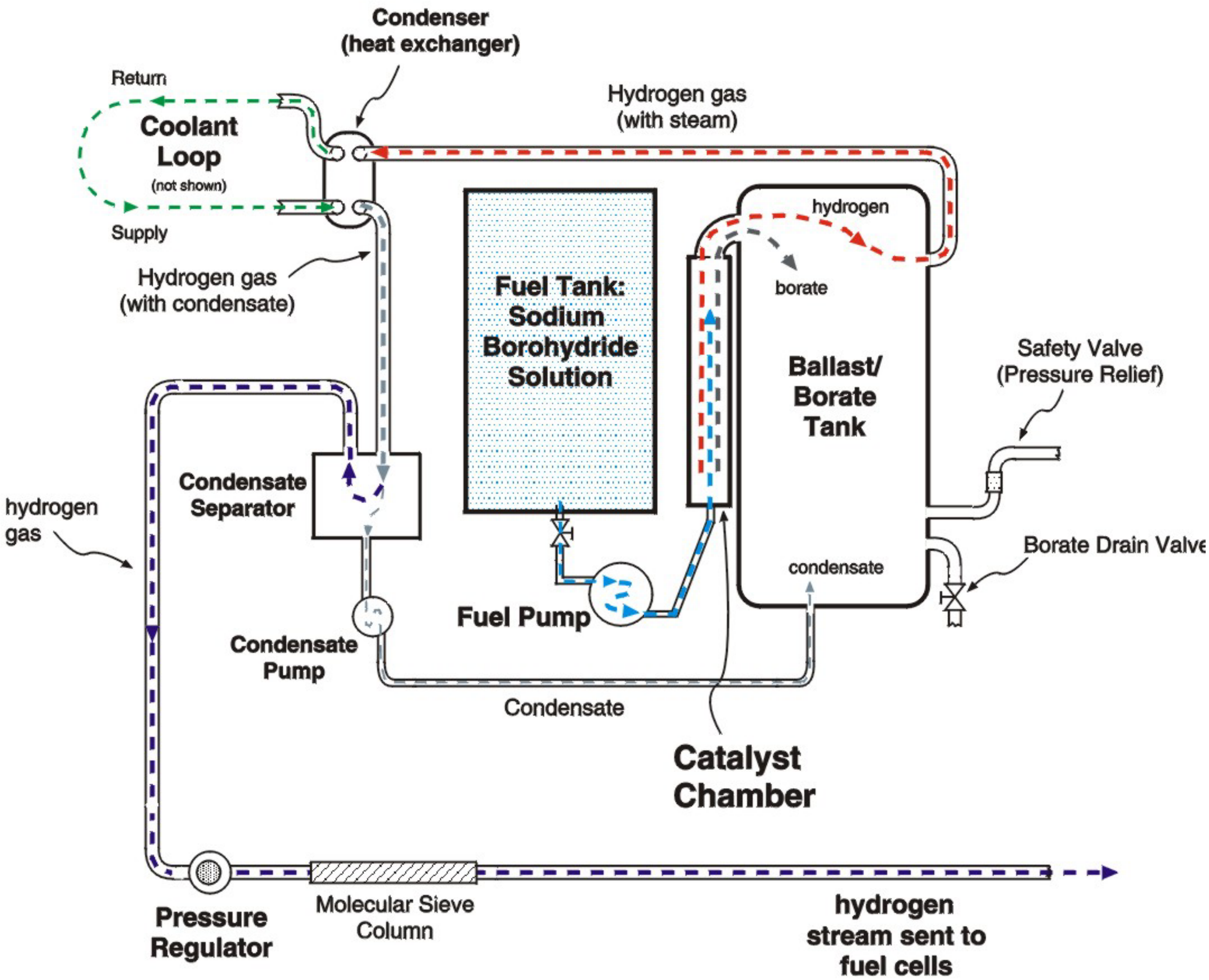


Figure 5 Millennium Cell, Inc. Hydrogen-On-Demand™ System showing pumps siphon the sodium borohydride from the fuel tank and deliver it into the reaction chamber followed by the coolant system utilizing heat exchanger to cools the hydrogen stream.

The Hydrogen-On-Demand™ system is designed using stainless steel and plastics, which are resistant to the alkalinity of the fuel. The fuel solution can be stored in stainless steel, mild steel, or fiberglass vessels; with stainless (316 SS or 304 SS) recommended for piping, valves, pumps, etc. The fuel solution cannot be stored in vessels, which may react with caustic such as aluminum.

In the Hydrogen-On-Demand™ system as shown in Figure 5, a solution of sodium borohydride in water is stored in a plastic fuel tank see Figure 6. Pumps siphon the sodium borohydride solution from the fuel tank to the reaction chamber. Millennium Cell's proprietary catalyst is contained within the reaction chamber; sodium borohydride solution flows over but does not disassociate the catalyst. As the solution flows over the catalyst, hydrolysis occurs and hydrogen gas is released; the byproducts of this reaction are water, heat, sodium borate, sodium hydroxide, and of course hydrogen. The spent fuel, sodium borate, as shown in Figure 7 and gaseous hydrogen from the reactor passes into a pressurized separation/buffer storage tank also shown in Figure 6. The hydrogen and the water in the form of steam pass from the separation/buffer storage tank into the condenser. The steam is converted to liquid water and any residual sodium borate and sodium hydroxide are solidified as the water collects in the condensate reservoir where it can be removed.

In regards to freezing of the solution, all aqueous salt solutions exhibit the colligative property of freezing point depression. As the fuel solution is a solution of two inorganic salts – sodium hydroxide and sodium borohydride – both will have an effect on the freezing point of water. This effect is similar to the use of ethylene glycol as antifreeze. The fuel solution should not freeze at temperatures above $-30^{o}C$.

In the condensate / sodium borate tank the spent fuel sodium borate is collected. This material must be drained and disposed of after each run of the generator. The drain valve on the bottom of the tank is opened and the material is gravity drained from the tank. Sodium borate is known to crystallize as demonstrated in Figure 7 and could potentially cause clogging issues within the system, though this has not been observed to date. After the tank is drained the entire system is flushed with clean warm water to remove the sodium borate spent fuel. Sodium borate is not considered to be toxic, and can be disposed of down the drain to the sewer in aqueous solutions in accordance with the MSDS and all federal, state and local environmental regulations.[13] See Appendix 3 for the full MSDS information on the spent fuel sodium borate. There is currently research underway by other organizations into methods to recycle the sodium borate product back into sodium borohydride to make the generation system viable for the market.

Figure 6 Spent fuel condensate / sodium borate tank (left) and fuel tank (right) prior to installation in genesis vehicle.

Figure 7 Crystallized sodium borate byproduct of reaction.

After the hydrogen gas passes through the condenser and the condensate tank, it passes through a mist filter. Then the stream passes through two molecular sieves connected in series, to help insure that no entrained sodium hydroxide was carried into the cell which could poison the fuel cell membranes. In general, high purity hydrogen is generated by hydrolysis of sodium borohydride. The Hydrogen-On-Demand™ system is a pressurized system. As the reaction chamber generates hydrogen the overall system pressure increases. After the hydrogen gas stream passes through the molecular sieves a regulator controls the pressure. The regulator maintains a system pressure of 100 psi, the pressurized hydrogen is then supplied to the fuel cell system at 7 to 9 psi.

One obstruction encountered during the reaction chamber development was a thermal management problem. The system was running hotter than the anticipated design parameters, the hydrogen gas going to the fuel cells was gradually increasing in temperature during the reaction. Increasing the size of the heat exchanger and adding a second cooling fan solved this issue. Also since the bench tests were done in a laboratory the tests was lacking airflow, therefore vehicle motion was simulated by mounting two fans near the heat exchangers. This was only a temporary solution for two reasons 1) the vehicle in real word conditions may sit in traffic without air exchange and 2) exact airflow rates were not calculated to simulate field conditions. Hence this was only an approximation of what could occur during vehicle operation. Further evaluation, in particular field testing will be required to resolve the thermal management issues completely.

Millennium Cell, Inc. has evaluated several reactor designs in the course of development of their proprietary Hydrogen-On-Demand™ technology. The design used in the New Jersey Genesis project maximizes hydrogen generation for this particular system. For a discussion of the reaction chamber, catalysts, and attempts to increase efficiency through re-design of the chamber please see the paper entitled “An ultrasafe hydrogen generator: aqueous, alkaline Borohydride solutions and Ru catalyst” published in the 2000 Journal of Power Sources.[10]

Pressure and thermal management of Hydrogen-On-Demand™ System

A 12V diaphragm pump pumps sodium borohydride solution through a check valve/high pressure fluid release into the catalyst chamber. The check valve/high pressure fluid release valve will release fluid directly into the condensate / sodium borate tank in the event of a high pressure condition in the liquid line.

The reaction of sodium borohydride and water produces heat when the materials are pumped over the catalyst. Heat is generated at the rate of 300 KJ/mol $NaBH_4$ - or in the case of Genesis, 7.8 KW. The majority of this heat is rejected via a heat exchanger coupled with a glycol/water cooling loop to 2 fan-cooled radiators. The rest is radiated and convected from the catalyst chamber and condensate / sodium borate tank into the well-ventilated trunk area.

The Compressed Gas Association Guidelines for hydrogen were used for guidance in designing the genesis system. The tank and its fittings are welded and pressure tested. The tank is steel. Piping and fittings in the system from the check valve onward are stainless steel with threaded fittings (with high-temp Teflon thread sealant). The operating temperature is 130^{o}C to 170^{o}C the tank temperature rating is 300^{o}C.

The entire system is pressure tested overnight on hydrogen to 200 psi and monitored for any loss of pressure. The normal operating pressure is 100 psi with the pressure relief setting at 150 psi. In addition to this fluid pressure relief valve, there is a solenoid-operated pressure-relief valve and a backup mechanical pressure relief valve at the exit to the condensate / sodium borate tank. The tank itself is secured by an aluminum cradle/clamp assembly attached through a 3/16" double-wall aluminum floor to two 3/26" aircraft grade aluminum rails tied to the vehicle frame at four points. The tank is entirely contained within the trunk space and is inside the boundaries formed by the vehicle frame and bumper. A short section of high-pressure stainless steel braided tubing on the hydrogen outlet provides strain relief to maintain the integrity of the hydrogen piping should the tank ever shift in the event of a collision.

Fuel Cell Power Control System

Recon Industrial Controls Corporation designed and manufactured the fuel cell control and data acquisition system for testing a high power (> 1KW) PEM (Proton Exchange Membrane) fuel cell stack. The fuel cell that was tested consisted of cells, connected electrically in series, producing an open circuit voltage (no load) of 1V per cell and a full load voltage of 0.65V per cell at the rated operating current of 100A. The fuel cell stack used a humidified air stream and dry hydrogen. Temperature management was best achieved through water-cooling.

The Recon test system consisted of a Recon single stack controller, and a Recon Data Acquisition Module. The controller was connected to a PC through a serial port to monitor fuel cell operating parameters and to adjust operating parameters. The Data

Acquisition Module, which was connected to the serial connection, also allowed continuous data storage. Software consisted of Recon Controller Interface Software, Data Acquisition Interface and Charting Software, and Recon Performance Analysis Software.

The controller consisted of a control circuit board including analog signal conditioning, 12-bit A/D conversion, an 8-bit microcontroller, and output drivers. This controller connected to peripheral control devices with solid-state relays. The controller continuously measures fuel cell stack current (0-140A), fuel cell stack voltage (0-1.1V per cell), fuel cell stack temperature (0-100C), and the cooling water temperature (0-100C). Current was measured using a resistive shunt and temperatures were measured with thermistor sensors. Other system parameters, such as battery voltage, were also measured. Output devices controlled included a DC motor/compressor, water pump, cooling fans, hydrogen shutoff and purge valves, and a water-recycling pump.

The Recon Controller Interface software provides a graphical operator interface to monitor fuel cell stack operating variables, to setup operating parameters to optimize performance, and to provide manual control of system devices for diagnostic purposes. Operating parameters also included operating variable limits to allow for automatic system shutdown. The software also included a strip chart recorder screen and file logging to the PC hard drive with time and date stamps.

Task 2 - Produce an operational prototype vehicle – the New Jersey Genesis – and ready it for driving.

Beginning in November 2000, Team New Jersey began work on the New Jersey Genesis in design meetings, which were held at H-Power Corp. facilities or at NJDOT. By this time, the vehicle serving as the platform for Genesis had already been donated by Ford Motor Co. and received at Rutgers University. The vehicle is a prototype Mercury Sable (the same as a Ford Taurus) which has a body and frame made from aluminum. The difference in density between steel and aluminum is approximately 3:1, therefore for the same size component constructed of steel is 3 times heavier than an aluminum one[11]. Only twenty of these aluminum intensive prototypes were ever constructed by Ford, and we were fortunate enough to receive the last one available. The donation of this vehicle by Ford gave Team New Jersey a large, lightweight, and attractive platform upon which to build the New Jersey Genesis.

The net output of the fuel cells is 11.7 kW. Of that net voltage there are approximately 2 to 2.5 kW of system loads and efficiency losses. The boost converters are approximately 96 percent efficient therefore nearly 500 watts is lost in the converters. The compressor is one of the most significant loads in the fuel cell system at roughly 800 watts. One of the other most noteworthy loads is the cooling fans at about 500 watts. There are several additional system component loads like miscellaneous pumps and blowers among others that also draw down the net power estimated at another 300 watts. After taking into consideration all these loads the total usable power supplied to the motor is on the order of 9.6 kW. All of the main electrical systems were selected to reduce the power loss and loads as much as possible. There were a few options available to utilize cogeneration principles to reclaim some of the heat generated by the fuel cells and other components and reclaim that as usable power, however those systems seems to large, heavy, and elaborate for use in the remaining space of the vehicle. With few options left to reduce the systems electric loads the team decided to further reduce the vehicle weight to obtain a better overall vehicle efficiency.

Team New Jersey proceeded to further enhance the efficiency and weight advantages of the vehicle. Considerable effort was expended on optimizing weight. A number of engineering decisions were made to reduce vehicle weight. These decisions were primarily based on the availability of project funding and sponsorship opportunities. A cost benefit analysis would be needed to determine the true value of the modifications. In 1999 the University of Wisconsin – Madison FutureCar Team release a paper entitled "Optimizing the University of Wisconsin's Parallel Hybrid-Electric Aluminum Intensive Vehicle" this paper discuses in detail strategies to reduce the overall weight of a identical aluminum intensive Mercury Sable.[13] Thus this paper was used as a framework for initial vehicle lightening concepts and initiatives. They were able to retrofit their vehicle into a parallel hybrid electric vehicle and achieve a weight of 2805 lbs. The Genesis initially weighed about 3600 lbs prior to any retrofit work, after adding all the vehicle systems it now weighs about 3100 lbs.

Titanium Grade 5 has a specific weight of 0.16 lb/in3 and an ultimate strength of 130,000 lb/in2 whereas stainless steel 18-8 has 0.28 lb/in3 and 90,000 lb/in2 respectively[12]. Structural aluminum 7075 has a lower specific weight than both materials at 0.10 lb/in^2 but is significantly weaker 12,000 lb/in^2. By volume aluminum is normally the cheapest of the three materials, steel is still relatively comparable at about 20 percent more costly than aluminum. However the extremely high strength to density ratio of titanium comes at a substantial cost of about 300 percent more expensive than aluminum. On the other hand since titanium is significantly stronger, most components that were replaced with titanium were considerably smaller and thus closer in cost to comparable steel or aluminum counterparts. A cost benefit analysis would be needed to determine the true value of the modifications. Nonetheless due to budget restraints and the cost for the usage of titanium, replacement titanium parts were minimized to either donated materials or to critical systems. It was estimated that for every 10 percent reduction in weight there is a 6 percent gain in fuel economy[13]. However strength, durability, and heat resistance of the materials were also considered in our optimization design. Custom axles were re-engineered from the originals. Plates, brackets and motor mounts were re-fabricated in aluminum. The alloy wheels were replaced with extremely light magnesium wheels. Prototype tires were obtained which are lighter than standard automotive tires as well as designed to reduce friction and drag. Special materials were used throughout the suspension system. For example, coil springs were eliminated and replaced with air struts. This created a tunable suspension, which can be adjusted to compensate for different driving conditions. During the Tour de Sol one of the events is an autocross event in which an adjustable suspension can be utilized to enhance handling and consequently safety of the vehicle in swerving and cornering at high speeds. For a comprehensive list of the primary modifications and a impact / safety analysis of these changes please see Appendix 5 – List of Primary Vehicle Components/System Modifications [21]

The custom made sub-frame shown in Figure 8 and Figure 9 weighs 50 percent less than the original. Cast iron and steel parts have been replaced throughout to reduce the weight further, for example the spindle housings are now aluminum this reduced the weight by 10 pounds per wheel. Bi-metal brakes as shown in Figure 10 with aluminum rotors have been installed which are 60 percent lighter than the originals; while aluminum calipers save another 9 pounds per wheel. Fabricating new wiring harnesses saved additional weight. The original harness weighed 40 pounds, while the replacement weighs approximately 12 pounds. Students at Hunterdon County Vocational Technical Institute and Mercer County Vocational Technical Institute made new brackets for many components, this time from aluminum to save weight. Nuts and bolts were replaced for further weight reduction. Structural bolts were replaced with titanium bolts; non-structural bolts were replaced with aluminum bolts.

Figure 8 Pre-assembly custom components of alloy sub-frame.

Figure 9 Tower Automotive custom alloy sub-frame.

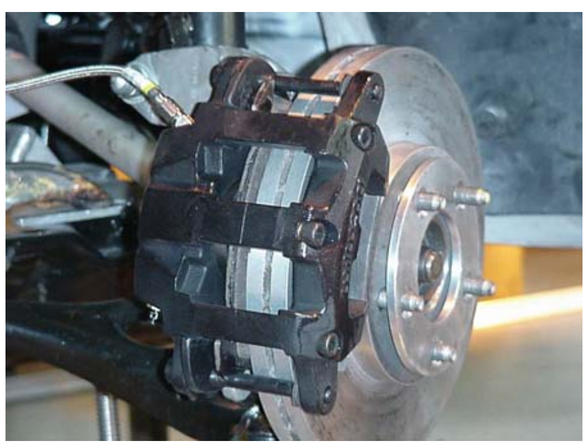


Figure 10 Steering assembly showing lightweight components: bi-metal aluminum rotor and caliper, special break shoes, aluminum bearing housing, and custom axles.

The original interior was removed by students at Mercer Vocational Technical School and replaced with new components, including titanium-framed seats with leather upholstery, significantly lighter than the factory-installed originals. The steering wheel was replaced with a lightweight alternative.

A Global Positioning System (GPS) was installed both for consumer endorsement and to enable Team New Jersey to better follow the Tour de Sol rally route. Side view mirrors and their housings were replaced with state-of-the-art cameras that display their images on an in-dash video screen. By replacing the side view mirrors with cameras, the drag produced by wind resistance on the mirror housings was reduced; this also further promoted consumer acceptability and demonstrated the development of new automotive technologies. Replacement of standard incandescent turn signals with custom LED turn signals improved electrical efficiency and reduced spark potential as well. During the design phase of the vehicle the need to avoid spark potential was evaluated, it was determined that even a small hydrogen leak has the potential to collect in the trunk cavity and ignite. Thus the incandescent light bulbs were replaced with LED lights to help minimize the possibility of a spark. Other similar design changes including the venting of free hydrogen from the trunk, cabin, and under the hood are addressed in Appendix 2 - NJ Genesis Safety/Function Audit Report. The Team removed the heater core and air conditioning unit, taking them out of the heater box and replacing them with a ceramic heater. The climate control features were also removed. The pre-existing onboard computer, no longer needed, was removed as well. The Team installed custom digital gauges for data acquisition. Recon Technologies installed a data acquisition system with a dashboard readout of critical functions of the fuel cell.

To begin the vehicle's conversion to fuel cell/hybrid power, the Team removed the original drive train and installed a custom 105 horsepower, 78-kilowatt Solectria motor see Figure 11 and Figure 13. The motor is 3-phase AC, the torque and efficiency graph used to select motor is shown in Figure 14. Its matched controller as shown in Figure 15 accepts 324-volt (nominal) power from the battery pack. Power from the motor is transferred to the wheels via a Solectria transmission. Specifications sheets for both the motor and motor controller can be found in Appendix 6 – Solectria Motor and Motor Controller Specification Sheets .

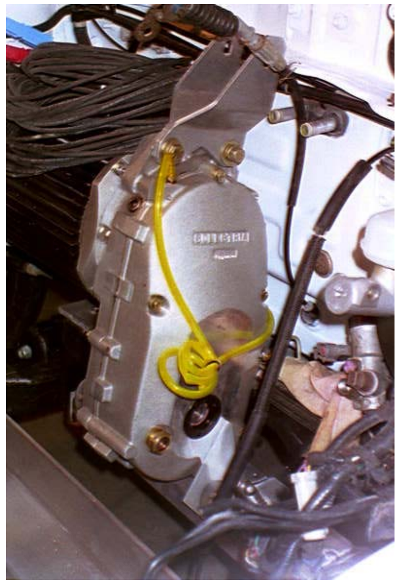


Figure 11 Side view of Solectria electric motor and gearbox installed in the Genesis.

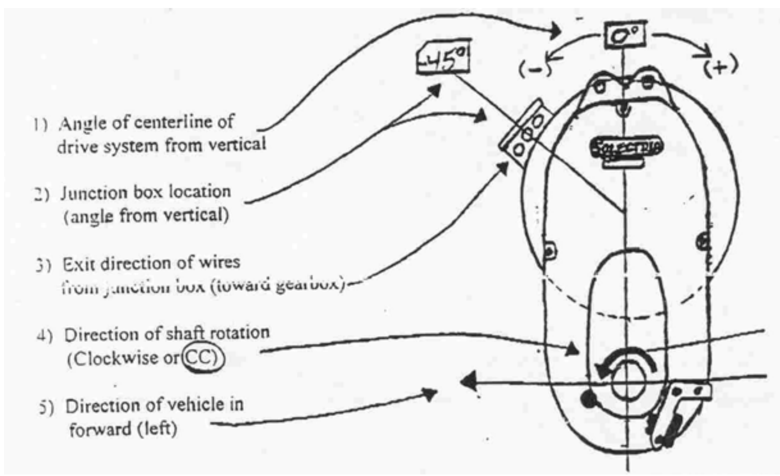


Figure 12 Solectria schematic of motor and gearbox assembly, information provided by Solectria.

Figure 13 View of engine compartment prior to fuel cell installation showing Solectria 78 kW electric motor, gearbox, and Ford electric power steering, and vacuum brake assembly.

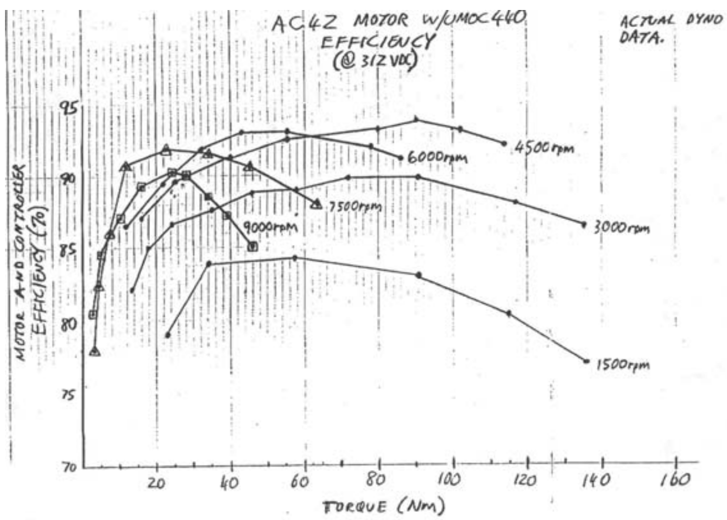


Figure 14 Solectria AC42 motor efficiency versus torque based on actual dynometer data, information provided by Solectria.

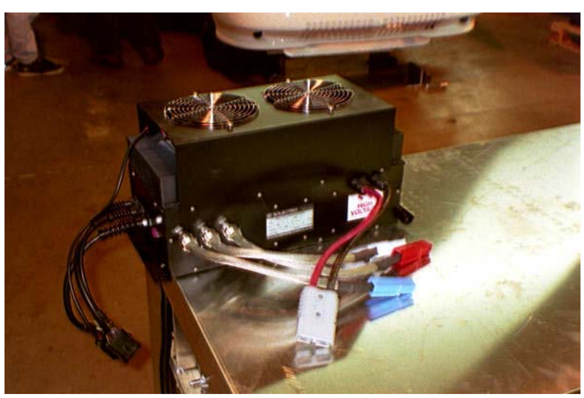


Figure 15 Solectria U-Mach 3-phase AC Motor Controller – 324 V DC input nominal, 78 kW maximum.

The batteries alone would be expected to provide Genesis with a range of approximately 75 miles. The fuel cell system consists of two stacks with an anticipated net out of 5.85 kW each, or 11.7 kW total at 90Amps and 120V to 130V. The differential between gross and net output is as a result of losses and other drains such as various electrical systems such as pumps, fans, and blowers which are part of the fuel cell system. Each fuel cell stack generates power at 60-65 V DC nominal, and they are connected in series for 120-139 V DC output. The 120-volt power from the fuel cell system is converted to power in the range of 300 V DC to approximately 350 V DC to charge the battery pack and run the motor as shown in Figure 16.

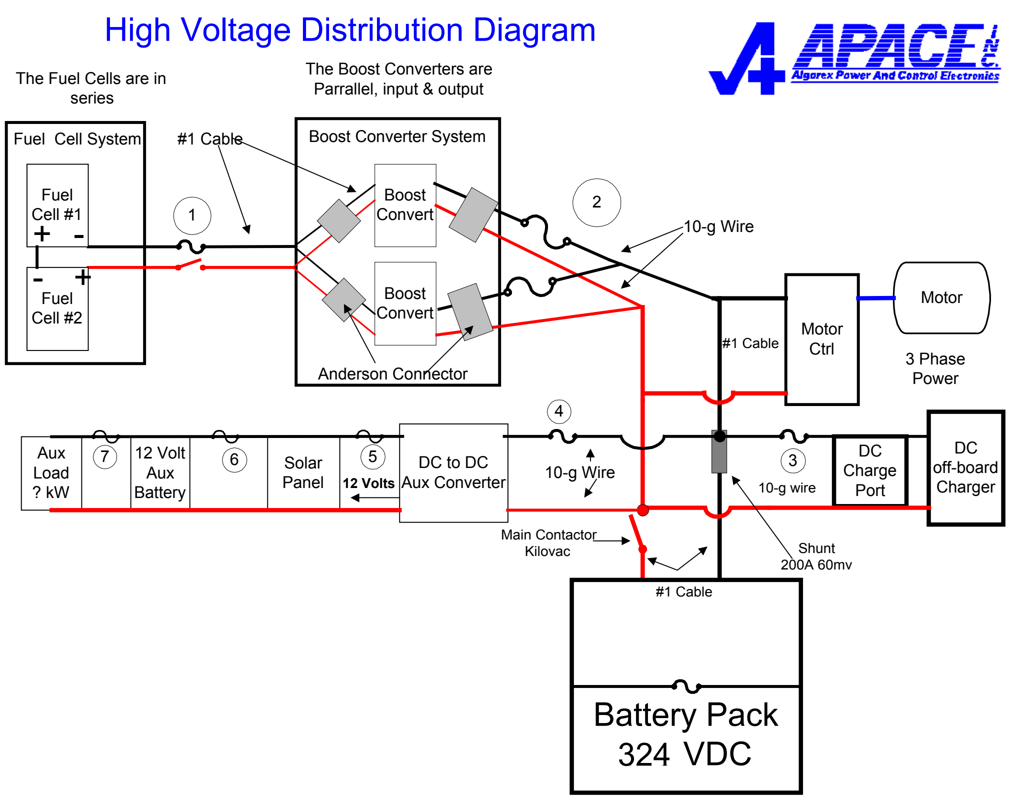


Figure 16 High voltage distribution diagram for NJ Genesis.

The battery pack shown in Figure 17 and Figure 18 consisted of 27 12-volt, 45 amp-hour nickel-metal hydride battery modules in series for a nominal pack voltage of 324. The total energy capacity of the battery pack is 15 kWH. Specification sheets for the batteries can be found in Appendix 7 – Gold Peak Battery Specification Sheet .

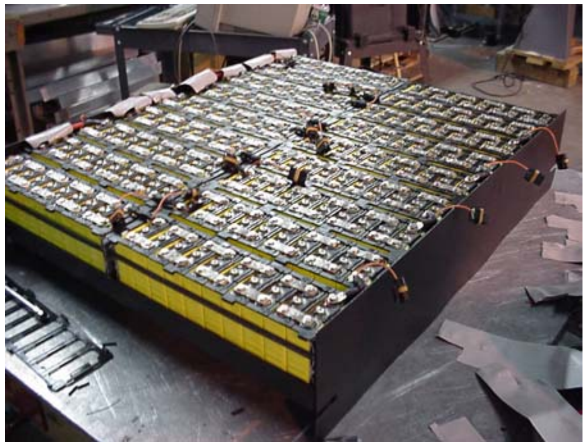


Figure 17 Gold Peak batteries nickel-metal hydride rear battery pack.

Figure 18 Rear battery pack partially installed in the Genesis.

The combination of a powerful motor, hydrogen storage for a 450-mile driving range, and enhanced fuel safety compared to gaseous hydrogen or gasoline, make this vehicle possibly the first zero-emissions vehicle in the world to achieve performance standards that consumers expect in a passenger vehicle.

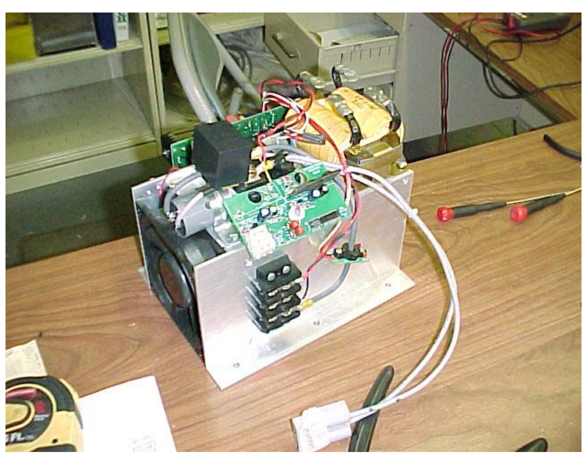


Figure 19 One of two custom DC-DC converters by Advanced Power Associates – 5 kW, 96% efficient.

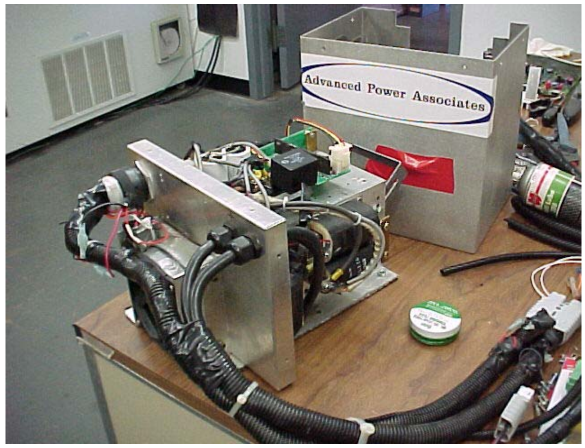


Figure 20 Advanced Power Associates DC-DC converter on test stand.

A typical fuel cell will provide power at a relatively low voltage with high current. In many everyday uses of electrical energy the voltage demand is considerably higher than that produced by the fuel cells. Therefore the low voltage fuel cell needs to be boosted to significantly higher levels, this task was performed in the Genesis by the boost converter as shown in Figure 19 and Figure 20. In the design phase it was determined that the most critical factor in selecting the boost converter would be its efficiency. It was determined that two custom built boost converters would be constructed and installed in the vehicle in parallel. The converters were designed with an efficiency of 92 to 96 percent[14]. In addition to high efficiency the boost converter also controls the output power such that it maximizes the fuel cell power while keeping it within tolerable limits. When the power demand causes the fuel cell voltage to drop below tolerable limits, the pulse width modulation is cut back maintaining the cells at optimum voltage. It was expected that the two fuel cells would operate in series to produce about 14kW gross power however a majority of the system losses occur within the fuel cells, thus the projected design net output of the fuel cells was expected to be about 10kW. Therefore the boost converters were designed with the input power of 10kW. "To obtain the requirement of 10 kW, two 5kW modules we designed and operated in parallel. Each module has a power module, inductor, control and drive boards, as well as input and output filters.[14]" The system allows for a redundancy, the modules can be switched on and off without affecting the other unit or the system. When one of the converters is switched off or malfunctions they have a programmable feature, which reduces the power of the fuel cells, for instance from 10kW to 5kW. Therefore the power output of the fuel cells is reduced via an interface between the fuel cells and converters. The power output of the converters will consequently be half as well as the current, however the voltage will remain unchanged. This programmable interface acts as the over-current protection allowing the fuel cells to be linked in a series and converters to be linked in parallel. The units are fully programmable via a RS-232 port. Since the units are highly efficient heat generation is limited and along with the air cooling and heat sink the temperature is expected to be maintained below 60 degrees Celsius[14]. After the initial bench testing of the fuel cell stacks it was found that the stacks have a net output 11.7kW, since the boost converters were designed for

10kW they required additional work. The boost converters were modified to handle the higher voltages; they can now handle a net of nearly 15kW between the two converters or about 7.5kW each.

A summary of specifications of the New Jersey Genesis follow:

Body & Frame	Prototype all-aluminum Mercury Sable
Motor & transmission	Solectria 78 kW 105 hp motor, Solectria transmission
Batteries	27 Gold Peak nickel-metal hydride modules at 12V and 45 AH each
Battery pack voltage	324 nominal
Fuel Cell	2 H-Power fuel cells 5.85 kW each or 11.7 kW total @ 120V to 130 V and 90Amps
Voltage converter	2 Advanced Power Associates converters @ 7.5 kW [15] each as shown in Figure 19 and Figure 20
Hydrogen storage	Sodium borohydride solution in water, 32+/- gallon fuel tank
Hydrogen generation	Millennium Cell, Inc. 120-150 lpm hydrogen generator, with an average generation rate of 130 lpm
Lightweight parts	Aluminum sub-frame, spindle housings, rotors, front brake calipers, bumper brackets, and miscellaneous bolts.

The preceding text contains detailed information concerning specific design elements or modification that were installed in the vehicle. However a wide variety of modifications were carried out on the vehicle not only to retrofit it from internal combustion to electric, but also to incorporate the fuel cells, a hydrogen storage and generation system, as well as lowering overall weight and wind resistance. For a comprehensive list of the primary modifications and a impact / safety analysis of these changes please see Appendix 5 – List of Primary Vehicle Components/System Modifications [21]. Table 4 of Appendix 5 provides a list of the primary vehicle components that have been modified as well as brief discussion into it functionality and safety impacts in comparison to the original vehicle. Table 5, also of Appendix 5, provides similar information but for the system modifications.

Estimated Range Calculations

To begin with an overall vehicle efficiency must be calculated. During design meeting estimates of other electric vehicle overall efficiencies were substituted for an actual value. This practice continued until the initial road tests were performed on the vehicle. The actual vehicle efficiency was measured by running the vehicle on the roadway and measuring the total watt-hours used, miles traveled, and speed. This of course is a rather conservative estimate because the batteries must be cycled several time before they hold their full charge, and not until extensive field tests have been performed can the exact efficiency be measured. The basic concept is that the batteries contain a known watt-hour of energy, the watt-hours are divided by the total miles that can be driven on a fully charged battery pack. This results in a watt-hour per mile efficiency of the vehicle, which can be used to calculate other factors like projected ranges. The speed the vehicle is driven at will greatly affect the efficiency, a range of efficiencies can be generated depending on the average speed traveled.

During one of the first cycles on the batteries, they were charged and the vehicle was driven at an average speed of 50 mph until the battery pack was completely depleted. The batteries are 45 amp-hour batteries there are 27 batteries total in the pack each with a voltage of 12 V nominal. Therefore the pack voltage is 324 V nominal, multiplying the pack voltage by the amp-hour results in the total watt-hours of the pack, hence 14,580 watt-hours. On batteries alone the vehicle was driven for nearly 75 miles.

The battery range was measured to be about 75 miles; therefore dividing the watt-hours by the range will yield the overall vehicle efficiency. Taking the 14,580 watt-hours dividing by 75 miles equals 194.4 watt-hours per mile efficiency at an average speed of 50 mph.

To calculate the projected range as a result of the hydrogen generator working with the fuel cells requires several steps.

STEP 1 For use in the Hydrogen-On-Demand™ generator, a 20 percent by weight solution of sodium borohydride is stabilized by 1 percent by weight sodium hydroxide. Therefore the fuel composition by weight is 20 percent sodium borohydride ($NaBH_4$), one percent sodium hydroxide stabilizer, and 79 percent water. At this concentration, the system is capable of supplying hydrogen at about 520 liters of hydrogen gas per liter of fuel.
STEP 2 The fuel tank can hold up to 32 gallons (121.1 liters) of the 20 percent sodium borohydride ($NaBH_4$) fuel solution. Multiplying the hydrogen generation rate of 520 L/min by the storage capacity of the fuel solution of 121.1 L yields the total hydrogen supplied by the generator of 62,972 liters of hydrogen.
STEP 3 The fuel cell system requires an average hydrogen flow of 4.9 scfm (138.8 L/min). The flow rate will also vary with time; flow will increase when the fuel cell system purges. The actual flow rate will vary proportionally with the load. Dividing the net hydrogen from the generator 62,972L by the fuel cell usage of 138.8 L/min it results in a total runtime for the fuel cells of 454 minutes or approximately 7.57 hours. Therefore for one tank of 20 percent sodium borohydride ($NaBH_4$) fuel solution the fuel cells can operate continuously for 7.57 hours.
STEP 4 The net output of the fuel cells is 11.7 kW. Of that net voltage there are approximately 2 to 2.5 kW of system loads and efficiency losses. After taking into consideration all these loads the total usable power supplied to the motor is on the order of 9.6 kW. Multiplying the total continuous runtime of 7.57 hrs by the net output (after loads and efficiency losses) to the motor of 9.6 kW, the result is 72,672 watt-hours.
STEP 4 Utilizing the overall vehicle efficiency developed in the battery field testing the projected generator and fuel cell system range can be estimated. Dividing the energy on the generator fuel cells system 72,672 watt-hour by the overall vehicle efficiency 194.4 watt-hours per mile the range is 374 miles.

STEP 5 Adding together the range from the batteries full charged 75 miles and the range from the generator fuel cell system 374 miles the resultant is 449 miles at a continuous 50 mph.

Consumption rates and run times

As stated above the projected range of the Genesis is about 450 miles at 50 mph. At slower speeds the overall vehicle efficiency actual get better and following the same steps the vehicle could theoretically achieve ranges of over 500 miles. One goal of the project was to minimize on-board gaseous hydrogen therefore as hydrogen generation only occurs in the presence of selected catalysts, hydrogen generation rates can be controlled. The hydrogen generator has an average generation rate of about 130 L/min until the flow of sodium borohydride solution is ceased. This 130 L/min is slightly less than the demand from the fuel cell of 138.8 L/min. The generator produces about 520 L hydrogen per liter of fuel thus at 150 L of hydrogen per minute the generator can run continuously on the 121.1 L fuel storage for 8.07 hours. If the fuel cells ran continuously they would consume this amount of hydrogen in 7.57 hours. Thus in order for the generator to produce all of the hydrogen for use in the fuel cells there will be a delay of approximately 0.5 hours. This does not indicate that the vehicle will have to pull off the road in order to generate the hydrogen necessary to continuously feed the fuel cells, actually the batteries provide 75 miles of range. The batteries can easily act as an adequate buffer to sustain the vehicle if need be for that 0.5 time differential between the two systems.

Location of key vehicle components

The majority of the Hydrogen-On-Demand™ system can be seen in Figure 21. The product tank, catalyst chamber, and fuel tank can be seen from right to left. Under this system was the location of the battery pack. While the hydrogen storage and generation system was being installed an incident occurred which lead to the destruction of approximately half the batteries of the battery pack, please see Appendix 2 - NJ Genesis Safety/Function Audit Report for details of this accident.

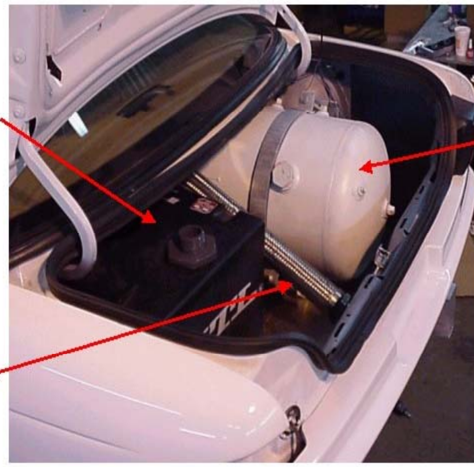


Figure 21 Trunk view of the New Jersey Genesis vehicle showing locations of key hydrogen generator system.

With the loss of the battery pack the team hired a safety consultant to evaluate the vehicle systems and research the battery accident. "The audit revealed that the actual configuration of the battery area of the vehicle did not provide sufficient protection from above. Such protection is specifically required by the NESEA rules and similarly intended information contained in SAE Standards for electrical vehicles. Further, it is clear that certain reasonable safety practices were compromised during the assembly process which, had they been followed, would have avoided the incident. Finally, the audit of the overall vehicle revealed several areas where the vehicle design can be improved for safety.[16]" With the safety audit complete the team decided to redesign several system locations in the vehicle. The following four figures are drawing of proposed changes to be incorporated into the vehicle. It should be noted that the goal of maintaining the vehicle with full seating capacity was lost due to the redesign. The back seat area was utilized to provide additional room for the batteries, there was a safety need to separate the potentially "wet" chemical systems from the high voltage battery pack. The good news is that the redesigned vehicle should be safer for two reasons the weight is more equally distributed thus producing better stability and handling plus it has increased trunk cargo space.

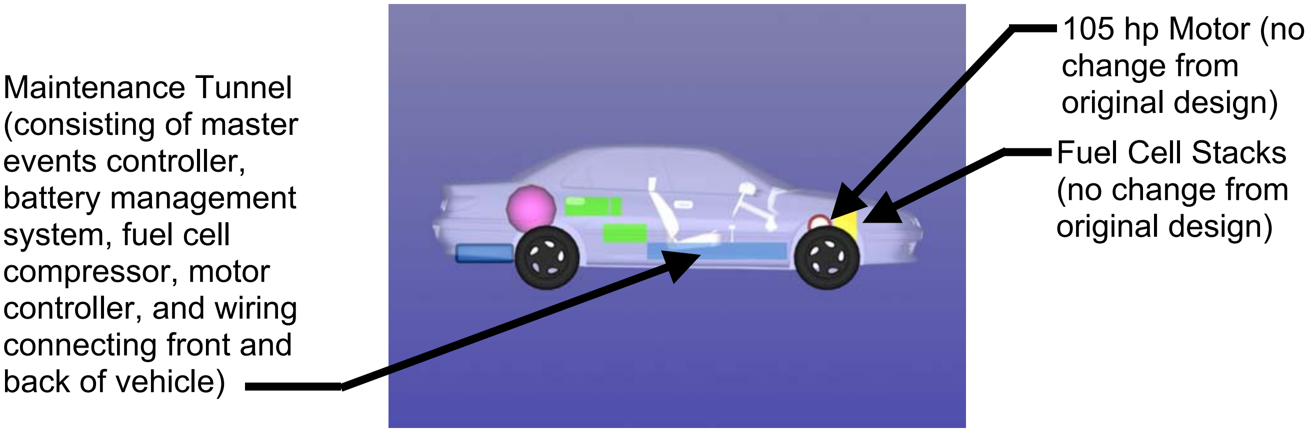


Figure 22 Side view schematic of vehicle systems.

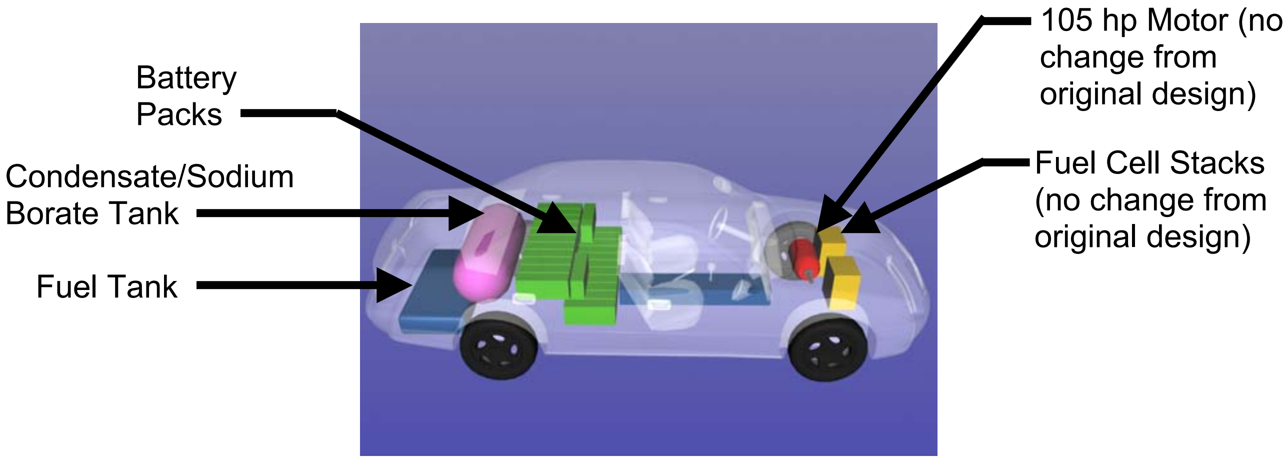


Figure 23 Top view schematic of vehicle systems.

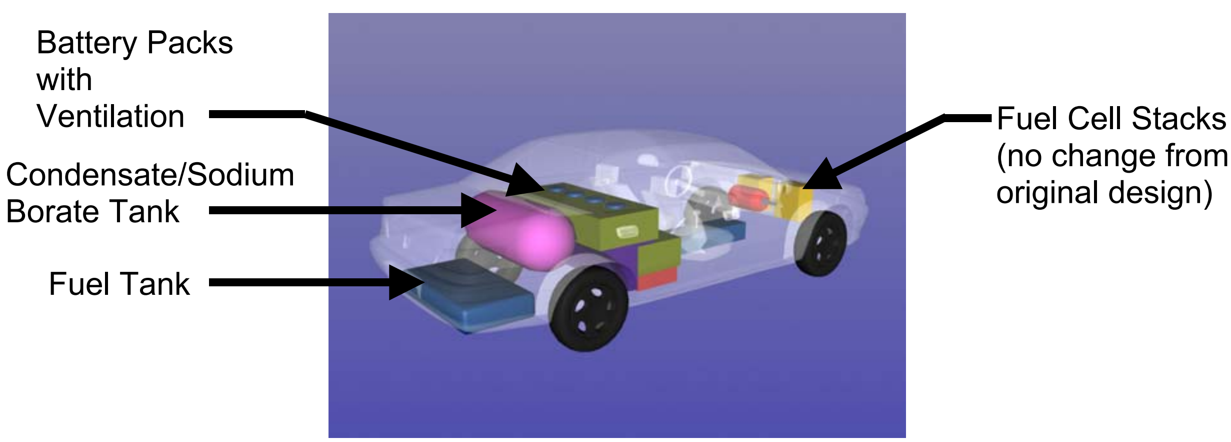


Figure 24 Rear view schematic of vehicle systems.

During the safety audit Future Fuels Consulting "found that the project lacked a chronological log to document the sequence of events and who was involved in various decisions. Likewise, there were no technical drawings of the Genesis vehicle provided. No performance data was taken during the brief time the vehicle was operated. This made the job of understanding the fire incident dependent only on statements made by participants. Research and development projects generally need such extensive documentation to maximize the benefits of the work. Recording such information is normally considered the responsibility of the project manager. At a minimum, an activity log would include: location, dates and times, names of people present, and status of the work going on that day i.e., without benefit of hindsight." The information provided in this report includes nearly all the technical data available on the vehicle.

Task 3 - Make minor improvements to the New Jersey Venturer – Team New Jersey's fuel cell / electric hybrid vehicle from the 1999 program – and ready it for the 2000 Tour de Sol.

The New Jersey Venturer was made ready for the 2000 Tour de Sol by Team New Jersey while work on the Genesis was taking place. The hydrogen storage containment system was improved, the battery pack was rehabilitated, and controls were repaired or replaced as necessary[17]. Even though the team had hoped that all the bugs had been worked out of the vehicle and that the systems were refined, several failures were still experienced throughout the 2000 road rally. The only significant failure was the problems experienced with the motor controller. The power transistors in the Venturer overloaded and burnt out as a result of the regenerative braking system and the fuel cell operating at a condition when the batteries were fully charged. The regeneration caused a voltage spike that the controller could not absorb when the batteries were fully charged. In short the voltage input exceeded limits of the Solectria motor controller. The solution to this problem would have been to utilize a controller that could handle the higher voltage spikes. The controller selected for the Genesis was chosen such that it could handle these higher voltage spikes.

Task 4 – Technology Transfer - Educate the public regarding the benefits of the new clean vehicle technologies represented by Genesis and Venturer, and provide opportunities for students to learn and gain hands-on experience in an advanced technology development environment.

The Venturer entered the Tour de Sol and finished the Tour successfully. Throughout the competition, the only source of power used to fuel the Venturer was power from the solar photovoltaic power from Team New Jersey's unique PV / fuel cell hybrid power station (charge stations fuel cells were not used only the solar panels); no utility power or any other source was used to complete the 360-mile trek. During the tour the New Jersey Venturer placed first in overall scoring among all entrants in the 2000 American Tour de Sol and won First Place in the Renewably Fueled Vehicle category.

Throughout the development effort to design and produce the New Jersey Genesis and throughout the Tour de Sol, New Jersey college students, high school students, and vocational institute students were intimately involved in the process. Students from Burlington County College / NJIT participated in the design, planning, and production of the vehicle. Burlington County College students and faculty and Hunterdon Central High School students and faculty also participated in the Tour de Sol competition, traveling with Team New Jersey along the tour route.

Overall, approximately 60 students and faculty were involved in the design and production of New Jersey Genesis and New Jersey Venturer, and 20 students and faculty participated in the 2000 Tour de Sol. During the Tour de Sol, the vehicles were displayed daily at high schools, technical schools, and public venues. They were displayed in Trenton, NJ in the capitol area in conjunction with an environmental conference and exhibit. In Washington, D.C. they were displayed on the Mall, drawing attention from numerous DOE officials, New Jersey Senators Torricelli and Lautenburg, who conversed with Team members extensively and test drove the New Jersey Venturer.

Students were taught and participated in many aspects of the vehicles retrofit. Some were taught **MA**trix **LAB**oratory (MATLAB) in order to perform an analysis of vehicle dynamics, while others worked to develop a series-resonant power converter circuit for use in the Genesis vehicle. Photographic documentation, meeting minutes, and the construction of the web site were all tasks that students were actively involved in. They were also involved on the actual construction of the vehicle systems and retrofit process. They were responsible for changing the original suspension to an air suspension and installation of the drive shaft axles. They were instructed in the basic weight reduction methods and ultra lightweight but strong metal alloys. Titanium and aluminum brake rotors were installed to reduce overall weight. All non-essential wiring was removed and the vehicle was rewired for only essential uses to ensure maximum weight reduction. The entire interior was removed and super-light weight seats were installed. The students performed these tasks under the supervision of technical experts from the New Jersey Department of Transportation and their vocational instructors.

Students were also involved in modeling the Genesis and simulating crash tests to evaluate the car's safety. However, without several actual crash tests (which is unrealistic for this project) or a comprehensive dynamic computer simulation run by a certified facility (which is too expensive for this type of program) there is little else that can be done to validate the crash worthiness of the vehicle due to changing so many structural components and the removal of the engine. Therefore, students utilized Structural Impact Simulation and Model Extraction (SISAME) to extract approximate models from crash test results. Like many other finite element modeling packages it breaks the overall system down to a combination of masses and springs moving together. Students obtained information pertaining to a Ford Taurus, which is basically the same vehicle as a Mercury Sable. The SISAME model consisted of three mass components and six different springs as shown in Figure 25. The mass-spring model summarizes the complex vehicle system into quantifiable numbers including approximate masses of each main component and the structural impact response into different spring constants. One flaw in the analysis was that since the SISAME model was based on real crash test data the students were unable to account for the aluminum intensive body of the Genesis thus affecting the spring constants. However this does not imply that the simulations do not have merit as a baseline or comparison to our vehicle after all it is the same volume and we can adjust for weight in the second software simulation package **MA**thematical **DY**namic **MO**dels (MADYMO). The students also prepared models in ProEngineer to include the batteries, hydrogen system, and fuel cells these models were then imported into MADYMO. The MADYMO software was then used to analyze occupant safety and asses simulated injuries, a sample occupant model generated by the software during a collision is shown in Figure 27. The complete simulation was then used to generate graphs showing the force levels exerted on each compartment, Figure 26 shows the force levels exerted on the occupant compartment. Due to lack of structural data on the vehicle additional work needs to be performed to accurately analyze the occupant safety

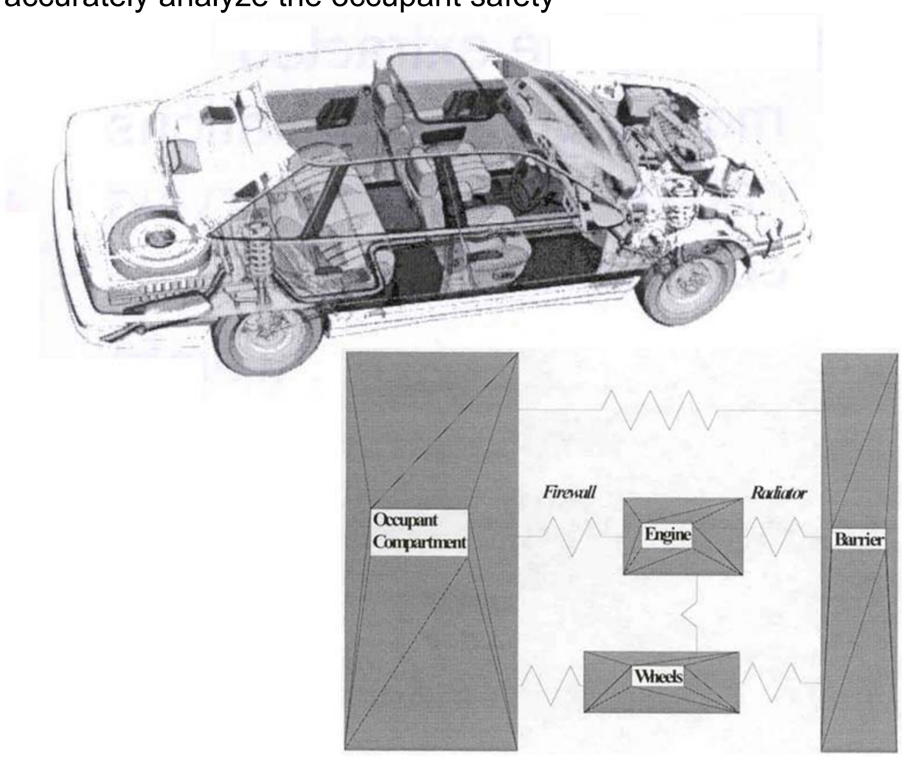


Figure 25 Genesis model based upon three mass components and six different springs derived from SISAME.

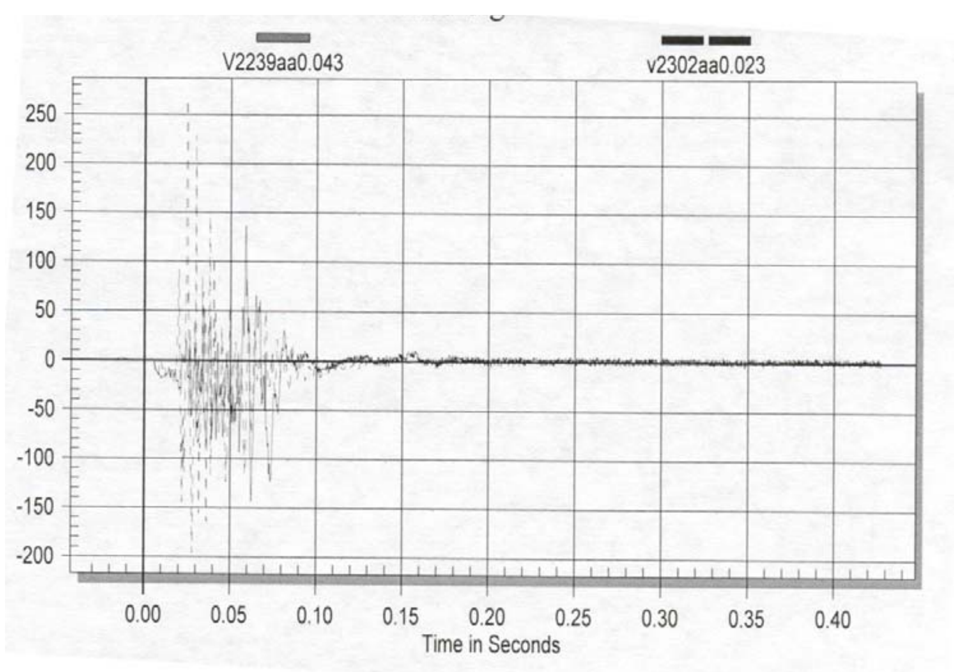


Figure 26 Output graph showing force levels exerted on each compartment.

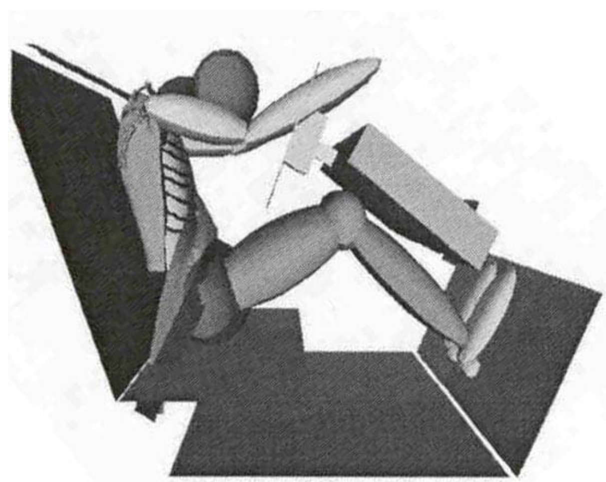
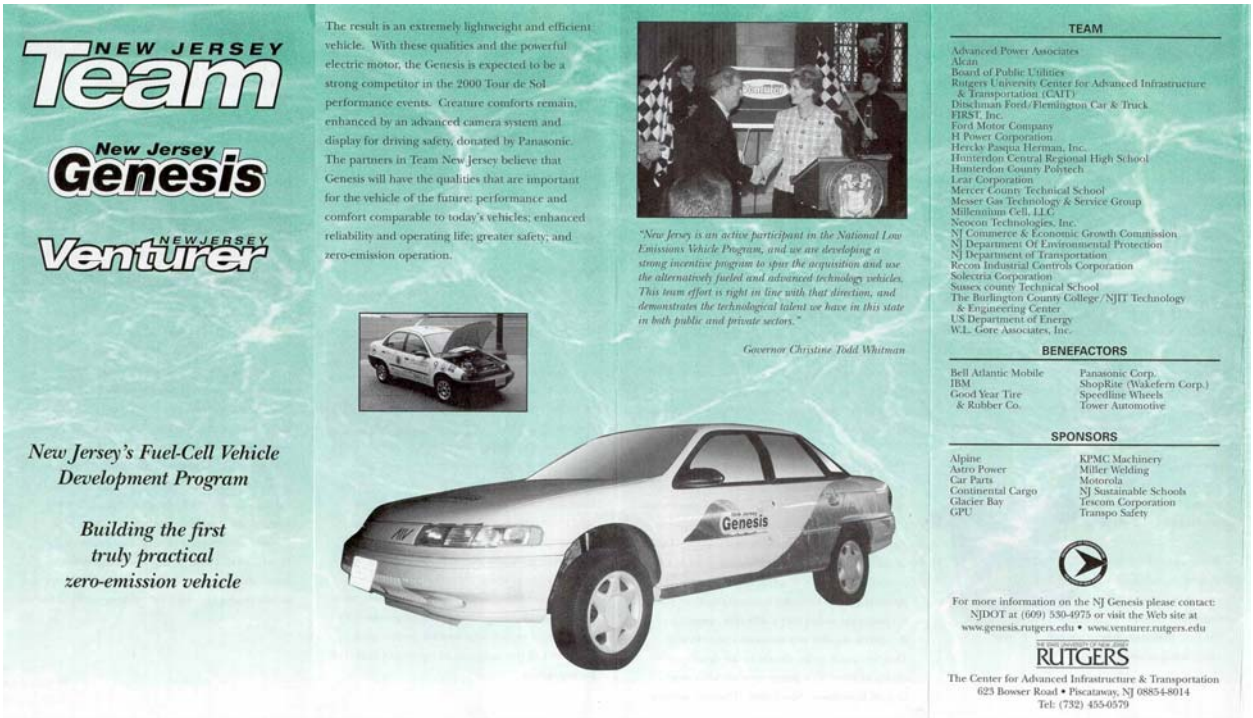


Figure 27 MADYMO 3-D model simulating occupant response in a crash environment.



NEW JERSEY Team

New Jersey Genesis

NEW JERSEY Venturer

New Jersey's Fuel-Cell Vehicle Development Program

Building the first truly practical zero-emission vehicle

The result is an extremely lightweight and efficient vehicle. With these qualities and the powerful electric motor, the Genesis is expected to be a strong competitor in the 2000 Tour de Sol performance events. Creature comforts remain, enhanced by an advanced camera system and display for driving safety, donated by Panasonic. The partners in Team New Jersey believe that Genesis will have the qualities that are important for the vehicle of the future: performance and comfort comparable to today's vehicles; enhanced reliability and operating life; greater safety; and zero-emission operation.

"New Jersey is an active participant in the National Low Emissions Vehicle Program, and we are developing a strong incentive program to spur the acquisition and use the alternatively fueled and advanced technology vehicles. This team effort is right in line with that direction, and demonstrates the technological talent we have in this state in both public and private sectors."

Governor Christine Todd Whitman

TEAM

Advanced Power Associates
Alcan
Board of Public Utilities
Rutgers University Center for Advanced Infrastructure & Transportation (CAIT)
Ditschman Ford/Flemington Car & Truck
FIRST, Inc.
Ford Motor Company
H Power Corporation
Hercky Pasqua Herman, Inc.
Hunterdon Central Regional High School
Hunterdon County Polytech
Lear Corporation
Mercer County Technical School
Messer Gas Technology & Service Group
Millennium Cell, LLC
Neocon Technologies, Inc.
NJ Commerce & Economic Growth Commission
NJ Department Of Environmental Protection
NJ Department of Transportation
Recon Industrial Controls Corporation
Solectria Corporation
Sussex county Technical School
The Burlington County College/NJIT Technology & Engineering Center
US Department of Energy
W.L. Gore Associates, Inc.

BENEFACTORS

Bell Atlantic Mobile
IBM
Good Year Tire & Rubber Co.
Panasonic Corp.
ShopRite (Wakefern Corp.)
Speedline Wheels
Tower Automotive

SPONSORS

Alpine
Astro Power
Car Parts
Continental Cargo
Glacier Bay
GPU
KPMC Machinery
Miller Welding
Motorola
NJ Sustainable Schools
Tescom Corporation
Transpo Safety

For more information on the NJ Genesis please contact: NJDOT at (609) 530-4975 or visit the Web site at www.genesis.rutgers.edu • www.venturer.rutgers.edu

RUTGERS

The Center for Advanced Infrastructure & Transportation
623 Bowser Road • Piscataway, NJ 08854-8014
Tel: (732) 455-0579

Figure 28 Front of the 2000 New Jersey Genesis Project Brochure.

Who is Team New Jersey?

Team New Jersey Members:
Team New Jersey is an unprecedented, multi-disciplinary partnership of State government, New Jersey hi-tech companies, and academic institutions. Using the talents of top scientists, engineers, and managers as well as many students, in 1999 Team New Jersey became the first U.S. entity to field test a hydrogen fuel cell-powered car in competition, the New Jersey Venturer. They successfully raced the vehicle in the 1999 American Tour de Sol, garnering second place in the Hybrid category, and winning the Technical Excellence Award for the Tour.

The program was conceived and is led by the New Jersey Department of Transportation's Technology Bureau, a leader in fuel cells for transportation and electric vehicle development. Team New Jersey's efforts are a natural extension of the Department's continuing work to promote renewable energy and clean emissions vehicles as an alternative to continued reliance on fossil fuels.

The Venturer Project

The New Jersey Venturer is a hybrid electric vehicle based on a Geo Metro body. It incorporates a 55-horsepower Solectria electric motor and nickel-cadmium batteries to store electric power. As such it is similar to other electric vehicles. The use of electric vehicle technology holds the promise of highly reliable operation and extremely long motor life. But Venturer also added a unique source of power - a hydrogen-powered fuel cell. Hydrogen stored in pressurized, lightweight tanks is fed to the 5-kilowatt fuel cell produced by H Power Corporation of Belleville, New Jersey, a leader in fuel cell development. In the fuel cell, the hydrogen is combined with oxygen from the air in an electrochemical process which produces heat and electric energy to charge the batteries and power the motor. The hydrogen and oxygen, in the meantime, have recombined into pure water. Enough hydrogen and electric energy is stored on board the vehicle to allow approximately a 375-mile driving range.

The hydrogen which powered the vehicles was produced in Canada using hydropower. With emission-free production of hydrogen, and no emission from the vehicle other than pure water, the Venturer represented the first demonstration of a totally clean transportation system.

Team New Jersey's Mission for 2000... The Genesis Project

In 2000, building upon its experience in 1999, Team New Jersey has taken on a much more ambitious mission: nothing less than the design, production, and introduction of the first truly practical zero-emission vehicle. In addition to improving the New Jersey Venturer and re-entering it in the 2000 Tour de Sol, Team New Jersey is designing and building a much more advanced vehicle, the *New Jersey Genesis*. The Genesis vehicle will be the first vehicle ever to achieve zero emissions while offering all of the performance, range, and comforts expected in a modern automobile. Building on a unique platform - a prototype all-aluminum Sable generously donated by Ford Motor Company - Team New Jersey will assemble a power plant using totally new technology developed in New Jersey.

The Automotive Fuel of the Future

Imagine a transportation fuel that is concentrated enough to be produced cleanly by midwestern wind power or Canadian hydropower, then shipped to New Jersey and other markets; that is shipped as a safe, non-toxic, non-flammable solid powder; that is dissolved in plain water; and then can be pumped into an ordinary fuel tank; that can power a 5-passenger sedan over a 450-mile range; and that produces only one emission - pure water! That fuel exists today, thanks to the development efforts of Team New Jersey member Millennium Cell, of Eatontown, New Jersey. The fuel, sodium borohydride, is a derivative of sodium borate (borax), a common household material. The borohydride fuel is essentially a concentrated carrier for hydrogen. The clear solution of borohydride in water will be stored in the Genesis vehicle's fuel tank. Millennium Cell's hydrogen generator will produce enough hydrogen from the fuel to power the vehicle's advanced power plant. But the hydrogen is only produced as needed. Only a very small amount of hydrogen is present in the vehicle at any given time, so the vehicle is expected to be safer than any gasoline-powered vehicle.

More Power - Less Weight

The Genesis vehicle will sport a more powerful fuel cell than the Venturer - a 10-kilowatt fuel cell by H Power - and a larger electric motor, a 106 horse-power AC induction motor by Solectria Corp. of Billerica, MA. This advanced power plant will be used in a vehicle that is highly optimized for weight and efficiency. Starting with the prototype aluminum body and frame, Team New Jersey is adding ultra-light wheels, low rolling resistance tires, prototype titanium seats, custom-made aluminum alloy suspension parts, and other efficiency enhancements. Unneeded parts are being taken out. Even nuts and bolts are being replaced with aluminum alloy parts. Electric energy storage will be provided by an advanced nickel-metal hydride battery pack - less than half the weight of an equivalent lead-acid battery system.

Figure 29 Back of the 2000 New Jersey Genesis Project Brochure.

Other components of the technology transfer and outreach efforts consisted of interviews, poster boards, and printed material. The project brochure is shown in Figure 28 and Figure 29, it was generated and distributed at press conferences and public events. Considerable time and effort was spent on outreach efforts, the project was even recognized for its creativity and inventiveness by the White House. A letter from the Advisor to the First Lady on the Millennium is shown in Figure 30, clearly this honor demonstrates just how much recognition the project generated. In order to be eligible to become a Millennium Council Partner we had to demonstrate that we were facilitating "public discussion and awareness regarding important health, environmental, educational, economic, scientific, cultural, or social issues that we as a Nation will face in the millennium.[18]" The project has made a concise effort educate the public regarding the benefits of the new clean vehicle technologies represented by Genesis and Venturer, as well as provide opportunities for students to learn and gain hands-on experience in an advanced technology development environment.

2000

WHITE HOUSE
MILLENNIUM COUNCIL

Honor the Past–Imagine the Future

June 5, 2000

Patrick J. Szary, Associate Director
Center for Advanced Infrastructure and Transportation
Rutgers University
623 Bowser Road
Piscataway, NJ 08854

Dear Mr. Szary:

The White House Millennium Council (WHMC) is pleased to approve the application of the Rutgers University to be a Millennium Partner on your "Team New Jersey" program.

As you know, the WHMC is a multi-year initiative to mark the end of the 20th century and the beginning of the new millennium. By recognizing projects that encourage the creativity and inventiveness of the American people, the WHMC will help Americans "Honor the Past - Imagine the Future." Your project furthers the WHMC's mission and goals and we look forward to working with you.

As a Millennium Partner, the Rutgers University is entitled to use the WHMC logo and mottoes in connection with approved projects, as set forth in the attached Guidelines. To ensure the success of the WHMC's mission, we require Partners and their projects to adhere strictly to the Guidelines. As a Partner, the Rutgers University is also responsible for ensuring individuals, nonprofits, or business entities that assist in a specific project under your approved program abide by the Guidelines. Under the Guidelines, details of any such partnership arrangements between the Rutgers University and a third-party entity (public, corporate or nonprofit), should be submitted in writing to the WHMC for review and approval at least ten business days prior to the effective date of the partnership. Similarly, the WHMC requests that the Rutgers University notify the WHMC in writing of any entity that donates funds or resources for a particular project.

The new millennium holds tremendous opportunity for all Americans. The President and Mrs. Clinton are committed to supporting the American people in reflection, action and celebration to mark the millennium in meaningful ways. Your participation and support are greatly appreciated.

Sincerely,

Ellen McCulloch-Lovell
Deputy Assistant to the President and
Advisor to the First Lady on the Millennium

708 Jackson Place, NW Washington D.C. 20503 T: 202 456-2000 F: 202 456-2008 http://www.millennium.whitehouse.gov

Figure 30 Letter from the White House Millennium Council approving the project as a Millennium Council Project.

PROJECT COST BREAKDOWN

In Table 2 there is a breakdown of the budget for this project. This budget represents the actual dollars that were utilized for the project. The Salaries were used to pay for support from Rutgers students and Staff. The Direct Cost category can be further broken down into Supplies ($29k), Services ($32k), and Travel ($8k). The supplies category includes car parts, tools, fittings, pumps, fans, motors, etc. The Services category includes a safety consultant, towing, and gas piping system work. The Travel category includes travel to various project meetings, events, and other miscellaneous activities. The Equipment category includes the batteries ($17k), Motor and Motor Controller ($10k), Gear Box ($3k), Vehicle Trailer ($5k), Data Logger and System ($11k), Disc Break System ($2k), Upgraded Boost Converter ($2k), and other miscellaneous components installed in the vehicle. The Subcontracts included Marketing ($21k), Power Systems and Converters ($38k), Miscellaneous Support (Tour de Sol Coordination, Student Coordination, and Technical Support) ($18k), and System Integration ($70k).

Table 2 Project Budget

A. Salaries	$ 32,500.00
B. Fringe Benefits	$ 3,725.00
C. Direct Cost	$ 69,699.00
D. Equipment	$ 63,250.00
E. Subcontract	$ 147,380.00
F. Rutgers Overhead	$ 10,596.00
TOTAL	$ 327,150.00

There were many instances where in-kind support was provided to the project, materials were donated, or supplied at cost. Since these funds are more subjective and related to so many company specific factors, we have erred on the side of caution and not discussed these dollar amounts because they were not handled through the University Accounting System. However, in Appendix 1 - Project Partners and Sponsors we have included a listing of efforts and support of all participants of the project. The Sponsors Section includes companies that provided services and materials for free, at cost, or a substantial discount. Other companies listed loaned more expensive pieces of equipment or provided store credit to purchase off the shelf items.

CONCLUSIONS

The New Jersey team, headed by the New Jersey Department of Transportation, was engaged in incorporating this new technology into an optimized hybrid fuel cell/battery electric drive train in an advanced, optimized car. The vehicle platform is a prototype all-aluminum Mercury Sable contributed by Ford Motor Company. The electric motor drive train is a 78 kW - 105 hp Solectria motor and Solectria gearbox. Advanced nickel-metal hydride batteries provided the electrical power storage. Many of the vehicle parts, including seats, wheels, tires, sub-frame, and others, are advanced, lightweight, and/or purpose-built parts. The solution of the sodium borohydride in water can achieve hydrogen production rates between 120 to 150 L/min at about 100 psi. This high energy density fuel storage system combined with the high efficiency of the drive train allows a vehicle driving range equal to or better than current-art cars. However there was an increase in fuel storage volume with the usage of the trunk for the Hydrogen-On-Demand™ system. It is expected that this prototype vehicle will be able to achieve at least a 450-mile range on a charge of sodium borohydride. The products of power production will be pure water, hydrogen gas, and sodium borate. It is possible to recycle the spent fuel sodium borate back into sodium borohydride, however this process is outside the scope of this project. Future research may show an inexpensive process to regenerate sodium borohydride from sodium borate, which would be a significant step in demonstrating this fuel as a renewable resource. It is anticipated that the vehicle will be completed using a more developed configuration and made operational to participate in a future American Tour de Sol, where it will compete with other hybrid vehicles and electric vehicles. This will provide operating experience in a relatively uncontrolled and stressful environment, providing key information on performance and reliability of the major subsystems. The project timeline was adequate to develop a bench test version of the system and begin vehicle retrofit work. However the full integration of the system into a vehicle is a longer-term goal.

Potential refinements and future work for the project include a technology comparison with other types of hydrogen generation and to perform a really good dynamic simulation model to assess stability and control performance issues.

While it is clear that the objectives of this project have been met, this project has opened many broader issues as to the uses of this technology. Numerous projects could stem from this research.

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APPENDIX 1 - PROJECT PARTNERS AND SPONSORS

Academic Partners:

- Rutgers University – provided students to work on vehicle integration and development of the project web site. Also provided faculty oversight in meeting and the generation of the final report.
- Center for Advanced Infrastructure Technology (CAIT) – technical and administrative support; coordinated the formation of the team partners, distributed RFPs to potential subcontractors, oversaw performance and payment to contractors and vendor.
- Mercer County Vocational School - students removed the original suspension and replaced it with an air suspension as well as performed several other weight reduction activities.
- Hunterdon Central Regional High School – provided several students that generated photographic documentation of the integration work, as well as took meeting minutes and assisted in the construction of the web site.
- Hunterdon County Vocational School District – provided initial vehicle preparation including engine removal and a paint job.
- Burlington County College (BCC) / New Jersey Institute of Technology (NJIT) – assembled a group of engineering and technology students and reached out to industry professionals as well.
- Sussex County Technical School – students engineered and manufactured structural and mechanical parts which could be used to reduce overall weight of vehicle components.

Government Partners:

- NJ Department of Transportation's Technology Bureau – principal funding source for the project as well as provided expertise based on its broad experience. Supplied project management, communications oversight, Tour de Sol sponsorship, and state funding.
- United States Department of Energy - principal funding source for additional hydrogen research project.
- NJ Board of Public Utilities – provided assistance to the team during the vehicle development.
- NJ Department of Environmental Protection – provided technical expertise and assistance to the team during the vehicle development.
- NJ Commerce Commission – provided a full-time staff member, as well as provided additional fundraising assistance and worked with each participating New Jersey Company to advance their technology towards commercialization.

Corporate Partners:

- H Power Corporation – fuel cell developer; provided services including fuel cell design and manufacture as well as assisted in the overall vehicle design engineering.
- Messer Gas Technologies & Services, LP – has assisted in the creation of Venturer's hydrogen gas handling system and provided fuel, a support vehicle , and technical personnel during the 2000 Tour de Sol.
- Millennium Cell, Inc. – Designed and fabricated a hydrogen storage system / hydrogen generator, as well as participated in the vehicle design engineering.
- Advanced Power Associates - design and fabrication of power conversion modules that convert the fuel cell voltage to a higher voltage with a high frequency switching, high efficiency, compact, and lightweight unit.
- Neocon Technologies – vehicle system integrator; interfaced between all of the vehicle sub-system manufactures and provided selection of the battery, drive train, and power electronics.
- Fully Independent Residential Solar Technologies – provided services as a consultant on the vehicle design engineering including the data acquisition system and student coordination.
- Recon Industrial Controls Corporation – built the fuel cell system controllers for both the Venturer and Genesis vehicles.
- Hercky*Pasqua*Herman – performed the communications, publicity, and marketing functions for Team NJ, worked with all the members to get the broadest possible attention for the project.
- W. L. Gore – worked with H-Power Corporation to design, manufacture, and integrate the advanced membrane electrode power assemblies into the fuel cell stacks.
- SGL Carbon Corporation – supplied the graphite composite plates that H-Power Corporation utilize in the fuel cell stack to feed fuel and air, and efficiently collect power.
- KPMC Machinery – provided the fabrication of suspension parts and expertise during the construction of the NJ Genesis.

Project Sponsors*:

- Ford Motor Company – provided a custom built Aluminum Intensive Vehicle (AIV) Mercury Sable, usage of 2 pickup trucks during the Tour de Sol, and technical expertise.
- Tower Automotive – has created a prototype engine cradle for NJ Genesis, stamped out of Ultra-High Strength Steel at half the thickness of the original Ford Sable structure.
- Alcan – provided bi-metal rotors used to reduce the overall weight of the vehicle.
- Speedline Wheels – supplied the lightweight wheels used to reduce the overall weight of the vehicle.
- Ditschman Flemington Ford – provided both parts and expertise during the construction of the NJ Genesis.
- Continental Cargo – supplied a project vehicle trailer, used to transport the vehicle, spare components, and a mobile workshop for field modification and support of the vehicle.
- Transpo Safety – provided financial support for student participation in the Tour de Sol.
- Bell Atlantic – supplied mobile telephones and cell service during the Tour de Sol, allowing key team member and drivers to coordinate or efforts.
- Solectria Corporation – provided the motor and controller, gearbox, half shafts, driver interface, and mounting kits used in the NJ Genesis as well as technical and engineering support for these components.
- Glacier Bay – supplied lightweight air-conditioner unit for the vehicle.
- IBM – made two laptops available to the team, which were used for overall project management, web site design, and data acquisition.
- Car Parts – provided both parts and expertise during the construction of the NJ Genesis.
- Alpine - supplied a GPS tracking system which can be used to track vehicle and help analyze the performance of the vehicle.
- Goodyear – provided prototype tires used to reduce rolling resistance and increase handling performance of the vehicle.
- Lear Corporation – equipped the vehicle with lightweight seats used to reduce the overall weight.
- Normans Auto Glass – furnished lightweight glass used to reduce the overall weight of the vehicle.
- Miller Welding – provided welding equipment to aid in the retrofit of the NJ Genesis.

* This list includes companies that provided services and materials for free, at cost, or a substantial discount. Other companies listed loaned more expensive pieces of equipment or provided store credit to purchase off the shelf items.

Project Sponsors Continued:

- Motorola - supplied two-way radios during the Tour de Sol, allowing key team member and drivers to coordinate or efforts.
- General Public Utilities (GPU) - provided financial support for student participation in the Tour de Sol.
- Panasonic – provided a three-piece multimedia system that allows the driver to easily see behind the vehicle utilizing a rear-facing compact video camera and on-dash LCD display.
- Diversatech, Inc. - provided the fabrication parts and expertise during the construction of the NJ Genesis.
- Wakefern Food Corporation (Shoprite) - provided financial support for student participation in the Tour de Sol.

APPENDIX 2 - NJ GENESIS SAFETY/FUNCTION AUDIT REPORT

New Jersey Genesis Safety Function Audit Report

Prepared for:
New Jersey Department of Transportation
Technology Bureau

NJDOT Consulting Agreement: PO21128

Executive Summary

The New Jersey Genesis project has the very aggressive goal of providing a road-ready 4-5 passenger electric vehicle powered primarily by fuel cells supplied by hydrogen stored on-board in the form of a solution of sodium borohydride in water. On the afternoon of May 9, 2000, during preparation of the vehicle for final testing prior to participation in the 2000 Tour de Sol, an electric short circuit occurred in the rear battery pack resulting in a self-sustaining fire in that area of the vehicle. Due to fast action by the NJGenesis team, the fire was contained, no one was injured and minimal damage was done to the vehicle itself though the involved battery pack was a total loss.

The New Jersey Department of Transportation Technology Bureau desired an investigation of the event and an evaluation of the feasibility of continuing the project. In July, Future Fuels Consulting was selected to perform the study using a team of experienced senior engineers to provide an assessment of key technology areas on the vehicle. During August, this audit team met with members of the NJGenesis team to collect information concerning the vehicle's design and the events of May 9. Our investigation was based on the information provided by the NJGenesis team and on additional information obtained from the Northeast Sustainable Energy Association (NESEA), Society of Automotive Engineers (SAE) Standards sections, the Eatontown Police and Fire Volunteer departments and other sources.

The audit revealed that the actual configuration of the battery area of the vehicle did not provide sufficient protection from above. Such protection is specifically required by the NESEA rules and similarly intended information contained in SAE Standards for electrical vehicles. Further, it is clear that certain reasonable safety practices were compromised during the assembly process which, had they been followed, would have avoided the incident. Finally, the audit of the overall vehicle revealed several areas where the vehicle design can be improved for safety. A general audit of the hydrogen generation equipment was also conducted. While the equipment has yet to be fully installed in the vehicle and is in a prototype stage, it was found that basic design successfully limits the amounts of free hydrogen that would escape in the event of an overpressure condition. Concerns for reactant, catalyst and byproduct carryover into the fuel cells could not be addressed due to lack of data.

The needed changes discovered as a result of this audit appear within normal engineering efforts on the part of the involved NJGenesis team members. In addition, full compliance to current NESEA/SAE safety procedures is necessary in all future NJGenesis activities.

I. Introduction and Objectives

The State of New Jersey Technology Bureau is coordinating a project to demonstrate a fuel cell powered car with an on-board hydrogen gas generation system. This project is known as the **New Jersey Genesis.** During construction of this vehicle a battery fire incident occurred on May 9, 2000. Concern existed in the following areas:

- Has the cause of the battery fire been correctly identified and eliminated?
- Are there other identifiable safety problems – structural, control, or system - inherent in the current design? And,
- Is the hydrogen generation system able to perform as needed to power the vehicle without contaminating downstream components?

An investigation into these safety-related questions was conducted. Components were evaluated based on available data and determinations made whether they were properly installed and functioning safely. Thus **safe component function**, not component optimization, was the goal of the study.

A team of specialists was assembled to conduct a short-term third-party review of the vehicle (Phase I of Future Fuels Consulting (FFC) Proposal dated July 15, 2000). The purpose: to answer the questions above and, hence, to provide an overall safety/function audit of the various components installed in the vehicle.

Further a recommendation for a Go/No Go decision on the current project was requested.

The results of this effort conducted during the months August and September of 2000, with additional revisions in October, are provided in this final report.

II. Summary of Findings

Three engineering disciplines were required for this technical audit. These included:

- Electrical engineering to explore the battery, electric drive and control systems on the vehicle,
- Mechanical/vehicle engineering to consider overall vehicle information, and
- Chemical engineering to evaluate the hydrogen generator system that represents the most advanced component of the NJGenesis project.

Each specialist has prepared an individual report for this project and these reports are included in the Appendices A1 and A2, B, and C, respectively, attached to this report. This section will provide a summary of those findings. For further information please refer to the reports in the Appendix.

A1. Question: Has the cause of the battery fire been correctly identified and eliminated?

Answer: The cause of the fire was a short circuit from the battery pack to the chassis of the vehicle. It is likely the short was created by material - either drilling debris or leak check fluid - generated by the installation process going on directly above the rear battery pack. The decision to leave the unprotected, removable battery pack in place while installation was occurring compromised safety. This answer was reached after conducting interviews, inspecting the damage and by process of elimination.

At the beginning of this project there was no single identified cause for the battery fire nor was any incident documentation available. During the incident, all 28-battery modules were being charged while the hydrogen generator was being installed in the trunk of the all-aluminum Mercury Sable vehicle. The array of the batteries is given in Figure 1, Neocon Genesis Wiring Diagram, dated 4/1/00.

- Because the hydrogen generator was not installed and functioning, its **function** is ruled out as a cause of the fire.
- Because the vehicle was in “key-off” position, other onboard electrical systems were isolated from the battery pack.
- Only the battery chargers, the batteries, and the environment in the area of the batteries were then considered.

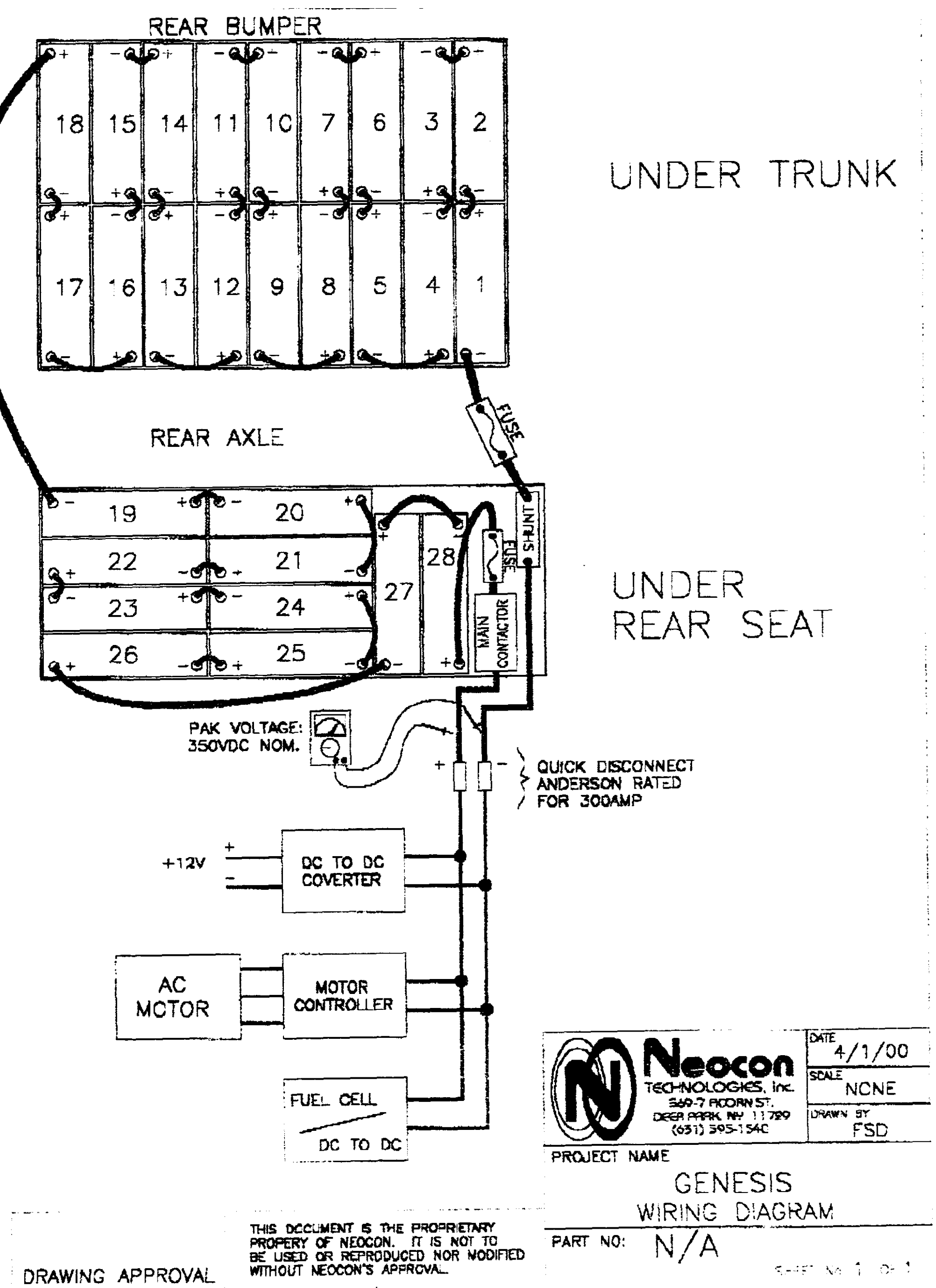

Figure 31 Neocon Genesis wiring diagram, April 1, 2000

- As reported in the Electrical Engineering report Appendices 1 and 1A by Victor Wouk, Ph.D. and a letter received on August 24, 2000 from Neocon – a NJ Genesis team member, a number of possible causes of the fire were eliminated from consideration. Table 3.

Table 3 Possible Causes for Battery Fire

Possible Cause	**Comment**
Battery Failure due to Excessive Heating	Not likely. Batteries had been charged previously. Visual and tactile monitoring by Neocon Technician Jim Green revealed normal conditions. The battery pack heat sensors on the battery pack were active and were not triggered.
Failure Due to Overcharging	Not likely. Battery charging rate was within normal range and temperature according to witness Jim Green. Both battery chargers were reported to be operating properly on a normal charging schedule.
Short Circuit of Batteries to Vehicle	Likely. There is an indication (melted portion of frame – see Figure 2.) that the rear battery pack arced to the battery pack frame. This would have been a high current DC arc. Even though the GP battery terminals were properly fused and insulated from above, the fact that debris generating work was occurring directly above the battery compartment, makes it possible that debris contacting other battery surfaces allowed the battery pack to discharge to the vehicle.

Regarding some subjects raised in a review with NJDOT:

- **Proper Battery pack fusing**: Neocon confirms that the battery packs were indeed properly fused as shown in their installation drawing of April 1, 2000.

- **Battery Terminal Insulation**: The battery terminals were all insulated but that insulation could not prevent all possible contacts since the top of the batteries themselves were electrically conductive and probably left open for purposes of cooling.

- **The mesh cover over the battery packs** was loose and possibly disturbed when the batteries were removed and installed.

- **The mesh was installed for reasons of battery cooling**. The batteries were secured in the battery boxes to prevent them from falling out in the event of a rollover. Still, these precautions do not protect the ESS from conductive metal dust and chips or from conductive leak check fluid.

- **Possible liquid contacting the batteries**. As discussed in Appendix 1B, battery fires caused by liquid coming in contact with battery packs have occurred at both Logan Airport in Boston and in Long Beach, CA.

NJGenesis rear Battery Frame with Fire Damage

Figure 32 NJ Genesis Rear Battery Frame with Fire Damage

A2. Question: Has the problem been eliminated?

Answer: The problem can be eliminated in two ways:

1. **<u>Remove the removable battery pack from the vehicle while modifications are taking place in the battery pack area</u>. This alone will prevent the fire event from occurring again for the same reasons.**

2. **Bring the revised NJGenesis vehicle into compliance with the rules of the 2001 Tour de Sol (not yet available), and with SAE Standards:**
   - **J1766 – Electric & Hybrid Vehicle Battery Systems Crash Integrity Testing, and**
   - **J2344 – Guidelines for Electric Vehicles Safety**

   If a <u>suitably robust, non-conductive barrier</u> is placed between the battery pack and surrounding structure, it will protect the battery pack from being penetrated by material as was believed to be the case on May 9. Also required will be an alternate means for removing heat from the pack.

Prior to conducting the site visits to the vehicle, a request was issued (and then reissued) for documents (drawings, plans, parts lists, et al.) to aid in analysis. See Table 4 (List of Pre-Visit Information and Responses). The responses received was limited and showed that there was a lack of project documentation. Millennium Cell, Inc. provided a copy of a hydrogen generator system flow schematic. Other information was obtained from the NJGenesis Website. The most comprehensive incident information was provided by Neocon in its letter of August 24. (Documentation for subsystems that were not involved in the May 9 incident was provided by H-Power and Recon.) It was found that the project lacked a chronological log to document the sequence of events and who was involved in various decisions. Likewise, there were no technical drawings of the Genesis vehicle provided. No performance data was taken during the brief time the vehicle was operated. This made the job of understanding the fire incident dependent only on statements made by participants. Research and development projects generally need such extensive documentation to maximize the benefits of the work. Recording such information is normally considered the responsibility of the project manager. At a minimum, an activity log would include: location, dates and times, names of people present, and status of the work going on that day i.e., without benefit of hindsight.

Table 4 Desired Pre-Visit Information & Actual Sources

System	Information	Source
Vehicle	- Subsystems Modified since delivery from Ford - Modified Parts Lists	-Obtained from Site visit and Website - No Parts List or drawings made available
Electrical Propulsion	-Block Diagrams - Circuit Diagrams - Component Lists - Operating Instructions - Nominal Performance Characteristics of the energy source	- Information obtained from Recon and H-Power - This information was not required for the incident analysis
Hydrogen Generator	- Description of design and functions of the Hydrogen Generator - Flow Diagrams Materials of construction	- Information obtained from Site visits and Website and technical paper obtained from NJDOT
Battery System	- Specifications of Battery System Information on Battery Fire Event	- Information obtained from Neocon Technologies and Millennium Cell - Eatontown Police and Volunteer Fire Depts. See Appendix D.

As a reference, portions of the 2000 Tour de Sol rules are provided in Table 5. These rules indicate that battery packs (Energy Storage Systems - ESS) are to be covered by an electrically insulated cover to prevent conductive material from falling on the batteries or to contain the batteries safely in the event of a rollover. At the time of the incident only an unsecured fiberglass mesh was in use, if that. Further, it was a questionable practice to conduct physical modifications near the batteries while the batteries are installed and being charged, as was the case during the incident.

Table 5 Selected Rules on Electrical Requirements: 2000 Tour de Sol Rulebook

Rule No./Name	Pertinent Content of Rule
B-3.2 Covers, Boxes and Shielding	All high voltage systems (greater than 36v) must be covered or be shielded to prevent accidental contact with high-voltage surfaces. Covers, boxes, and shielding should not carry current.
B-3.10.3 ESS (Energy Storage System) Enclosure	…If there is a metal surface above the batteries, (e.g. trunk floor), then either **a suitable robust insulating barrier must be mounted in-between**, or the batteries must be restrained from (vertical) movement, and sufficient clearance provided to reasonably assure safety.
B-3.10.6 ESS Terminal Covering	All ESS terminals and **electrically exposed conductors within the ESS must be covered against accidental contact.** All terminals should be insulated when the ESS is open to avoid accidental contact while servicing.
B-3.10.8 ESS Fuses	ESS Fusing system: All energy storage systems shall incorporate a fuse in a location that minimizes the effects of an accidental short circuit. Multiple fuses, or fuses in the middle of battery strings are encouraged. Fuse size must be more than twice the maximum current draw. If the vehicle has two or more energy storage system groups, a fuse in each group is required. (See Figure 1. Reported condition on 5/9/00)

The non-conductive fiberglass mesh/screen above the batteries had been installed instead of a more substantial material to prevent battery overheating. The GP batteries installed are limited to a maximum charging temperature of 131degrees F (55 degrees C).

It appears that the installation of the hydrogen generator with the batteries in place was a safety-compromising procedure allowed by the NJ Genesis project manager in the interest of saving time. The fiberglass mesh/screen may have allowed some metallic chips/dust or leak check liquid to come in contact with the electrically conductive surfaces of the ESS.

B. Question: Are there any identifiable safety problems – structural, control, system or procedural– inherent in the current design?

Answer: There were no obvious safety problems identified during the static inspection of the NJGenesis that could not be corrected to allow use of the vehicle in demonstration driving and in participation in the upcoming Tour de Sol. This is to be confirmed by actually operating the NJGenesis vehicle.

A static inspection of the vehicle and components was conducted. See Appendix B. The vehicle was driven previously at Neocon using battery power on May 8 without mishap and briefly again at Millennium Cell. Information received on the vehicle components installed in the NJGenesis would not appear to have degraded the operating safety of the vehicle aside from the removal of the driver's airbag. Still, actual, documented testing of the vehicle for operation of brakes (friction and regenerative), steering and handling is needed prior to declaring the vehicle is properly assembled and functioning properly at normal speeds.

A comprehensive listing of the NJGenesis modifications and their impact of those modifications on function and safety is included in Appendix B and provided as Table 4. A total of twelve (12) Negative Findings for Vehicle Systems were identified for comment and consideration by the NJGenesis team. Among those items identified are:

- Exposed underside-cooling fans/heat exchangers are subject to contamination/damage from road debris and water contamination in the battery pack and power electronics tunnel. See Figure 3.
- The waste tank pressure bleed vent line releases vapor very close to the right rear wheel well. This appears to violate a National Fire Protection Association (NFPA 52) guideline for natural gas venting in similar circumstances.
- The hydrogen fuel lines need better protection.
- A hydrogen fuel cut-off solenoid valve (or an excess flow valve) should be installed at the exit of the waste tank to prevent hydrogen escape if the fuel line is separated or severed.
- Hydrogen sensors are needed in both the front (engine) and rear (trunk) spaces to report hydrogen leakage.
- Some rear brake components damaged in the incident need to be replaced.

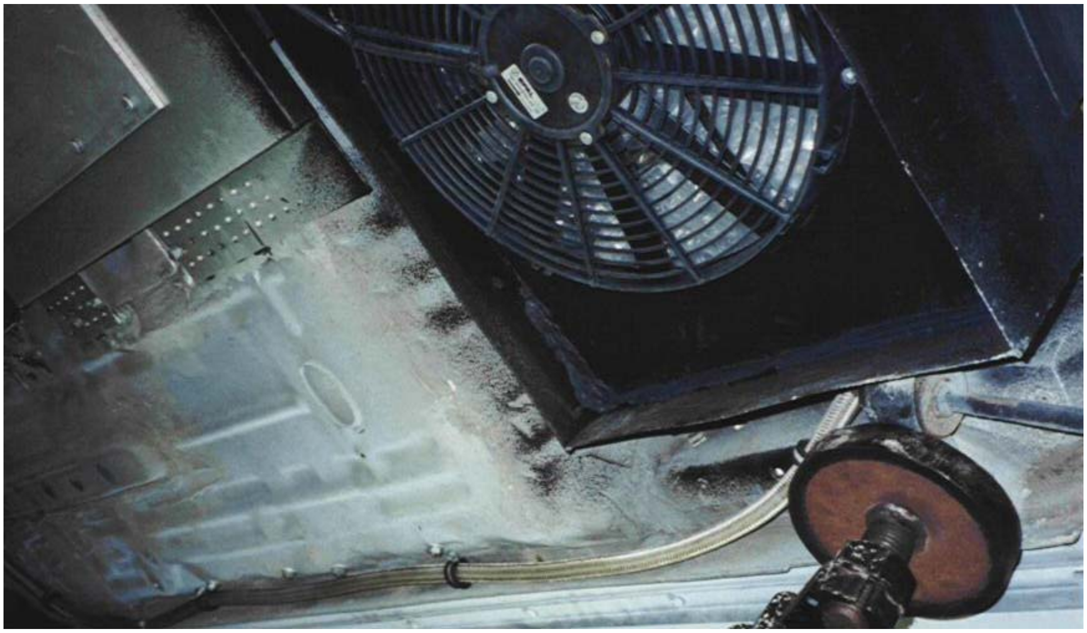

Figure 33 NJ Genesis underbody views - rear seat battery area cooling fan (1 of 2) installation.

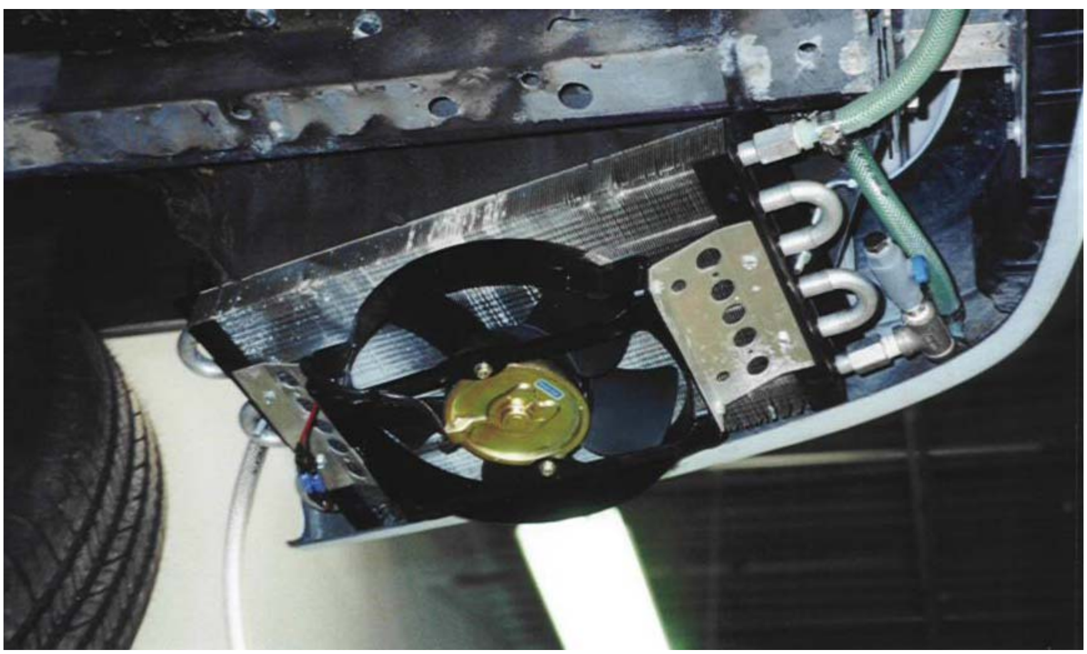

Figure 34 NJ Genesis underbody views - rear heat exchanger and fan located behind right rear wheel.

Regarding some subjects raised in a review with NJDOT:

- **Wiring Harness** – a simplified vehicle harness seems to have been installed for reasons of weight saving. Records of the harnesses manufacturer should be sought so wiring color schemes can be verified. The harness should be checked after installation with the vehicle at rest. Fuses should be checked to see if they are not
oversized. The harness wires should be traced to be sure they are protected from abrasion or interference with vehicle components.

- **Special testing of braking and steering components** – Normal safety precautions and testing should be conducted, especially for wet road surfaces. The braking characteristics should be compared with those of the stock (OEM) vehicle. The lighter vehicle weight, the low rolling resistance tires, the new racing brakes, may significantly change the vehicle tendency for skidding and braking distance. This information should be communicated to the drivers of the vehicle.

- **H-Power stack test data** – was provided in September.

- **Demonstration Drive Crash Absorbtion** – No special procedures are needed. Seat belts must be worn. Because of engine compartment modification (removal of the engine, addition of a latitudinal body stiffener between the from wheel wells, installation of fuel cells, etc), the crash characteristics of the Sable have been changed. Hence, it is not known when the crash sensors would trigger the air bags. Reinstallation of the original air bag steering wheel and its sensing system is not required as long as the driver uses the racing-quality seat belt.

- **Regenerative ("Regen") braking** does not replace the Antilock Braking System. The regenerative braking applies to the front wheels only. It is not modulated according to skidding sensed by the vehicle (if one wheel stops while the other is still turning during braking.)

C. Question: Is the hydrogen generation system able to perform as needed to power the vehicle without contaminating downstream components?

Answer: The hydrogen generator was operated briefly during our 15 August site visit. Millennium Cell appears to have anticipated carryover problems by installing a multistage recovery system including a mist trap and condenser in the trunk and a dual tower molecular sieve in the fuel cell compartment. In late September, Millennium Cell requested additional time to continue development of the hydrogen generator.

The analysis presented in Appendix C is based on limited data provided by Millennium Cell and on general knowledge and information provided by Material Safety Data Sheets (MSDS) provided by manufacturers of the chemicals involved. These sheets are only concerned about safety in handling the chemicals rather than in operating a hydrogen generator. Figure 4, a schematic of the Millennium Cell hydrogen generation system, is presented both here and in Appendix C.

In response to questions from NJDOT:

- **Rinsing of all materials used for handling fuels** – According to the Material Safety Data Sheet (MSDS), the fuel (Sodium Borohydride) is corrosive and the spent fuel (Sodium Metaborate) is an irritant. Hence, any exposed surfaces that are wetted with these solutions and can be touched should be rinsed. Unlike gasoline, these solutions do not evaporate quickly. As in normal refueling however, proper equipment should be use to eliminate splashing of exposed surfaces.

- **Internal Surfaces within the Hydrogen Generator** - The concentration of sodium borate in the warm, spent fuel is higher than its room temperature solubility, so that whether or not the reactor is drained of spent fuel, some sodium borate product will precipitate on the catalyzed ropes as the solution cools. It may be possible to restart the catalyst by pumping in fresh fuel solution. This will need to be confirmed by experiment unless data is provided to show that precipitated sodium borate will dissolve in new fuel solution. Preheating the fuel solution - using some battery energy to warm up the catalyst section of generator - may help by increasing solubility, but there is no provision for doing this in the current configuration.
- **Safety Impact of manual controls** – At its current level of development, manual start-up of the hydrogen generator should not be considered a safety hazard.

- **Fuel Pump Internal Materials –** The internal components of the diaphragm type fuel pump are made of EPDM elastomer.

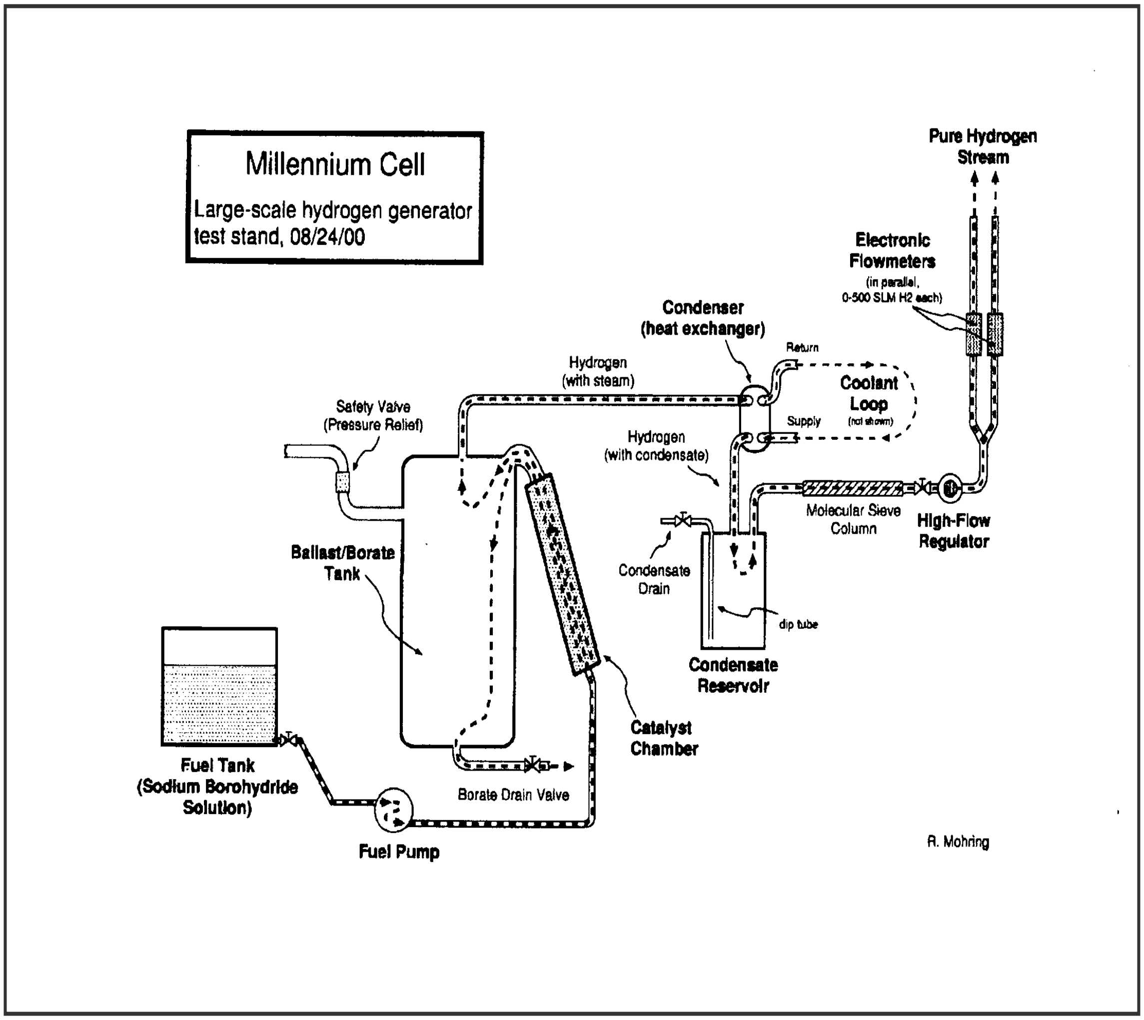

Figure 35 Schematic of Hydrogen Generation System

Go/No Go Decision

There were five main components that were considered for audit at the beginning of project. These included:

- Hydrogen Generator - Millennium Cell
- Propulsion System - Solectria
- Vehicle - Mercury all aluminum Sable
- Battery Systems – Batteries (GP) and Energy Storage System and Controls (Neocon)
- Fuel Cells - H-Power

After the battery incident in May, there was concern that the project might not be ready to proceed any further. This evaluation was intended to supply some guidance for this concern. Since the vehicle has not been fully repaired or operated, there has been only limited data to consider. It would appear however, that certain NJGenesis components were not involved in the fire incident and would not present a high risk because of their success in other applications. These include the Solectria propulsion system, the Mercury Sable vehicle, and the H-Power fuel cells. Only the hydrogen generator's installation, not its operation, was involved in the incident. Only the battery system was fully involved. Future, similar events can be eliminated by closer adherence to standard Society of Automobile Engineers and Northeast Sustainable Energy Association requirements. Hence, there seems no technical reason to halt the process of eliminating the current identified problems and to identifying any other potential problems in the NJGenesis vehicle. Table 5 is the current version of the Audit List indicating some of the already identified concerns for the NJGenesis vehicle that should be addressed prior to its operation for Demonstration or Tour de Sol competition.

III. Conclusions/Recommendations

The Audit Process has revealed a number of areas that do require additional vigilance on the part of NJGenesis team.

- The Audit Team found very little documentation on the construction of the NJGenesis vehicle and virtually no data was recorded before or during the May 9 incident. In the future, more effort must be made to document the engineering information installed in the vehicle and the events that the vehicle experiences.
- Had the fire incident not occurred, it is not clear that the vehicle would have been accepted for the 2000 Tour de Sol due to the potentially exposed nature (lack of a "robust insulating barrier" or restraint or sufficient clearance) of the NJGenesis battery pack. The NJGenesis team needs to integrate reasonable safety features, such as those referenced in this report, into the design of the vehicle.
- Drawings of the modified vehicle should be obtained/generated so additional modifications are properly referenced from existing hardware.
- Several vehicle changes noted in Appendices A1, A2 and B should be installed in the NJGenesis if not already installed.
- The Hydrogen Generator design needs to be refined and proven so that its operation is safe, effective and reliable in a road environment. There are packaging revisions to be made to protect electrical components from road moisture and debris and to protect passengers/technicians from hydrogen leaks. Also, vibration, wide temperature variation (from –20 degrees F to 180 degrees F in the trunk) and corrosion should be considered in the design of the system.

Future Fuels Consulting

Appendices

A1. Analysis of Battery Failure: Genesis Fuel Cell EV Project: Victor Wouk, Ph.D., Victor Wouk Associates

A2. Response to E-mails of 9/23,10/16 and 10/29, Victor Wouk, Ph.D., Victor Wouk Associates

B. NJGenesis – Vehicle System Audit: Gregory Wilcox, Antares Group, Inc.

C. Safety/Function Inspection Report: Millennium Cell Hydrogen Generator: Irwin Weinstock, EA Engineering, Science and Technology, Inc.

D. Eatontown Police and Volunteer Fire Department Reports.

Future Fuels Consulting

A1. Analysis of Battery Failure: Genesis Fuel Cell EV Project: Victor Wouk, Ph.D., Victor Wouk Associates

2000 September 1 vwa ref: 20480

SUBJECT: Analysis of Battery Failure; GENESIS Fuel Cell EV Project
- Examination of Vehicle at MILLENNIUM CELL, Inc.
- Examination of Batteries at NEOCON Technologies, Inc.

****

As background for the analysis below, I cite Standards of the SAE (Society of Automotive Engineers) J1766 and J2344. I was on the Electric Vehicle Standards Forum of the SAE, when the cited references were developed. I serve on the EV SAFETY Committee, and contributed to the development of both standards.

From an Electrical Engineering point of view, and specifically in light of the two referred-to standards:

* J1766: "ELECTRIC & HYBRID VEHICLE BATTERY SYSTEMS CRASH INTEGRITY TESTING"

and

* J2344: "GUIDELINES FOR ELECTRIC VEHICLES SAFETY"

the safety/function audit revealed weakness in the GENESIS system that contributed to the "incident", including insufficient insulation of the battery packs, and lack of fuses in the packs.

(NOTE: I am aware that this vehicle was not designed as a PRODUCTION vehicle. It is a proof-of-principle EV, or, more accurately, what will soon be called a "FUEL CELL VEHICLE", in accordance with TERMINOLOGY STANDARDS being developed by ISO/TC22 SC21, WG2 "TERMINOLOGY AND METHODS OF MEASURING RANGE AND ENERGY CONSUMPTION". I am a USA delegate to the ISO Technical Committee, and serve on WG2.)

1: Component Safety -- Electrical Systems:

1.1: Battery System:

The batteries were the source of the fire damage, described in detail, along with some photographs, by Mr. Vatsky. Since the fire occurred during battery charging, one might suspect that the battery was being charged improperly.

Battery failure, during operation or charging, is usually caused by excessive heating. Faulty construction can also cause failure, particularly during the "break in" period.

Unfortunately, NO data have been recorded. Therefor, my analyses are based on verbal reports that I assume are reasonably accurate, or at LEAST not deliberately falsified.

1.1.1: EXCESSIVE HEATING:

- (It is reported that the problem occurred in NORMAL ambient atmospheric condition, There is no reason to doubt the word of the engineers and/or technicians from MILLENNIUM CELL and NEOCON.)

The NiMH batteries were being charged when the incident occurred. Therefor, I analyze possible failure modes during charging:

1.1.1.1: FAILURE DUE TO FAULTY CELL/CELLS: It is reported that the NiMH battery string, as illustrated in NEOCON drawing "GENESIS WIRING DIAGRAM", dated 3/30/00, had been charged and used before the incident, "more than once." (CONT. on pg. 2)

(1.1.1.1 cont.)

Since there no reported difficulties nor anomalies of CHARGING CURRENT nor BATTERY VOLTAGE during the occasions when the batteries were charged at NEOCON, it can be reasonably concluded that there were no faulty cells.

1.1.2: FAILURE DUE TO OVERCHARGING: This is a frequent cause of failure of ANY battery modules. Overcharging was a problem during the early development of commercially available NiMH modules. However, over the course of recent years the causes and effects of overcharging of NiMH modules have been determined and corrected. There was apparently NO overcharging during the "incident". Again, I depend on the reports by engineers/technicians of MILLENNIUM and NEOCON.

1.1.2.1: The batteries were being charged by TWO battery chargers during the incident. One was connected across modules 1-14 of the NEOCON drawing, the other across modules 15-18. The two chargers, ZIVAN of Italy, are high-quality chargers, with programmable charging profiles. As I understand it, the charging profile was "I-U-I" (IEC standard for CONSTANT CURRENT - CONSTANT VOLTAGE -CONSTANT CURRENT). This is a recognized acceptable profile for battery charging.

1.1.2.2: The NEOCON technician who was overseeing the charging during the incident, states that he checked the two chargers at regular intervals, and all was "OK". The current in both chargers was approximately 8 amperes, and the voltage as required (approximately 110v each -- there is no record).

If a cell in any module had failed, i.e., short-circuited, the current would have been controlled by the ZIVAN to remain constant, but there would have been a noticeable drop in charging voltage. No such anomalous condition was reported.

I therefor conclude that it was not a cell shorted during charging that caused, nor led up to, the incident.

1.1.3: SHORT CIRCUIT TO CHASSIS OF VEHICLE, FROM ONE OR MORE TERMINALS OF THE BATTERY STRING:

There is evidence that supports a conclusion that there was at least one short-circuit to the chassis from a terminal near modules 16 and/or 17 and/or 18 of the NEOCON drawing.

1.1.3.1: A large portion of an aluminum angle bar that supported the tray on which modules 1-18 were mounted, is melted. This is apparent in one of the photographs. This indicates extreme heat, which could be caused by a string of modules discharging through an electric arc from a cell terminal to the bar.

1.1.3.2: This scenario is consistent with the observation by the NEOCON technician who was monitoring the charging of the batteries. He states:

> "I heard a 'bang' or 'zap' that came from the forward right side of the trunk (where terminals of modules 16, 17 and 18 were located.) I then heard a series of hissing sounds coming from the same area, progressing along the battery bank".

(item 1.1.3.2 continued)
The technician disconnected the "QUICK DISCONNECT ANDERSON (connector)" of the NEOCON drawing. He saw NO arc when he disconnected, meaning that NO LARGE CURRENT WAS FLOWING INTO THE BATTERIES. This was to be expected, since the charging currents were NOT flowing through the Anderson connector.

1.1.3.3: There NO fuses shown on the NEOCON drawing, nor did I see any in the vehicle at MILLENNIUM, nor in the material at NEOCON that had been removed from the vehicle.
SAE J2344 recommends not only that fuses be placed at the input and output terminals of an EV battery pack, but also at the central point of the pack.

1.1.3.4: There are no recorded measurements of the insulation resistance of the battery pack(s) to the chassis.

1.1.3.5: There are no devices to indicate a short of any part of the battery pack to the chassis.
We were told by NEOCON personnel that the insulation HAD been measured, and measurements indicated that the battery packs, and hence individual modules, were all isolated from the carrying trays and the vehicle chassis

1.1.3.6: I therefor come to the following conclusions re the manner in which the incident was initiated. I also offer some conjectures as to the phenomenological events that led up to the incident..
The conclusions:
1.1.3.6.1 There was a short to ground somewhere along the string of modules, MOST probably between modules #1 and modules #10 (the accuracy of these numbers need not be in question. Even if the ground existed someplace else, the reasoning and conclusion is not affected.)

1.1.3.6.2: A HIGH CURRENT electric arc to the chassis was initiated by conducting matter touching a terminal near modules 16, 17 and 18, as discussed in item 1.1.3 above.

1.1.3.6.3: The arc-initiating conductor was vaporized, but the arc persisted. It was a dc arc, which would be extinguished ONLY if the current dropped below a certain sustaining value (meaning that the modules had discharged), or the arc was extinguished when the tray was pulled out. This would lengthen the arc, and thus require a voltage higher than available from the shorted batteries; the arc would then be extinguished.

1.1.3.6.4: If a fire had started before the arc was extinguished, the fire would propagate. I am not competent to discuss the chemistry of the fire and its apparent propagation in arcs with the melted angle support as the center of propagation.

1.1.3.7: There had to be at least TWO shorts to the chassis from the string of NiMH modules to the chassis. If the chassis were indeed initially insulated from the batteries when the vehicle arrived at

(item 1.1.3.7 continued)

MILLENNIUM from NEOCON, then a single short to the chassis from the battery bank (due possibly to drilling chips discussed elsewhere) would NOT cause any current to flow from the battery bank to the aluminum angle iron mentioned in item 1.3.1 above. There HAD to be two shorts to complete the circuit.

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1.1.4: General observations for reconstruction of the GENESIS, or construction of another proof-of-principle Fuel Cell Vehicle:
These are recommendations mainly per J2344; J1766 should be followed where possible. I realize that, for example, on this proof-of-principle vehicle it would be prohibitively expensive to guarantee that in a crash no electrolyte from the battery would enter the passenger compartment.

1.1.4.1: Have a fuse between the equivalent of the connection between modules 9 and 10 of the NEOCON drawing. Also, one in the second pack.

(NOTE: experience has shown that it is better to have the modules run as linearly as possible, and back. Have a FUSE at the turnaround point. Thus, if a short from an external object were to go between the two banks, the fuse would blow.)

1.1.4.2: If at all possible INSULATE THE TERMINALS OF THE CELLS. This will avoid the problem that was at the heart of this incident.

1.1.4.3: If it is not feasible to insulate the terminals, then protect the entire pack with a cover as was attempted at MILLENNIUM.

**8

With regard to other aspects of the vehicle as constructed, I have little to add since I have seen no test data, nor point-to-point wiring diagrams.

I recommend STRONGLY that whenever the batteries are being charged, or the vehicle is being operated, that FULL DATA BE RECORDED of currents, voltages, and all other parameters relating to the operation of a battery-powered EV.

Victor Wouk, Ph.D.
Victor Wouk Associates

Future Fuels Consulting

A2. Response to E-mails of 9/23,10/16 and 10/29,Victor Wouk, Ph.D., Victor Wouk Associates

2000 October 30

Art:

Per your e-mails of 9/23. 10/16 and 10/29, I respond herewith.
The major question:

1) If the arc started from a terminal at the TOP of a cell, why is the angle aluminum melted, where that is the BOTTOM of cells?

1.1: This question is answered to some degree by the statement in the second paragraph of your e-mail of 16 October. There could have been established from one (or more) terminals to the aluminum support A LEAKAGE PATH for one or more of the following:

1.1.1: The "soapy leak-check fluid" referred to in said paragraph is a possibility, depending on the conductivity of the solution. Such a path usually has a NEGATIVE coefficient of temperature. Once the leakage current path is started, as the current flows and the path is heated, the resistance DROPS. More current flows, and a runaway condition can occur. An arc is initiated along the surface, and the arc is essentially a short circuit to the frame.

1.1.1.1: The above is not just theoretical. Such runaway conditions have caused fires in E-buses at the Logan Airport in Boston, and in Long Beach, California.

To minimize the potential damage, the fuses that I have discussed in previous communications, particularly my report, should be employed in the center of the battery packs.

1.1.2: The "soapy fluid" of item (1.1.1) is NOT the only possible source of starting the runaway condition described. If a single cell shorted to a conductive circuit grounded (per UL definitions) due to the metal filings "problem", that cell would overheat and vent conductive electrolyte. This electrolyte could settle onto the surfaces of OTHER cells, and cause the runaway conditions mentioned.

It is unfortunate that the battery packs are in such poor condition, that doing a complete forensic analysis to determine at which cells the various phenomena started, and how they propagated, would be overwhelmingly expensive.

2) With regard to "who called the shots", I cannot contribute to SPECIFIC "finger pointing". I have stated that the system is burdened with an excessive load of NiMH batteries for a FUEL CELL VEHICLE. Since this MILLENNIUM CELL source of H_2 for the FCV does NOT have noxious emissions, there is no reason that I can see for having such a large amount of battery.

The claim that the vehicle must be able to travel some minimum distance as a battery-energized EV has NOT been verified to my satisfaction. As a ZEV, yes. Maybe it takes a long time for the H_2 generator to function from a cold start. Does it?

My statement that the construction with the two battery packs as used in the GENESIS is inherently poor practice, still stands.

NJGenesis – Vehicle Systems Audit

Project Background and Purpose

The New Jersey Genesis vehicle was originally prepared to participate in the Tour de Sol solar car race in May 2000. However, the vehicle experienced a battery fire a few days before the race. The fire was contained but damaged one of the two battery packs and several onboard components. NJDOT decided to contract outside consultants to perform an independent safety and function audit of the vehicle in the following areas: hydrogen generator system, fuel cell system, propulsion system, battery system, and auxiliary vehicle systems. As part of this study, a physical inspection of the concept vehicle by the consultant team was made.

This memorandum discusses the findings of the physical inspection and audit related to vehicle systems. It discusses the primary modifications made to vehicle systems in developing the concept vehicle and their implications for function and safety. Recommendations are provided for addressing negative impacts as well as an overall assessment of vehicle safety and viability.

Primary Auxiliary Vehicle System Modifications

The concept vehicle began as a prototype, all aluminum Model Year 1993 Mercury Sable donated by Ford Motor Company. A variety of vehicle modifications were made in order to incorporate the new drivetrain components, but also to be competitive in the Tour de Sol road race including lowering overall weight and coefficient of drag. A list of modified parts and systems was not available from the NJGenesis project manager. However, the primary modifications made to vehicle components and systems were determined form the site visit and discussions with Millennium Cell personnel. Table 1 provides a comprehensive listing of these modifications and a brief analysis of their impacts on vehicle functionality and safety relative to the original vehicle.

Summary of Findings

A general summary of the positive and negative impacts on vehicle systems found as part of this evaluation are identified and discussed below.

Table 1. List of Primary Vehicle Component/System Modifications

Modification	Functional Impact	Safety Impact
Components		
Subframe replaced with modified subframe from Tower Automotive	Equal - basic subframe design same Positive – lighterweight	Equal
Original 1993 Sable suspension parts replaced with 1998 Sable suspension parts	Equal - suspension mounting points similar, suspension capability similar	Equal
Coil spring dampers replaced with 1998 Lincoln Towncar air bag suspension	Positive – Lincoln system is active air dampening system; provides potentially better control and less vibration for new electronic systems	Equal
Front calipers, rotors, and baking plates replaced with custom racing versions	Positive – racing braking systems would provide better braking response under panic stop conditions. Also, provide weight reductions to vehicle.	Positive – better panic stop response Negative - may result in slightly less brake "feel" relative to original brake system
Rear rotors replaced with custom racing versions	Positive – less potential for brake fading under panic stops and less weight	Positive – less potential for brake fading under panic stops
Magnesium wheels used in place of original aluminum wheels	Positive – stronger, lighterweight wheels	Equal
Original tires replaced with Goodyear low rolling resistance tires.	Positive – lower rolling resistance, longer wear tires	Equal
Used existing fuse box, but wiring harness is custom	Uncertain – does custom wiring meet duty requirements of new electronic systems	Uncertain – if custom wiring does not meet new duty requirements, may result in loss of vehicle system control during operation
High strength axle shafts were custom made to fit Solectria motor drive	Equal – high strength axle shafts match electric motor requirements	Equal
Removed incandescent bulbs in engine and trunk compartments. Replaced with xenon or low power LED lights	Equal – xenon and LED lights are proven in these and other applications	Positive – remove potential ignition sources for hydrogen leaks in trunk and engine compartments
Front frame was modified to mount radiator. Aluminum radiator is integral	Equal – frame integrity does not appear to be compromised. In fact, radiator	Equal

Modification	Functional Impact	Safety Impact
with frame using rivets.	mounting appears to provide additional strength to frame.	
Power brake vacuum pump added to assist brake booster.	Equal – pump needed to replace lost engine vacuum. Uncertain – has pump has been sized correctly?	Uncertain – as long as pump has been sized correctly
Electric power steering pump was added.	Uncertain – Has pump has been sized correctly?	Equal – as a long as pump has been sized correctly
Ford original SHO engine and transmission removed. Added H-Power Fuel Cell stacks (2) mounted to new subframe and shock tower brace.	Equal – fuel cells appear to be adequately mounted. Uncertain – fuel cell operation could not be evaluated; have fuel cells have been sized to provide adequate power requirements for vehicle? Negative – have fuel cell mounts been adequate damped for vibration?	Uncertain – fuel cell operation could be evaluated Negative – original engine provided frontal crash stability. Fuel cell stacks will not offer same frontal crash absorbing capacity as original engine since vehicle frame not designed for fuel cell powerplant.
Added Solectria electric motor and power electronics (motor controller, boost converters, etc.) Axle shafts were custom made chrome moly steel.	Equal – motor mounts appear to be adequate Uncertain – motor operation could not be evaluated Positive – if motor has been sized to provide maximum vehicle power requirements and may actually improve vehicle acceleration characteristics.	Uncertain – motor operation could not be evaluated.
Added Neocon battery controller and nickel metal hydride battery packs (2), one under passenger back seat, the other under trunk area in place of spare tire location. Battery packs secured with brackets to underbody frame rails.	Equal – battery packs secured adequately to frame rails. Batteries should provide necessary power and energy storage requirements Uncertain – battery operation could not be evaluated	Equal – Battery locations are low on vehicle so weight inertial impacts minimal. Batteries brackets and mounting locations on frame rails appear to be adequate. Uncertain - unsure about battery off gas isolation from passenger compartment, and battery and electronic controls exposure to road debris from underside battery fans.

Modification	Functional Impact	Safety Impact
Removed original gasoline fuel tank. Added Millenium Cell hydrogen generator, fuel tank, fuel pumps (2), waste tank to trunk and hydrogen gas fuel lines to fuel cell stacks at front of vehicle.	Uncertain – system was not fully operational during site visit. Negative – loss of functional trunk space	Equal – component mounting appeared reasonable. Negative – hydrogen generator not properly shielded to prevent exposures to hot materials or reactant loss. Waste tank vent line opening improperly installed in rear wheel well. Hydrogen lines to fuel cell in front of vehicle not routed properly to prevent road damage. Need electronic hydrogen fuel cut-off solenoid and fuel pump shut-off in case of fuel line or fuel cell leaks. Need hydrogen monitors installed in both trunk and engine compartments.
Original steering wheel replaced with non-air bag competition wheel.	Equal	Negative – new steering wheel does not have air bag as original did.
Fuel cell humidifier system added.	Equal – system generally self sufficient since uses fuel cell water by-product.	Equal
Vehicle Systems		
Original 1993 Sable ABS braking system replaced with standard Taurus braking system	Negative – non-ABS vehicle braking characteristics degraded relative to original ABS system.	Negative – ABS provides significant panic stop benefits in terms of stopping distance and vehicle stability.
Regenerative braking capability added to vehicle.	Uncertain – regenerative system could not be evaluated Positive – depending on regenerative braking system control, the system should increase vehicle braking capability and vehicle stability, and longer brake component life.	Uncertain – system could not be evaluated Positive – system could provide better stopping distances and vehicle stability
Body undercarriage modified. Transmission tunnel removed and replaced with riveted aluminum tunnel. Also,	Equal – modifications did not compromise frame rails. Riveted connections are adequate	Equal

Modification	Functional Impact	Safety Impact
undercarriage removed under passenger seat for battery pack installation.		
Switched from gasoline powered drive system to fuel cell electric drive system.	Uncertain – system operation could not be evaluated; motor control function and driver input response could not be evaluated. Positive – likely improved vehicle acceleration Negative – vehicle operation limited to ambient temperatures above 40 F to prevent fuel cell humidifier freeze-up.	Uncertain – system operation could be evaluated.
Switched from gasoline fuel system to sodium borohydride/hydrogen fuel system.	Uncertain – system operation could not be evaluated. Negative – waste borax must be removed periodically. Manual start-up necessary for hydrogen reactor system. Significant loss of trunk space with current prototype system.	Uncertain – system operation could not be evaluated Positive – $NaBH_4$ is much more inert than gasoline. Negative – hydrogen is gas with wide flammability range.

Positive Findings for Vehicle Systems

- Based solely on a static investigation of vehicle systems and components, none of the modifications appear to have significantly degraded vehicle steering, handling, or braking abilities.
- The majority of vehicle system components added to the vehicle were obtained from certified vendors recommended from Ford. This ensured the components were consistent with original Ford specifications when applicable and provides confidence in their quality and durability.
- Several components such as wheels and braking components added to the vehicle were race quality. In general, racing components are generally stronger to match more severe duty cycles as well as lighter in weight.
- Regenerative braking capability was added to the vehicle. Regenerative braking systems recapture normally lost kinetic energy in the form of electric energy during braking episodes by reversing electric motor function so that the motor serves as a generator. In this scheme, the electric power generated during vehicle braking is sent to the battery pack for storage. Regenerative braking systems can be set up to operate in conjunction with the existing mechanical braking system on the vehicle. Regenerative braking can improve vehicle stopping distances and stability and lessens wear on mechanical braking systems.
- The use of Lincoln active air damper suspension should improve vehicle suspension capability and control. This will be important for vibration stability in terms of the fuel cell stacks and power electronics.
- The modifications made to the body/chassis do not appear to have degraded their rigidity. Body longitudinal frame rails remain intact since all underside cuts were made between the rails. The new lightweight subframe matches the original the original chassis mounting points and appears to provide more than adequate mounting capability for the fuel cell stacks and electric motor. The strut tower brace in the engine compartment increases some body rigidity that may have been lost due to the removal of the engine.
- Overall, Millenium Cell claims that the prototype vehicle is lighter than the original vehicle by 400 lb. They also claimed a 50/50 weight balance had been achieved through effective component placement. Both have beneficial impacts for vehicle handling, acceleration, braking, fuel economy, and component wear.
- Driver/passenger positions were not compromised through the modifications made to the vehicle.

Negative Findings for Vehicle Systems

- A thorough evaluation of vehicle systems and operation was not possible since the vehicle was not operational during the site visit. System integration, vehicle performance, and driver control issues are still major questions since only a static investigation was made.
- The original driver air bag system was removed. Although this does not degrade vehicle functionality, it does reduce overall vehicle safety capability.
- Vehicle battery packs appeared to have been mounted and secured adequately for vehicle operation. However, questions arise as to their isolation from the passenger compartment both electrically and for off-gassing. In addition, the underside cooling fans do not appear to

limit road debris and water contamination to the battery pack compartment and to the power electronics tunnel.

- The waste tank pressure bleed vent line is currently routed to release vapor in the right rear wheel well. This should be changed. Referencing the National Fire Protection Association's (NFPA) Standard 52 for guidance in dealing with natural gas, "vents for the venting system shall not exit into a wheel well," and "vent outlets should be protected by caps, covers, or other means to keep water, dirt, and insects from collecting in the lines." It is recommended that the vent line be directed to the right rear corner of the vehicle and routed through a body grommet to point down and away from the vehicle. A protective cap or cover should be used to keep the line free of debris.
- The engine removal likely results in degraded frontal crash worthiness since most vehicle manufacturers design engine location/mountings to absorb some of the crash force. The fuel cell stacks will likely not exhibit the same crash absorbing capabilities as the original engine.
- The hydrogen fuel lines from the waste tank outlet to the fuel cell stacks should be better protected. Although steel braided line is currently used, the line should follow the same path as the original gasoline fuel line if possible. If the line must pass through a panel or flange, appropriate grommets should be used.
- A hydrogen fuel cut-off solenoid should be placed at the outlet of the waste tank in case the hydrogen fuel line is severed, the fuel pressure regulators fail, or a fuel line connection is lost.
- The hydrogen generator/reactor in the trunk did not appear to have adequate heat barrier/shielding to protect against exposure hot surfaces and/or hot reactants in the event of a leak. The shielding to insulate hot surfaces and direct hot reactant leaks downward to the bottom of the trunk.
- It was uncertain whether the NaBH4 fuel pumps had a by-pass loop back to the fuel tank or pressure bleed in case the reactor becomes clogged.
- The two hydrogen moisture condensers located on the right and left rear undersides of the vehicle should be better protected/shielded from road debris and possible hydrogen release.
- Hydrogen monitors should be located in the engine compartment to protect against hydrogen release from the fuel cell, fuel regulators, or fuel lines. A hydrogen monitor should also be installed in trunk as planned. Monitors should be connected to audible and/or visual signal systems within the passenger compartment
- It was uncertain whether the fuel cell stacks are hard mounted or mounted with vibration relief. Isolation from vibration impacts provides less potential for hydrogen leaks from the fuel cells.

Recommendations

As already discussed above, a true evaluation of vehicle systems was not possible for purposes of this audit since the vehicle was inoperable for the site visit. That is, dynamic tests could not be performed. Therefore, a Go/No recommendation for the NJGenesis vehicle had to be made based solely on the static investigations discussed above.

Although several safety concerns related to vehicle systems were identified, none were considered significant enough to label the vehicle as unsafe or preclude its limited use in demonstrations. It should be remembered that this is a showcase vehicle, not a production ready vehicle. Its potential limitations in terms of crash worthiness under Federal Motor Vehicle Safety Standards (FMVSS) or component/system packaging should not necessarily be used against it in terms of its use in this manner.

Overall, the vehicle systems of the NJGenesis vehicle are deemed functional and safe with the performance of the following recommended modifications:

- Verification of proper battery pack insulation from passenger compartment
- Rerouting of waste tank vent line per NFPA 52 guidelines
- Rerouting/Protection of hydrogen fuel lines
- Placement of hydrogen fuel cut-off solenoid at outlet of waste tank
- Verification of proper shielding of hydrogen generator in trunk
- Better protection and/or relocation of hydrogen gas moisture condensers on rear vehicle underside
- Placement of hydrogen monitors in engine compartment and trunk space

It is also recommended that dynamic tests be performed on the vehicle to verify safe operational characteristics once it has been reassembled and appropriate modifications been made.

Future Fuels Consulting

C. Safety/Function Inspection Report: Millennium Cell Hydrogen Generator: Irwin Weinstock, EA Engineering, Science and Technology, Inc.

Safety/Function Inspection Report: Millennium Cell Hydrogen Generator

Prepared for:
Future Fuels Consulting
and the
New Jersey Department of Transportation

Prepared by:
EA Engineering, Science, and Technology, Inc.
15 Loveton Circle
Sparks, MD 21152
EA Project No. 61476.01

Irwin B. Weinstock — Date
Project Manager

Robert P. Newman, P.E. — Date
Program Manager

CONTENTS

CHEMISTRY

The Millennium Cell Hydrogen Generator is based on the hydrogen storage capacity of sodium borohydride ($NaBH_4$) solutions. These solutions store a relatively large amount of hydrogen (H_2) per unit weight and volume and are being explored as compact, portable systems for storing enough hydrogen for practical purposes, including driving a car.

Solutions of sodium borohydride decompose spontaneously, at a very low rate, generating hydrogen, sodium hydroxide, and sodium borate. The rate of this spontaneous reaction can be reduced to essentially zero by adjusting the pH of the solution to around 13 by the addition of approximately 4 grams/liter of sodium hydroxide.

When hydrogen is desired, the rate of the hydrolysis reaction between the $NaBH_4$ and water is accelerated by bringing the solution into contact with a high surface area catalyst. The reaction them proceeds as shown in the following formula.

$$NaBH_4 + 2H_2O \xrightarrow[Catalyst]{} 4H_2 + NaBO_2$$

The catalyst used is ruthenium (Ru), but other transition metals, such as cobalt (Co), might also be used.

OPERATION OF THE HYDROGEN GENERATOR

A schematic illustrating the basic components of the Millennium Cell hydrogen generator installed in the Genesis vehicle is shown in Figure 1 and the operation outlined below.

The $NaBH_4$ fuel solution is stored in a 25 gallon polypropylene tank, similar to those used to store fuel on race cars. When hydrogen is required, the fuel solution is pumped, by two diaphragm pumps, through the catalyst chamber, where it comes into contact with nylon rope impregnated with the high surface area Ru catalyst. The spent reaction mixture, a super-heated borax solution (at about 250°F) and hydrogen, enters the epoxy-coated steel ballast (waste) tank, where the hydrogen gas separates from the spent fuel solution. The warm hydrogen gas is cooled in a heat exchanger/condenser where any remaining vapors (which should be nearly pure water vapor) are condensed. The hydrogen is further dried by passing through a molecular sieve column. The pressure of the hydrogen is reduced from the 100 psig ballast tank pressure to just a few psig before entering the fuel cells.

The process is manually controlled during startup to allow the temperature in the catalyst chamber to build to 200–250°F and the pressure in the ballast tank to increase to its 100 psig operating pressure. The startup procedure consists of cycling the pumps on and off to increase the time the fuel is in contact with the catalyst. The frequency at which the pumps are cycled on is increased as the temperature and pressure approach their normal operating values.

During normal vehicle operation the flow of fuel through the catalyst chamber is adjusted by an electronic controller which turns the pumps on and off to maintain the 100 psig pressure in the tank.

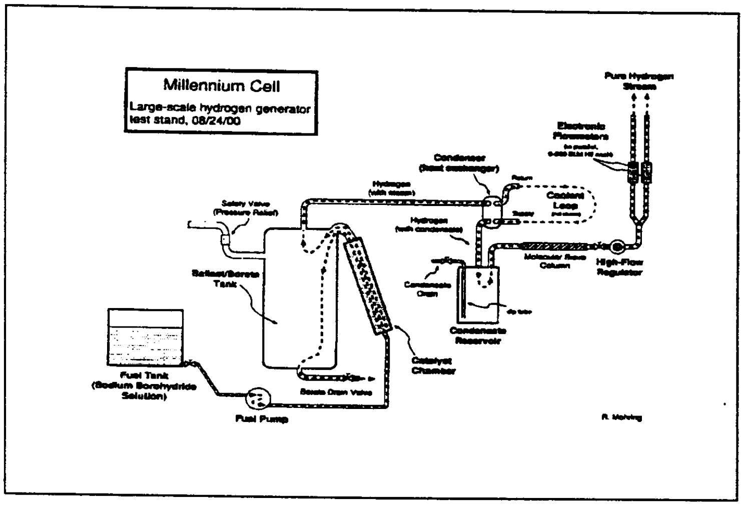


Figure 1. Schematic of hydrogen generator.

POTENTIAL HAZARDS

CHEMICAL HAZARDS

The fuel used in the hydrogen generator is an alkaline (pH 13) solution of sodium borohydride and the spent reactant is a solution of sodium borate. The pure, powder forms of both these chemicals are considered hazardous[1], but the hazards associated with the pure materials are confined to persons making up the fuel solution and/or recycling the spent reactant. The fuel and waste product solutions are in closed containers and the driver and passengers will not come into contact with them during normal operations.

Drivers and persons in close proximity to an accident involving the vehicle may come into contact with the solutions if there is any breaching of the tanks or connective piping. Though the solutions are alkaline and irritating to the skin, injury as a result of contact with them can be largely avoided by flushing any affected areas with plenty of water for at least 15 minutes. Contaminated clothing and shoes should be removed and washed before reuse. The solutions are also corrosive to metals, especially aluminum, and any vehicle structures which are contacted by these solutions should also be washed with plenty of water.

The materials used in the hydrogen generator system (polypropylene fuel tank, epoxy-coated steel waste tank. and stainless steel tubing/piping) are adequate for the task and should not present any corrosion problems under normal operating conditions. The quality of the

[1] Material Safety Data Sheets (MSDS) for these materials are included in the Appendix.

fabrication, as might be expected, does not be up to acceptable standards for a fully-engineered passenger vehicle but, with care, should be sufficient for a demonstration vehicle. To illustrate the weaknesses of the plumbing, it should be noted that during the inspection team's visit to visited Millennium Cell on 15 August it was necessary to shut-down a demonstration of the hydrogen generator on account of a leak in the fuel system piping. This points out the need to perform regular checks on the integrity of piping and tubing connectors that could be loosened by vibration when the vehicle is driven.

FIRE/EXPLOSION HAZARDS

The risk of fire or explosion from the hydrogen being generated by the hydrogen generator is small.

- Neither the fresh nor spent fuel solutions are flammable, so there is no danger of fire or explosion from spilled fuel or waste product.
- The system is fitted with several features to prevent an overpressure in the ballast tank:

1. The pumps that send fuel solution to the catalyst chamber are controlled by the pressure in the ballast tank and shut down when the pressure reaches 100 psig.
2. In case of controller failure, the ballast tank is equipped with a pressure relief device (PRD) that vents the tank when the pressure reaches 150 psig. The valve resets at about 80 psig, and the maximum amount of hydrogen vented to the atmosphere in case of an overpressure event is about 30 scf, with an energy content of about half a pint of gasoline. The hydrogen is vented through a plastic tube and exits the vehicle behind the right rear tire. Care should be taken to be sure that the vent tube is pointed outside the vehicle perimeter so that any vented H_2 does not accumulate in the wheel well.
3. The ballast tank also has both manual and remotely operated vent valves that allow a service technician or the driver to vent the tank from inside the trunk or from the driver's seat.

- The maximum amount of hydrogen contained in the ballast tank at the 100 psig normal operating pressure is about 40 standard cubic feet, having the energy of about a tenth of a gallon of gasoline. In the event of an accident that results in a breach in the ballast tank, this small amount of hydrogen would be quickly dispersed in the atmosphere.

  During operation, as the volume of waste solution in the tank increases, the head space, and the amount of hydrogen in the tank, is reduced. For example, after 20 gallons of fuel has been consumed, the head space is reduced to a little less than 25 gallons and the amount of hydrogen stored at 100 psig, about 26 scf, has the energy of about half a pint of gasoline.
- Vehicle lights in the vicinity of the hydrogen generator, namely the rear turn signals and the cyclops light, have had the incandescent bulbs replaced with LEDs to prevent sparking.

- There is a hydrogen sensor in the trunk that turns on exhaust fans if the hydrogen concentration reaches 25% of the lower explosive limit[2] (LEL) and shuts the hydrogen generator down if the concentration reaches 50% of the LEL.

The flexible stainless steel tubing that carries H_2 from the hydrogen generator system to the fuel cell compartment is somewhat exposed and there is the possibility of it being eroded or otherwise damaged by road debris. Care should be taken to secure it as much as possible within the vehicle frame rails to minimize its exposure.

[2] For gases which form flammable mixtures with air, there are minimum and maximum concentrations below/above which propagation of flame does not occur on contact with a source of ignition. These boundary-line mixtures are known as the "lower and upper flammability limits" (LFL and UFL) or the "lower and upper explosive limits" (LEL and UEL), and are usually expressed in terms of percentage by volume of the gas in air. The LEL for hydrogen is about 4% in air.

APPENDIX

Materials Safety Data Sheets for
Sodium borohydride ($NaBH_4$)
and
Sodium *meta*borate ($NaBO_2$)

APPENDIX A

Materials Safety Data Sheets for:
Sodium borohydride ($NaBH_4$)
and
Sodium *meta*borate ($NaBO_2$)

Please reduce your browser font size for better viewing and printing.

MSDS *Material Safety Data Sheet*

24 Hour Emergency Telephone: 908-859-2151
CHEMTREC: 1-800-424-9300

National Response in Canada
CANUTEC: 613-996-6666

Outside U.S. and Canada
Chemtrec: 202-483-7616

From: Mallinckrodt Baker, Inc.
222 Red School Lane
Phillipsburg, NJ 08865

MALLINCKRODT J.T.Baker

NOTE: CHEMTREC, CANUTEC and National Response Center emergency numbers to be used only in the event of chemical emergencies involving a spill, leak, fire, exposure or accident involving chemicals.

All non-emergency questions should be directed to Customer Service (1-800-582-2537) for assistance.

SODIUM BOROHYDRIDE

MSDS Number: S3146 — *Effective Date: 11/17/99*

1. Product Identification

Synonyms: Sodium tetrahydroborate
CAS No.: 16940-66-2
Molecular Weight: 37.83
Chemical Formula: $NaBH_4$
Product Codes:
J.T. Baker: V023
Mallinckrodt: E823

2. Composition/Information on Ingredients

Ingredient	CAS No	Percent	Hazardous
Sodium Borohydride	16940-66-2	98 - 100%	Yes

3. Hazards Identification

Emergency Overview

DANGER! CORROSIVE. CAUSES BURNS TO ANY AREA OF CONTACT. HARMFUL IF SWALLOWED, INHALED OR ABSORBED THROUGH SKIN. FLAMMABLE SOLID. DANGEROUS WHEN WET.

J.T. Baker SAF-T-DATA(tm) Ratings (Provided here for your convenience)

Health Rating: 2 - Moderate

Flammability Rating: 2 - Moderate
Reactivity Rating: 3 - Severe (Water Reactive)
Contact Rating: 3 - Severe (Corrosive)
Lab Protective Equip: GOGGLES & SHIELD; LAB COAT & APRON; VENT HOOD; PROPER GLOVES; CLASS B EXTINGUISHER
Storage Color Code: Red (Flammable)

Potential Health Effects

Information on the human health effects from exposure to this substance is limited.

Inhalation:
Inhalation produces damaging effects on the mucous membranes and upper respiratory tract. Symptoms may include irritation of the nose and throat, and labored breathing. May cause lung edema, a medical emergency.
Ingestion:
Corrosive. Swallowing can cause severe burns of the mouth, throat, and stomach. Can cause sore throat, vomiting, diarrhea.
Skin Contact:
Severe irritation or skin burns can result from contact with wet material or contact by moist skin.
Eye Contact:
Corrosive. Contact can cause blurred vision, redness, pain and severe tissue burns.
Chronic Exposure:
No information found.
Aggravation of Pre-existing Conditions:
No information found.

4. First Aid Measures

Inhalation:
Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention immediately.
Ingestion:
If swallowed, DO NOT INDUCE VOMITING. Give large quantities of water. Never give anything by mouth to an unconscious person. Get medical attention immediately.
Skin Contact:
Wipe off excess material from skin then immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Get medical attention immediately. Wash clothing before reuse. Thoroughly clean shoes before reuse.

Eye Contact:
Immediately flush eyes with plenty of water for at least 15 minutes, lifting lower and upper eyelids occasionally. Get medical attention immediately.

5. Fire Fighting Measures

Fire:
Supports combustion. Flammable solid. Can ignite in air from an open flame, continuing to burn as hydrogen is evolved.

It reacts with water or steam to produce flammable hydrogen.
Explosion:
An explosion can occur by spontaneous ignition of the gases released from a saturated solution of sodium borohydride in dimethylformamide at 17C.
Fire Extinguishing Media:
Dry chemical or pulverized dolomite. DO NOT USE WATER, CARBON DIOXIDE, HALOCARBON or Wet Chemical Extinguishers.
Special Information:
In the event of a fire, wear full protective clothing and NIOSH-approved self-contained breathing apparatus with full facepiece operated in the pressure demand or other positive pressure mode.

6. Accidental Release Measures

Notify safety personnel of spills. Remove sources of heat or ignition. Provide explosion-proof ventilation. Clean up personnel need protection against contact with or inhalation of sodium borohydride. Collect solid for recovery or disposal, avoiding dust generation and using non-sparking tools. Liquid spills should be absorbed with sand or dolomite and picked up for disposal. Do not flush powder or solutions to sewer or watercourse. Disposal: Sodium borohydride can be decomposed by carefully adding diluted acetic acid or acetone to a water dispersion of the scrap. (Provide venting for hydrogen emission.) The residues are borates.

7. Handling and Storage

Protect against physical damage. Store in a cool, dry well-ventilated location, away from any area where the fire hazard may be acute. Outside or detached storage is preferred. Separate from incompatibles. Containers should be bonded and grounded for transfers to avoid static sparks. Storage and use areas should be No Smoking areas. Use non-sparking type tools and equipment, including explosion proof ventilation. PROTECT FROM MOISTURE. Containers of this material may be hazardous when empty since they retain product residues (dust, solids); observe all warnings and precautions listed for the product. Do Not attempt to clean empty containers since residue is difficult to remove. Do not pressurize, cut, weld, braze, solder, drill, grind or expose such containers to heat, sparks, flame, static electricity or other sources of ignition: they may explode and cause injury or death.

8. Exposure Controls/Personal Protection

Airborne Exposure Limits:
None established.
Ventilation System:
A system of local and/or general exhaust is recommended to keep employee exposures as low as possible. Local exhaust ventilation is generally preferred because it can control the emissions of the contaminant at its source, preventing dispersion of it into the general work area. Please refer to the ACGIH document, ***Industrial Ventilation, A Manual of Recommended Practices***, most recent edition, for details.
Personal Respirators (NIOSH Approved):
For conditions of use where exposure to the dust or mist is apparent, a half-face dust/mist

respirator may be worn. For emergencies or instances where the exposure levels are not known, use a full-face positive-pressure, air-supplied respirator. WARNING: Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.
Skin Protection:
Wear impervious protective clothing, including boots, gloves, lab coat, apron or coveralls, as appropriate, to prevent skin contact.
Eye Protection:
Use chemical safety goggles and/or full face shield where dusting or splashing of solutions is possible. Maintain eye wash fountain and quick-drench facilities in work area.

9. Physical and Chemical Properties

Appearance:
White to gray-white microcrystalline powder or lumps.
Odor:
Odorless.
Solubility:
Reacts with hot water; soluble in water
Specific Gravity:
1.074
pH:
No information found.
% Volatiles by volume @ 21C (70F):
0
Boiling Point:
400C (752F) Decomposes slowly
Melting Point:
36C (97F)
Vapor Density (Air=1):
1.3
Vapor Pressure (mm Hg):
No information found.
Evaporation Rate (BuAc=1):
No information found.

10. Stability and Reactivity

Stability:
Hygroscopic. Stable in dry air to 300C; decomposes slowly in moist air or in vacuum at 400C.
Hazardous Decomposition Products:
Sodium oxide and hydrogen gas.
Hazardous Polymerization:
Will not occur.
Incompatibilities:
Reacts with water to evolve hydrogen and sodium hydroxide. Heat decomposes it to release hydrogen gas. May react slowly or vigorously with acids or certain transition metal catalysts to liberate hydrogen. Incompatible with oxidizing agents, sulfuric acid, ruthenium salt, metal salts and palladium.
Conditions to Avoid:
Moisture, heat, flame, ignition sources, air and incompatibles.

11. Toxicological Information

No LD50/LC50 information found relating to normal routes of occupational exposure.

--------\Cancer Lists\--

Ingredient	---NTP Carcinogen--- Known	Anticipated	IARC Category
Sodium Borohydride (16940-66-2)	No	No	None

12. Ecological Information

Environmental Fate:
No information found.
Environmental Toxicity:
No information found.

13. Disposal Considerations

Whatever cannot be saved for recovery or recycling should be handled as hazardous waste and sent to a RCRA approved waste facility. Processing, use or contamination of this product may change the waste management options. State and local disposal regulations may differ from federal disposal regulations. Dispose of container and unused contents in accordance with federal, state and local requirements.

14. Transport Information

Domestic (Land, D.O.T.)

Proper Shipping Name: SODIUM BOROHYDRIDE
Hazard Class: 4.3
UN/NA: UN1426
Packing Group: I
Information reported for product/size: 100G

International (Water, I.M.O.)

Proper Shipping Name: SODIUM BOROHYDRIDE
Hazard Class: 4.3
UN/NA: UN1426
Packing Group: I
Information reported for product/size: 100G

International (Air, I.C.A.O.)

Proper Shipping Name: SODIUM BOROHYDRIDE

Hazard Class: 4.3
UN/NA: UN1426
Packing Group: I
Information reported for product/size: 100G

15. Regulatory Information

--------\Chemical Inventory Status - Part 1\--------

Ingredient	TSCA	EC	Japan	Australia
Sodium Borohydride (16940-66-2)	Yes	Yes	Yes	Yes

--------\Chemical Inventory Status - Part 2\--------

Ingredient	Korea	--Canada-- DSL	--Canada-- NDSL	Phil.
Sodium Borohydride (16940-66-2)	Yes	Yes	No	Yes

--------\Federal, State & International Regulations - Part 1\--------

Ingredient	-SARA 302- RQ	-SARA 302- TPQ	------SARA 313------ List	------SARA 313------ Chemical Catg.
Sodium Borohydride (16940-66-2)	No	No	No	No

--------\Federal, State & International Regulations - Part 2\--------

Ingredient	CERCLA	-RCRA- 261.33	-TSCA- 8(d)
Sodium Borohydride (16940-66-2)	No	No	No

Chemical Weapons Convention: No TSCA 12(b): No CDTA: No
SARA 311/312: Acute: Yes Chronic: No Fire: Yes Pressure: No
Reactivity: Yes (Pure / Solid)

Australian Hazchem Code: 2R
Poison Schedule: No information found.
WHMIS:
This MSDS has been prepared according to the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all of the information required by the CPR.

16. Other Information

NFPA Ratings: Health: 3 Flammability: 1 Reactivity: 2 Other: **Water reactive**
Label Hazard Warning:
DANGER! CORROSIVE. CAUSES BURNS TO ANY AREA OF CONTACT.
HARMFUL IF SWALLOWED, INHALED OR ABSORBED THROUGH SKIN.
FLAMMABLE SOLID. DANGEROUS WHEN WET.
Label Precautions:
Keep away from heat, sparks, flame and moisture.
Do not get in eyes, on skin, or on clothing.
Do not breathe dust.
Keep container closed.

Use only with adequate ventilation.
Wash thoroughly after handling.
Label First Aid:
In case of contact, wipe off excess material from skin then immediately flush eyes or skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash clothing before reuse. If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. If swallowed, DO NOT INDUCE VOMITING. Give large quantities of water. Never give anything by mouth to an unconscious person. In all cases get medical attention immediately.
Product Use:
Laboratory Reagent.
Revision Information:
No changes.
Disclaimer:
****

****

Prepared by: Strategic Services Division
Phone Number: (314) 539-1600 (U.S.A.)

Product Number:**228702**
Product Name:**Sodium metaborate,hydrate**

Valid 08/2000 - 10/2000

Description / Pricing
Cert. of Analysis
MSDS

Print Preview
Bulk Quote
Ask A Scientist

Aldrich Chemical Co., Inc.
1001 West St. Paul
Milwaukee, WI 53233 USA
Tel: 414-273-3850

```
M A T E R I A L   S A F E T Y   D A T A   S H E E T
SECTION 1. - - - - - - - - - CHEMICAL IDENTIFICATION- - - - - - - - -
    CATALOG #:          228702
    NAME:               SODIUM METABORATE HYDRATE
SECTION 2. - - - - - COMPOSITION/INFORMATION ON INGREDIENTS - - - - - -
    CAS #: 15293-77-3
    MF: BNAO2
    EC NO:  231-891-6
  SYNONYMS
    SODIUM METABORATE *
SECTION 3. - - - - - - - - - - HAZARDS IDENTIFICATION - - - - - - - - -
  LABEL PRECAUTIONARY STATEMENTS
    IRRITANT
    IRRITATING TO EYES, RESPIRATORY SYSTEM AND SKIN.
    IN CASE OF CONTACT WITH EYES, RINSE IMMEDIATELY WITH PLENTY OF
    WATER AND SEEK MEDICAL ADVICE.
    WEAR SUITABLE PROTECTIVE CLOTHING.
SECTION 4. - - - - - - - - - - FIRST-AID MEASURES- - - - - - - - - - -
    IN CASE OF CONTACT, IMMEDIATELY FLUSH EYES WITH COPIOUS AMOUNTS OF
    WATER FOR AT LEAST 15 MINUTES.
    IN CASE OF CONTACT, IMMEDIATELY WASH SKIN WITH SOAP AND COPIOUS
    AMOUNTS OF WATER.
    IF INHALED, REMOVE TO FRESH AIR. IF NOT BREATHING GIVE ARTIFICIAL
    RESPIRATION. IF BREATHING IS DIFFICULT, GIVE OXYGEN.
    IF SWALLOWED, WASH OUT MOUTH WITH WATER PROVIDED PERSON IS CONSCIOUS.
    CALL A PHYSICIAN.
    WASH CONTAMINATED CLOTHING BEFORE REUSE.
SECTION 5. - - - - - - - - - FIRE FIGHTING MEASURES - - - - - - - - - -
  EXTINGUISHING MEDIA
    WATER SPRAY.
    CARBON DIOXIDE, DRY CHEMICAL POWDER OR APPROPRIATE FOAM.
  SPECIAL FIREFIGHTING PROCEDURES
    WEAR SELF-CONTAINED BREATHING APPARATUS AND PROTECTIVE CLOTHING TO
    PREVENT CONTACT WITH SKIN AND EYES.
  UNUSUAL FIRE AND EXPLOSIONS HAZARDS
    EMITS TOXIC FUMES UNDER FIRE CONDITIONS.
SECTION 6. - - - - - - - - ACCIDENTAL RELEASE MEASURES- - - - - - - - -
    WEAR RESPIRATOR, CHEMICAL SAFETY GOGGLES, RUBBER BOOTS AND HEAVY
    RUBBER GLOVES.
    SWEEP UP, PLACE IN A BAG AND HOLD FOR WASTE DISPOSAL.
    AVOID RAISING DUST.
    VENTILATE AREA AND WASH SPILL SITE AFTER MATERIAL PICKUP IS COMPLETE.
SECTION 7. - - - - - - - - - - HANDLING AND STORAGE- - - - - - - - - - -
    REFER TO SECTION 8.
SECTION 8. - - - - - - EXPOSURE CONTROLS/PERSONAL PROTECTION- - - - - -
    CHEMICAL SAFETY GOGGLES.
    COMPATIBLE CHEMICAL-RESISTANT GLOVES.
    NIOSH/MSHA-APPROVED RESPIRATOR.
    SAFETY SHOWER AND EYE BATH.
    MECHANICAL EXHAUST REQUIRED.
    DO NOT BREATHE DUST.
    AVOID CONTACT WITH EYES, SKIN AND CLOTHING.
    AVOID PROLONGED OR REPEATED EXPOSURE.
    WASH THOROUGHLY AFTER HANDLING.
    KEEP TIGHTLY CLOSED.
    STORE IN A COOL DRY PLACE.
SECTION 9. - - - - - - - PHYSICAL AND CHEMICAL PROPERTIES - - - - - - -
  APPEARANCE AND ODOR
    WHITE GRANULAR POWDER
SECTION 10. - - - - - - - - -STABILITY AND REACTIVITY - - - - - - - - -
  INCOMPATIBILITIES
    STRONG OXIDIZING AGENTS
  HAZARDOUS COMBUSTION OR DECOMPOSITION PRODUCTS
    NATURE OF DECOMPOSITION PRODUCTS NOT KNOWN.
SECTION 11. - - - - - - - - - TOXICOLOGICAL INFORMATION - - - - - - - -
  ACUTE EFFECTS
    MAY BE HARMFUL BY INHALATION, INGESTION, OR SKIN ABSORPTION.
```

CAUSES EYE AND SKIN IRRITATION.
MATERIAL IS IRRITATING TO MUCOUS MEMBRANES AND UPPER RESPIRATORY TRACT.
TO THE BEST OF OUR KNOWLEDGE, THE CHEMICAL, PHYSICAL, AND TOXICOLOGICAL PROPERTIES HAVE NOT BEEN THOROUGHLY INVESTIGATED.

RTECS #: ED4640000
BORIC ACID, MONOSODIUM SALT

TOXICITY DATA
ORL-RAT LD50:2330 MG/KG PEMNDP 9,88,1991
ONLY SELECTED REGISTRY OF TOXIC EFFECTS OF CHEMICAL SUBSTANCES (RTECS) DATA IS PRESENTED HERE. SEE ACTUAL ENTRY IN RTECS FOR COMPLETE INFORMATION.

SECTION 12. - - - - - - - - - ECOLOGICAL INFORMATION - - - - - - - - - -
DATA NOT YET AVAILABLE.

SECTION 13. - - - - - - - - - - DISPOSAL CONSIDERATIONS - - - - - - - - -
CONTACT A LICENSED PROFESSIONAL WASTE DISPOSAL SERVICE TO DISPOSE OF THIS MATERIAL.
OBSERVE ALL FEDERAL, STATE AND LOCAL ENVIRONMENTAL REGULATIONS.

SECTION 14. - - - - - - - - - - - TRANSPORT INFORMATION - - - - - - - - -
CONTACT ALDRICH CHEMICAL COMPANY FOR TRANSPORTATION INFORMATION.

SECTION 15. - - - - - - - - - - REGULATORY INFORMATION - - - - - - - - - -
EUROPEAN INFORMATION
IRRITANT
R 36/37/38
IRRITATING TO EYES, RESPIRATORY SYSTEM AND SKIN.
S 26
IN CASE OF CONTACT WITH EYES, RINSE IMMEDIATELY WITH PLENTY OF WATER AND SEEK MEDICAL ADVICE.
S 36
WEAR SUITABLE PROTECTIVE CLOTHING.

REVIEWS, STANDARDS, AND REGULATIONS
OEL=MAK
EPA FIFRA 1988 PESTICIDE SUBJECT TO REGISTRATION OR RE-REGISTRATION FEREAC 54,7740,1989
NOHS 1974: HZD 80073; NIS 33; TNF 3745; NOS 27; TNE 10520
NOES 1983: HZD 80073; NIS 63; TNF 8275; NOS 56; TNE 68763; TFE 13782
EPA TSCA SECTION 8(B) CHEMICAL INVENTORY
EPA TSCA TEST SUBMISSION (TSCATS) DATA BASE, DECEMBER 1999

SECTION 16. - - - - - - - - - - - OTHER INFORMATION- - - - - - - - - - -
THE ABOVE INFORMATION IS BELIEVED TO BE CORRECT BUT DOES NOT PURPORT TO BE ALL INCLUSIVE AND SHALL BE USED ONLY AS A GUIDE. SIGMA, ALDRICH, FLUKA SHALL NOT BE HELD LIABLE FOR ANY DAMAGE RESULTING FROM HANDLING OR FROM CONTACT WITH THE ABOVE PRODUCT. SEE REVERSE SIDE OF INVOICE OR PACKING SLIP FOR ADDITIONAL TERMS AND CONDITIONS OF SALE.

Future Fuels Consulting

D. Eatontown Police and Volunteer Fire Department Reports.

Eatontown Police Department Records Bureau

47 Broad Street, Eatontown New Jersey 07724
(732) 389-7635

Fax

To:	Art Vatsky	**From:**	J. Rolly
Fax:	201-907-0074	**Pages:**	3
Phone:		**Date:**	11/09/00
Re:		**CC:**	

☐ **Urgent** ☐ **For Review** ☐ **Please Comment** ☐ **Please Reply** ☐ **Please Recycle**

- **Comments:**

NOTE: FIRE DEPT REPORT IS ATTACHED. WE HAD A COPY

Confidentiality Notice

The information contained in this facsimile transmission from the EATONTOWN POLICE DEPARTMENT may be privileged and confidential and is intended for the sole use of the persons or entities named on this transmission, the dissemination, distributions, copying or use of the information it contains is strictly prohibited. If you have received this transmission in error, please call the sender immediately to arrange for the returned of this information.

Visit Us On The Web *www.eatontownnj.com*

COUNTY OF MONMOUTH
OFFICE OF THE FIRE MARSHAL

1027 HIGHWAY 33 EAST, FREEHOLD, NEW JERSEY 07728-9998
732-938-5689

DATE OF INVESTIGATION: 5-9-00 DATE OF INCIDENT: 5-9-00

TIME OF ALARM: 16:41

LOCATION OF INCIDENT: 1 Industrial Way West Eatontown

MAKE OF VEHICLE: Mercury YEAR: 1994 MODEL: Sable

REGISTRATION: Genesis N.J. VIN: 1MECM54P2RS600251

OWNER Rutgers Univ. TELEPHONE: 542-4000

ADDRESS: Kilmer Campus BC 4088 Rm 102 New Brunswick N.J. 08903

OPERATOR: Not operated TELEPHONE: N/A

ADDRESS: N/A

FIRE DEPARTMENT: Eatontown INCIDENT COMMANDER: J. Miller

WEATHER: Clear TEMP: 85 - 88 WIND DIRE/SPEED: W 0 - 5

AREA OF ORIGIN: Rear under trunk CAUSE OF IGNITION: Electrical

PHOTOGRAPHS BY: N/A

EVIDENCE COLLECTED: No BY: N/A

DESCRIPTION OF EVIDENCE: N/A CUSTODY OF EVIDENCE: N/A

INVESTIGATING POLICE OFFICER: Sgt. D. Bennett 210

INJURIES: 0 BURNS: 0 DEATHS: 0

NOTIFIED BY: Eatontown P. D. TIME OF NOTIFICATION: 16:44

INVESTIGATORS RESPONDING: P. Payne

REPORT COMPLETED BY: P. Payne ID NUMBER: 933

COUNTY OF MONMOUTH - OFFICE OF THE FIRE MARSHAL

CONTINUATION

1. Alarm No. 5-9-00	2. State Report No. 1 Industrial Way West Eatontown	3. Fire Marshal Case No. 2000-5824

OVERVIEW: The undersigned was requested by Eatontown Police Dispatcher to respond to Millennium Cell, 1 Industrial Way West Eatontown, for the purpose of investigating a vehicle fire which occurred in the building. Upon arrival on location the undersigned was briefed by Fire Chief J. Miller and Sgt. D. Bennett Eatontown Police Dept.

VEHICLE: 1994 Mercury Sable, New Jersey registration, GENESIS, VIN 1MECM54P2RS600251. Registered to Rutgers University BC 4088 Rm. 102 New Brunswick 08903. Vehicle insured by J & H Marsh & McLennan 44 Whippany Rd. P.O. Box 1966 Morristown N.J. 07962 Comp. Code 357.

INVESTIGATION: Kevin Bellotti 75 Hudson Ave. Middletown N.J. telephone 495-2238, an employee of Millennium Cell, called 911 and reported a fire in a prototype vehicle located in the Millennium Cell building.
The vehicle an alternative fuel project vehicle, was being worked on by a team of employees of Millennium Cell and Rutgers University. A short circuit occurred in the wiring system of the vehicle causing a fire in the bank of batteries used to power the vehicle.
The battery assembly detached from the vehicle and was located on the floor of the business, east section of the building. Heat and smoke damage occurred to the rear under section of the vehicle.
The fire was extinguished using portable fire extinguishers.
The vehicle was removed from the building by Pro Craft 1317 Eatontown Blvd. Telephone 542-7171.

CONCLUSION: The fire is determined to be of accidental nature at this time.

PAGE # of PAGE #

2	2

Name **PHILIP C. PAYNE, MCDFM** Badge No. **93-3** Date Report **5-10-00** Reviewed By

signature [signature]

TOTAL P.04

APPENDIX 3 - MSDS AND PRODUCT INFORMATION [19]

SIGMA-ALDRICH

Material Safety Data Sheet

Date Printed: 06/05/2001
Date Updated: 02/21/2001
Version 1.10

Section 1 - Product and Company Information

Product Name	SODIUM BOROHYDRIDE, POWDER, 98%		
Product Number	452882		
Brand	Aldrich Chemical		
Company	Sigma-Aldrich		
Street Address	3050 Spruce Street		
City, State, Zip, Country	St. Louis, MO 63103 US		
Technical Phone:	314 771 5765	**Emergency Phone:**	414 273 3850 Ext.5996
Fax:	800 325 5052		

Section 2 - Composition/Information on Ingredient

Substance Name	CAS #	SARA 313
SODIUM BOROHYDRIDE	16940-66-2	No

Formula BH4.Na

Synonyms Borohydrure de sodium (French), Borol, Hidkitex DF, Sodium borohydrate, Sodium hydroborate, Sodium tetrahydridoborate(1-), Sodium tetrahydroborate(1-)

Section 3 - Hazards Identification

Emergency Overview
Flammable (USA) Highly Flammable (EU). Highly Toxic (USA) Very Toxic (EU).
Contact with water liberates extremely flammable gases. Toxic in contact with skin and if swallowed. Very toxic by inhalation. Causes burns.

HMIS Rating

Health: 3	Flammability: 0	Reactivity: 2	Special Hazard(s) : Water reactive

NFPA Rating

Health: 3	Flammability: 0	Reactivity: 2	Special Hazard(s) : Water reactive

For additional information on toxicity, please refer to Section 11.

Section 4 - First Aid Measures

Immediate Treatment - Work Site
In case of contact, immediately flush eyes or skin with copious amounts of water for at least 15 minutes while removing contaminated clothing and shoes.

Oral Exposure
If swallowed, wash out mouth with water provided person is conscious. Call a physician.

Inhalation Exposure
If inhaled, remove to fresh air. If not breathing give artificial respiration. If breathing is difficult, give oxygen.

Section 5 - Fire Fighting Measures

Explosion Hazards
Material readily reacts with water generating flammable and/or explosive hydrogen gas

Conditions of Flammability
Reacts with water to liberate flammable and/or explosive gas. Reacts with metals to liberate flammable hydrogen gas.

Explosion Limits: **Lower:** 3.02 %

Autoignition Temp: N/A

Extinguishing Media
Suitable
Dry chemical powder.
Unsuitable
Do not use water, foam, or carbon dioxide. Do not use halocarbon extinguishers.

Firefighting
Protective Equipment
Wear self-contained breathing apparatus and protective clothing to prevent contact with skin and eyes.
Specific Hazard(s)
Flammable solid. Emits toxic fumes under fire conditions.

Section 6 - Accidental Release Measures

Procedure to be Followed in Case of Leak or Spill
Evacuate area.

Procedure(s) of Personal Precaution(s)
Wear self-contained breathing apparatus, rubber boots, and heavy rubber gloves.

Methods for Cleaning Up
Sweep up, place in a bag and hold for waste disposal. Avoid raising dust. Ventilate area and wash spill site after material pickup is complete.

Section 7 - Handling and Storage

Handling
User Exposure
Do not breathe dust. Do not get in eyes, on skin, on clothing. Avoid prolonged or repeated exposure.

Storage
Suitable
Keep tightly closed. Store in a cool dry place.
Incompatible Materials
Reacts violently with water, Do not allow contact with water.

Special Requirements
Do not allow water to enter container because of violent reaction Protect from heat.

Section 8 - Exposure Controls / PPE

Engineering Controls
Safety shower and eye bath. Use only in a chemical fume hood.

Personal Protective Equipment
Respiratory
NIOSH/MSHA-approved respirator.

Hand
Compatible chemical-resistant gloves.
Eye
Chemical safety goggles.
Skin-Specific
Chemical resistant apron.
Other
Faceshield (8-inch minimum).

General Hygiene Measures
Wash contaminated clothing before reuse. Wash thoroughly after handling.

Section 9 - Physical/Chemical Properties

Appearance

Physical State	**Color**
Solid	White

Molecular Weight:	37.83 AMU
pH	N/A
BP/BP Range	N/A
MP/MP Range	300 °C
Freezing Point	N/A
Vapor Pressure	N/A
Vapor Density	N/A
Saturated Vapor Conc.	N/A
SG/Density	1.074 g/cm3
Bulk Density	N/A
Odor Threshold	N/A
Volatile%	N/A
VOC Content	N/A
Water Content	N/A
Solvent Content	N/A
Evaporation Rate	N/A
Viscosity	N/A
Partition Coefficient	N/A
Decomposition Temp.	N/A
Flash Point °F	N/A
Flash Point °C	N/A
Explosion Limits	Lower: 3.02 %
Autoignition Temp	N/A
Solubility	N/A

Section 10 - Stability and Reactivity

Stability
Stable
Stable.
Conditions to Avoid
Do not allow water to enter container because of violent reaction Protect from heat.
Materials to Avoid
Oxidizing agents, Chemically active metals, Acids, Reacts violently with water.

Hazardous Decomposition Products
Hazardous Decomposition Products
Borane/boron oxides, Sodium oxide, Hydrogen gas.
Hazardous Decomposition Products Formed Upon Contact with Water
Material readily reacts with water generating flammable and/or explosive hydrogen gas.

Hazardous Polymerization

Hazardous Polymerization

Will not occur.

Section 11 - Toxicological Information

Route of Exposure

Skin Contact

Causes burns.

Skin Absorption

Toxic if absorbed through skin.

Eye Contact

Causes burns.

Inhalation

May be fatal if inhaled. Material is extremely destructive to the tissue of the mucous membranes and upper respiratory tract.

Ingestion

Toxic if swallowed.

Signs and Symptoms of Exposure

Material is extremely destructive to tissue of the mucous membranes and upper respiratory tract, eyes, and skin. Inhalation may result in spasm, inflammation and edema of the larynx and bronchi, chemical pneumonitis, and pulmonary edema. Symptoms of exposure may include burning sensation, coughing, wheezing, laryngitis, shortness of breath, headache, nausea, and vomiting. To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

RTECS Number: ED3325000

Toxicity Data

Oral - Rat: 162 mg/kg(LD50)

Skin - Rabbit: 230 mg/kg(LD50)

Inhalation - Rat: 36 mg/m3(LC50)

Oral - Rat: 162 mg/kg (LD50)
Remarks: Sense Organs and Special Senses (Nose, Eye, Ear, and Taste):Eye:Other.
Behavioral:Convulsions or effect on seizure threshold.
Lungs, Thorax, or Respiration:Structural or functional change in trachea or bronchi.

Inhalation - Rat: 36 mg/m3 (LC50)
Remarks: Sense Organs and Special Senses (Nose, Eye, Ear, and Taste):Eye:Other.
Behavioral:Convulsions or effect on seizure threshold.
Lungs, Thorax, or Respiration:Structural or functional change in trachea or bronchi.

Intraperitoneal - Rat: 18 MG/KG (LD50)

Subcutaneous - Rat: 177 MG/KG (LD50)
Remarks: Sense Organs and Special Senses (Nose, Eye, Ear, and Taste):Eye:Other.
Behavioral:Convulsions or effect on seizure threshold.
Lungs, Thorax, or Respiration:Structural or functional change in trachea or bronchi.

Oral - Mouse: 50 mg/kg (LD50)
Remarks: Sense Organs and Special Senses (Nose, Eye, Ear, and Taste):Eye:Other.
Behavioral:Convulsions or effect on seizure threshold.
Lungs, Thorax, or Respiration:Structural or functional change in trachea or bronchi.

Oral - Rabbit: 50 mg/kg (LD50)
Remarks: Sense Organs and Special Senses (Nose, Eye, Ear, and Taste):Eye:Other.
Behavioral:Convulsions or effect on seizure threshold.
Lungs, Thorax, or Respiration:Structural or functional change in trachea or bronchi.

Skin - Rabbit: 230 mg/kg (LD50)
Remarks: Sense Organs and Special Senses (Nose, Eye, Ear, and Taste):Eye:Other.
Behavioral:Convulsions or effect on seizure threshold.
Lungs, Thorax, or Respiration:Structural or functional change in trachea or bronchi.

Section 12 - Ecological Information

No data available.

Additional Results/Data from Relevent Scientific Experiments
Avoid contamination of the environment

Section 13 - Disposal Considerations

Appropriate Method of Disposal of Substance or Preparation
Contact a licensed professional waste disposal service to dispose of this material.
Observe all federal, state, and local environmental regulations.

Section 14 - Transport Information

DOT
Proper Shipping Name: Sodium borohydride
UN#: 1426
Class: 4.3
Packing Group: Packing Group I
Hazard Label: Dangerous when wet.
PIH: Not PIH

IATA
Proper Shipping Name: Sodium borohydride
IATA Number: 1426
Hazard Class: 4.3
Packing Group: I
Not Allowed - Aircraft: Cargo aircraft only. Not permitted on passenger aircraft.

Section 15 - Regulatory Information

EU Additional Classification
Symbol of Danger: F T+
Indication of Danger
Highly Flammable. Very toxic.
Risk Statements **R:** 15 24/25 26 34
Contact with water liberates extremely flammable gases. Toxic in contact with skin and if swallowed. Very toxic by inhalation. Causes burns.
Safety Statements **S:** 22 26 36/37/39 43 45
Do not breathe dust. In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. Wear suitable protective clothing, gloves, and eye/face protection. In case of fire, use dry sand. Never use water. In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).

US Classification and Label Text
Indication of Danger
Flammable (USA) Highly Flammable (EU). Highly Toxic (USA) Very Toxic (EU).
Risk Statements
Contact with water liberates extremely flammable gases. Toxic in contact with skin and if swallowed. Very toxic by inhalation. Causes burns.
Safety Statements
Do not breathe dust. In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).

United States Regulatory Information
SARA Listed: No

TSCA Inventory Item: Yes

Canada Regulatory Information
WHMIS Classification
This product has been classified in accordance with the hazard criteria of the CPR, and the MSDS contains all the information

required by the CPR.

Section 16 - Other Information

Warranty

SIGMA-ALDRICH

Material Safety Data Sheet

Date Printed: 06/05/2001
Date Updated: 10/15/1999
Version 1.0

Section 1 - Product and Company Information

Product Name	SODIUM METABORATE TETRAHYDRATE		
Product Number	S0251		
Brand	Sigma Chemical		
Company	Sigma-Aldrich		
Street Address	3050 Spruce Street		
City, State, Zip, Country	St. Louis, MO, 63103, US		
Technical Phone:	314 771 5765	**Emergency Phone:**	414 273 3850 Ext.5996
Fax	800 325 5052		

Section 2 - Composition/Information on Ingredient

Substance Name	CAS #	SARA 313
SODIUM METABORATE TETRAHYDRATE	10555-76-7	No

Formula
Synonyms

Section 3 - Hazards Identification

Emergency Overview
Irritant.
Irritating to eyes, respiratory system, and skin.

HMIS Rating
Health: 1 Flammability: 0 Reactivity: 0

NFPA Ratings
Flammability: 0 Reactivity: 0

For additional information on toxicity, please refer to Section 11.

Section 4 - First Aid Measures

Oral Exposure
If swallowed, wash out mouth with water provided person is conscious. Call a physician.

Inhalation Exposure
If inhaled, remove to fresh air. If not breathing give artificial respiration. If breathing is difficult, give oxygen.

Dermal Exposure
In case of contact, immediately wash skin with soap and copious amounts of water.

Eye Exposure
In case of contact, immediately flush eyes with copious amounts of water for at least 15 minutes.

Section 5 - Fire Fighting Measures

Autoignition Temp: N/A **Flammability:** N/A

Extinguishing Media
Suitable
Water spray. Carbon dioxide, dry chemical powder, or appropriate foam.

Firefighting
Protective Equipment
Wear self-contained breathing apparatus and protective clothing to prevent contact with skin and eyes.
Specific Hazard(s)
Emits toxic fumes under fire conditions.

Exposure Hazard(s)
Material
Irritant.

Section 6 - Accidental Release Measures

Procedure(s) of Personal Precaution(s)
Wear respirator, chemical safety goggles, rubber boots, and heavy rubber gloves.

Methods for Cleaning Up
Sweep up, place in a bag and hold for waste disposal. Avoid raising dust. Ventilate area and wash spill site after material pickup is complete.

Section 7 - Handling and Storage

Handling
User Exposure
Do not breathe dust. Avoid contact with eyes, skin, and clothing. Avoid prolonged or repeated exposure.

Storage
Suitable
Keep tightly closed. Store in a cool dry place.

Section 8 - Exposure Controls / PPE

Engineering Controls
Safety shower and eye bath. Mechanical exhaust required.

Personal Protective Equipment
Respiratory
NIOSH/MSHA-approved respirator.
Hand
Compatible chemical-resistant gloves.
Eye
Chemical safety goggles.

General Hygiene Measures
Wash contaminated clothing before reuse. Wash thoroughly after handling.

Section 9 - Physical/Chemical Properties

Appearance

	Color	Form
	White	Fine crystals

Molecular Weight: N/A

Property	Value
pH	N/A
BP/BP Range	N/A
MP/MP Range	N/A
Freezing Point	N/A
Vapor Pressure	N/A
Vapor Density	N/A
Saturated Vapor Conc.	N/A
SG/Density	N/A
Bulk Density	N/A
Odor Threshold	N/A
Volatile%	N/A
VOC Content	N/A
Water Content	N/A
Solvent Content	N/A
Evaporation Rate	N/A
Viscosity	N/A
Partition Coefficient	N/A
Decomposition Temp.	N/A
Flash Point °F	N/A
Flash Point °C	N/A
Explosion Limits	N/A
Autoignition Temp	N/A
Solubility	N/A

Section 10 - Stability and Reactivity

Stability

Stable

Stable.

Conditions of Instability

May decompose on exposure to air Reacts with carbon dioxide in air to form sodium carbonate and sodium tetraborate

Materials to Avoid

Strong oxidizing agents.

Hazardous Decomposition Products

Hazardous Decomposition Products

Sodium/sodium oxides, Boron oxides.

Hazardous Polymerization

Hazardous Polymerization

Will not occur.

Section 11 - Toxicological Information

Route of Exposure

Inhalation

Material is irritating to mucous membranes and upper respiratory tract.

Multiple Routes

May be harmful by inhalation, ingestion, or skin absorption. Causes eye and skin irritation.

Signs and Symptoms of Exposure

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

RTECS Number:

Section 12 - Ecological Information

Section 13 - Disposal Considerations

Appropriate Method of Disposal of Substance or Preparation
For small quantities: cautiously add to a large stirred excess of water. Adjust the pH to neutral, separate any insoluble solids or liquids and package them for hazardous-waste disposal. Flush the aqueous solution down the drain with plenty of water. The hydrolysis and neutralization reactions may generate heat and fumes which can be controlled by the rate of addition.
Observe all federal, state, and local environmental regulations.

Section 14 - Transport Information

DOT
Proper Shipping Name: None
Non-Hazardous for Transport: This substance is considered to be non-hazardous for transport.

IATA
Proper Shipping Name: None
Non-Hazardous for Air Transport: Non-hazardous for air transport.

Section 15 - Regulatory Information

EU Additional Classification
Symbol of Danger: Xi
Indication of Danger
Irritant.
Risk Statements **R:** 36/37/38
Irritating to eyes, respiratory system, and skin.
Safety Statements **S:** 26 36
In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. Wear suitable protective clothing.

US Classification and Label Text
Indication of Danger
Irritant.
Risk Statements
Irritating to eyes, respiratory system, and skin.
Safety Statements
In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. Wear suitable protective clothing.

United States Regulatory Information
SARA 313 Listed: No

Section 16 - Other Information

Warranty
The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. Sigma-Aldrich Inc., shall not be held liable for any damage resulting from handling or from contact with the above product. See reverse side of invoice or packing slip for additional terms and conditions of sale.

APPENDIX 4 – COMMERCIALLY AVAILABLE SODIUM BOROHYDRIDE PRODUCT INFORMATION [20]

Synthesis, Intermediates, and Process Solutions

ROHM AND HAAS

VenPure® Powder

Product Description

A proprietary formulation of sodium borohydride designed for purification of organic chemicals. VenPure powder contains an anticaking agent and trace quantities of sodium hydroxide (NaOH) and sodium metaborate ($NaBO_2$).

Typical Properties

Molecular weight:	37.85
Specific gravity, 25°C:	1.074
Form:	White crystalline solid
Melting point:	Decomposes above 400°C without melting
Typical solubility:	
(g/100 g solvent @ 25° C)	
Water	55.0
Liquid ammonia	104.0
Ethanol (reacts slowly)	4.0
Dimethyl ether of diethylene glycol	5.5
Dimethylacetamide	14.0
Isopropylamine	6.0

Application

VenPure powder is a water soluble reducing agent exhibiting unique activity in organic and inorganic chemical systems. Due to ease of handling and high reducing power, this product is used extensively in a broad range of industrial applications. Major industrial applications include: reduction of carbonyl and peroxy compounds, reduction of metal ions, and removal of color, odor, and oxidation precursors in organic chemical products. Additional information on these and other applications of sodium borohydride is available from Morton International.

Recommended Use Level

The amount of VenPure products required for reduction depends upon the compound being reduced and the general reaction conditions. Reductions with VenPure products normally proceed as represented in the following typical reactions:

Organic: $NaBH_4 + 4R_2C{=}O + 2H_2O \rightarrow 4R_2CHOH$

Inorganic: $NaBH_4 + 8M^+ + 2H_2O \rightarrow 8M^o$

Under ideal reaction conditions, one mole of $NaBH_4$ (37.8 g) will reduce four moles of an aldehyde or ketone to the corresponding alcohol or provide eight electrons for the reduction of metallic ions. Thus, 37.8 pounds of VenPure powder will theoretically reduce 176 pounds of acetaldehyde to ethanol or 235 pounds of nickel ion (Ni^{+2}) to the free metal. However, under industrial reaction conditions, the use level of VenPure products will be greater than the stoichiometric level due to losses from side reactions, primarily hydrolysis/solvolysis. Consequently, the actual use level should be experimentally derived.

The rate and efficiency of reductions with VenPure products are dependent upon the concentration of the reactants, temperature, and pH. The reaction rate is generally more rapid at higher temperatures, however, satisfactory results can be obtained at low and moderate temperatures. One of the most important parameters in the efficient use of VenPure products is pH control. Reductions with VenPure products should be carried out at a pH of 10-11 or higher. If the pH is below 10, consumption of VenPure products may increase due to hydrolysis. Additional information on optimizing VenPure products use levels and reaction conditions is available from the VenPure Technical Services Group.

Availability

Six VenPure product forms are commercially available: VenPure powder, VenPure granules (10/40), VenPure granules (+10), VenPure caplets, VenPure solution (a stabilized water solution of 12% $NaBH_4$ and 40% NaOH) and VenPure K powder (KBH_4).

® registered trademarks of Rohm and Haas Company. *9/93*

Toxicity and First Aid

1. Composition:

	CAS Number
98% $NaBH_4$ minimum	16940-66-2

2. VenPure powder has an acute dermal LD_{50} on dry skin of 4-8 gm/kg, and is not a skin sensitizer. However, severe irritation and skin burns may result when VenPure products come into contact with moist skin. The acute oral LD_{50} of VenPure powder is 50-100 mg/kg. Sodium metaborate, the reaction or decomposition product of VenPure products, is considered slightly toxic orally (LD_{50}, 2000-4000 mg/kg), and non-toxic dermally.

3. All precautions should be taken against ingestion of VenPure products, inhalation of the dust, or contact with skin. In case of accidental contact with skin, the particles should be brushed off and the affected areas flooded with water. VenPure products and concentrated solutions of these are *very corrosive to the eye* and should be handled according to generally accepted procedures for corrosive chemicals. In case of accidental contact, *flush eyes with water and seek immediate medical attention.*

Product Handling and Storage

1. Personal Protection:
   Protective rubber gloves, clothing and safety goggles should always be worn when handling VenPure products and their solutions. Dust respirators should be worn when handling VenPure dry products.

2. Handling:
   VenPure dry products should be handled in the same manner as other *Division 4.3 Dangerous When Wet* materials. It is stable to shock and does not ignite on contact with moisture, but form a dihydrate which slowly hydrolyzes. VenPure powder is hygroscopic and should not be unnecessarily exposed to air or moisture. It is stable indefinitely in dry air or in sealed containers.

   Solutions of VenPure products will decompose and evolve hydrogen if overheated, subjected to neutral or acidic pH conditions, or brought into contact with oxidizers, metal salts or finely divided metallic precipitates of nickel, cobalt, copper, or iron. Reactions of VenPure products should always be carried out in adequately vented vessels with standard provisions for pressure relief. A nitrogen atmosphere is also recommended. Reactions of VenPure products should only be conducted in explosion proof equipment with proper grounding.

3. Storage:
   VenPure products should be stored in closed containers in a dry, cool and well ventilated area and kept separate from acids and oxidizing materials. Partially consumed containers should be carefully resealed.

   Solutions of VenPure products may be stored in stainless steel, mild steel, or approved fiberglass vessels that are adequately vented to the outside atmosphere. Caustic solutions of VenPure products should not be stored in vessels which react with sodium hydroxide, such as aluminum.

4. Firefighting:
   VenPure powder is classified as a *Division 4.3 Dangerous When Wet* solid. It will ignite in air from a free flame due to hydrogen formed from thermal decomposition, continuing to burn as hydrogen is evolved. VenPure products can also be ignited if they are brought in contact with acids, oxidizers, or transition metal salts or precipitates. The non-volatile product of combustion is sodium metaborate. Fire extinguishers available where VenPure products are stored or used should only be of the dry chemical type, such as those manufactured by Ansul Chemical Company or equivalent. *WATER, CARBON DIOXIDE OR HALOCARBON EXTINGUISHERS MUST NOT BE USED ON VENPURE PRODUCTS FIRES.*

Waste Disposal

1. VenPure products and their solutions containing unreacted $NaBH_4$ can be disposed of (hydrolyzed) by dissolving in a large excess of water, followed by slow addition of a dilute solution of acetic acid or acetone in a well ventilated area. Provisions should be made to safely vent hydrogen gas given off during the decomposition of unreacted VenPure products and their solutions. VenPure products and their solutions should not be flushed to the sewer.

2. In case of accidental spillage, absorb the VenPure product with an inert material such as sand or dolomite. Absorbed material should be allowed to weather in an outdoor disposal area or hydrolyzed as per above.

3. Any vessels which have been used for storage or reactions of VenPure products should be carefully vented, drained, and adequately flushed with water and purged with nitrogen and air before any repair operations are undertaken. Exposure to an open flame (e.g., welding torch) should be avoided. Morton International, Inc., should be contacted for more detailed procedures.

APPENDIX 5 – LIST OF PRIMARY VEHICLE COMPONENTS/SYSTEM MODIFICATIONS [21]

Table 6 List of primary vehicle component modifications

Modification	Functional Impact	Safety Impact
Components		
Subframe replaced with modified subframe from Tower Automotive	Equal- basic subframe design same Positive- lighterweight	Equal
Original 1993 Sable suspension parts replaced with 1998 Sable suspension parts	Equal- suspension mounting points similar, suspension capability similar	Equal
Coil spring dampers replaced with 1998 Lincoln Towncar air bag suspension	Positive-Lincoln system is active air dampening system; provides potentially better control and less vibration for new electronic systems	Equal
Front calipers, rotors, and baking plates replaced with custom racing versions	Positive- racing braking systems would provide better braking response under panic stop conditions. Also, provide weight reductions to vehicle.	Positive- better panic stop response Negative- may result in slightly less brake “feel” relative to original brake system
Rear rotors replaced with custom racing versions	Positive-less potential for brake fading under panic stops and less weight	Positive- less potential for brake fading under panic stops
Magnesium wheels used in place of original aluminum wheels	Positive-stronger, lighterweight wheels	Equal
Original tires replaced with Goodyear low rolling resistance tires	Positive- lower rolling resistance, longer wear tires	Equal
Used existing fuse box, but wiring harness is custom	Uncertain-does custom wiring meet duty requirements of new electronic systems	Uncertain-if custom wiring does not meet new duty requirements, may result in loss of vehicle system control during operation
High strength axle shafts were custom made to fit Solectria motor drive	Equal-high strength axle shafts match electric motor requirements	Equal

Table 6 Cont. List of primary vehicle component modifications

Modification	Functional Impact	Safety Impact
Removed incandescent bulbs in engine and trunk compartments. Replaced with xenon or low power LED lights	Equal- xenon and LED lights are proven in these and other applications	Positive-remove potential ignition sources for hydrogen leaks in trunk and engine compartments
Front frame was modified to mount radiator Aluminum radiator is integral with frame using rivets.	Equal- frame integrity does not appear to be compromised. In fact, radiator Mounting appears to provide additional strength to frame.	Equal
Power brake vacuum pump added to assist brake booster.	Equal- pump needed to replace lost Engine vacuum. Uncertain- has pump been sized correctly?	Uncertain- as long as pump has been sized correctly
Electric power steering pump was added	Uncertain — Has pump has been sized correctly?	Equal –as long as pump has been sized correctly
Ford original SHO engine and transmission removed. Added H-Power Fuel Cell stacks (2) mounted to new subframe and shock tower brace.	Equal — fuel cells appear to be adequately mounted. Uncertain — fuel cell operation could not be evaluated; have fuel cells have been sized to provide adequate power requirements for vehicle? Negative — have fuel cell mounts been adequate damped for vibration?	Uncertain- fuel cell operation could be evaluated Negative- original engine provided frontal crash stability. Fuel cell stacks will not offer same frontal crash absorbing capacity as original engine since vehicle frame not designed for furl cell powerplant.
Added Solectria electric motor and power electronics (motor controller, boost converters, etc.) Axle shafts were made chrome moly steel.	Equal- motor mounts appear to be adequate Uncertain- motor operation could not be evaluated Positive- if motor has been sized to provide maximum vehicle power requirements and may actually improve vehicle acceleration characteristics.	Uncertain- motor operation could not be evaluated.

Table 6 Cont. List of primary vehicle component modifications

Modification	Functional Impact	Safety Impact
Added Neocon battery controller and nickel metal hydride battery packs (2), one under passenger back seat, the other under trunk area in place of spare tire location. Battery packs secured with brackets to underbody frame rails.	Equal- battery packs secured adequately to frame rails. Batteries should provide necessary power and energy storage requirements Uncertain- battery operation could not be evaluated	Equal- Battery locations are low on vehicle so weight inertial impacts minimal. Batteries brackets and mounting locations on frame rails appear to be adequate. Uncertain- unsure about battery off gas isolation from passenger compartment, and battery and electronic controls exposure to road debris from underside battery fans.
Removed original gasoline fuel tank. Added Millennium Cell hydrogen generator, fuel tank, fuel pumps (2), waste tank to trunk and hydrogen gas fuel lines to fuel cell stacks at front of vehicle.	Uncertain — system was not fully Operational during site visit Negative- loss of functional trunk space	Equal — component mounting appeared reasonable. Negative — hydrogen generator not properly shielded to prevent exposures to hot materials or reactant loss. Waste tank vent line opening improperly installed in rear wheel well. I hydrogen lines to fuel cell in front of vehicle not routed properly to prevent road damage. Need electronic hydrogen fuel cut-off solenoid and fuel pump shut-off in case of fuel line or fuel cell leaks. Need hydrogen monitors installed in both trunk and engine compartments.
Original steering wheel replaced with non- air bag competition wheel.	Equal	Negative — new steering wheel does not have air bag as original did.
Fuel cell humidifier system added.	Equal- system generally self sufficient since uses fuel cell water by-product.	Equal

Table 7 List of primary vehicle system modifications

Modification	Functional Impact	Safety Impact
Vehicle Systems		
Original 1993 Sable ABS braking system replaced with standard Taurus braking system	Negative — non-ABS vehicle braking characteristics degraded relative to original ABS system.	Negative — ABS provides significant panic stop benefits in terms of stopping distance and vehicle stability.
Regenerative braking capability added to vehicle.	Uncertain — regenerative system could not be evaluated Positive — depending on regenerative braking system control, the system should increase vehicle braking capability and vehicle stability, and longer brake component life.	Uncertain — system could not be evaluated Positive — system could provide better stopping distances and vehicle stability
Body undercarriage modified. Transmission tunnel removed and replaced with riveted aluminum tunnel. Also, undercarriage removed under passenger seat for battery pack installation.	Equal — modifications did not compromise frame rails. Riveted connections are adequate	Equal
Switched from gasoline powered drive system to fuel cell electric drive system.	Uncertain — system operation could not be evaluated; motor control function and driver input response could not be evaluated. Positive — likely improved vehicle acceleration Negative — vehicle operation limited to ambient temperatures above 40 F to prevent fuel cell humidifier freeze-up.	Uncertain- system operation could be evaluated
Switched from gasoline fuel system to sodium borohydride/hydrogen fuel system	Uncertain — system operation could not be evaluated, Negative — waste borax must be removed period ically. Manual start-up necessary for hydrogen reactor system. Significant loss of trunk space with current prototype system.	Uncertain- system operation could not be evaluated Positive- $NaBH_4$ is much more inert than gasoline. Negative- hydrogen is gas with wide flammability range.

APPENDIX 6 – SOLECTRIA MOTOR AND MOTOR CONTROLLER SPECIFICATION SHEETS [22]

SOLECTRIA

Solectria Motors

AC42-A & B

Overview

The Solectria AC42 is a single output, 70kW 3-phase AC induction motor with a nominal speed of 4k rpm and a maximum speed of 10k rpm. It is available in two standard configurations:

AC42-A – Smooth shaft version that can be operated in single or, using the Solectria AT661 motor reduction box, dual motor systems. (See the AT661-AC42-2 data sheet for details.)

- **AC42-B** – Splined-shaft version designed for use with the Solectria AT1200 motor reduction box.

Applications and Features

The Solectria AC42 motor design is suited to large sedans, trucks, shuttle buses, industrial plant vehicles and other applications where low speed torque is important.

- High-efficiency brushless design
- Sealed motor casing
- Compact, lightweight construction
- Low rotating losses
- Low electrical resistance
- Cost effectiveness and high reliability

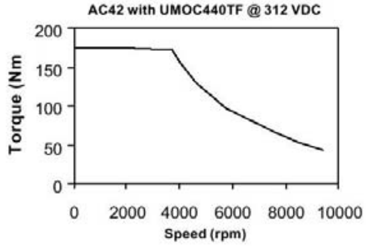
When used in conjunction with a Solectria UMOC, the motor functions as an "electronic transmission," eliminating the need for a multi-speed gearbox. It also can directly drive a vehicle's wheels with a fixed ratio.

Available and Custom Options

- Power and sensor lead and length options
- Available for use as a hybrid generator (Custom)
- Customized features such as end bells and shafts based on customer specifications.
- AT1200 motor reduction box with a 10:1 ratio.
- Optional cooling shroud
- Interface package includes mating connectors (not required if purchasing a Solectria motor controller)

An engineering fee applies to all customized orders.

Torque-Speed Envelope
AC42 with UMOC440TF @ 312 VDC

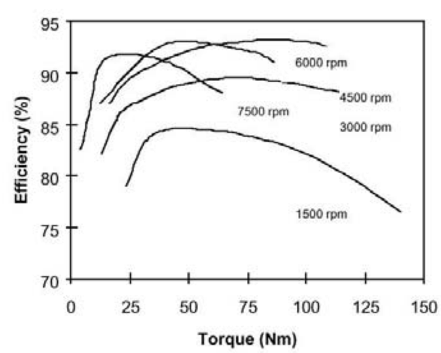


Shown with Optional Cooling Shroud

Specifications

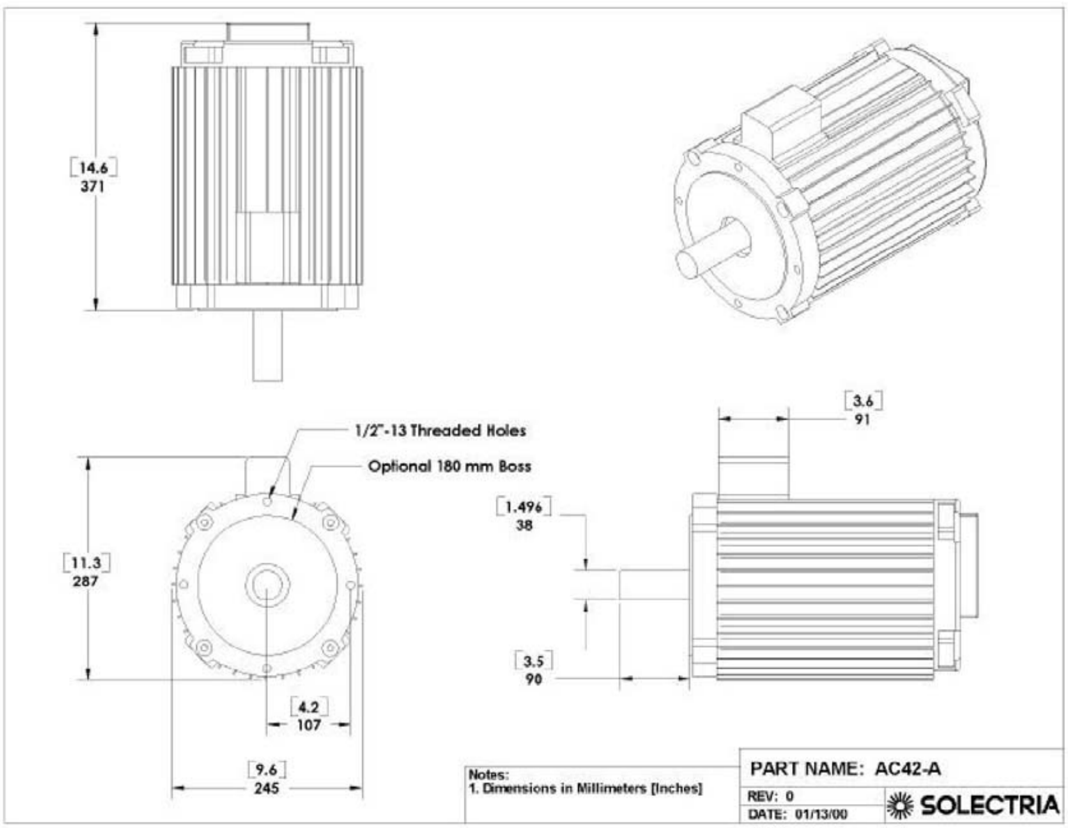
Peak Torque	150Nm
Maximum Current	240A rms
Continuous Torque	42Nm
Continuous Power	21kW
Peak Efficiency	93%
Motor Controller	UMOC440TF
Peak Electrical Power	78kW
At Voltage of	312 VDC
Nominal Speed	4k rpm
Maximum Speed	10k rpm
Weight	60.5kg
Diameter	248mm
Length	368mm

Efficiency vs. Torque
AC42 with UMOC440TF @ 312 VDC



Solectria Corporation, 33 Industrial Way, Wilmington, MA 01887 USA
Tel 978-658-2231 / Fax 978-658-3224 / sales@solectria.com / www.solectria.com
All specifications subject to change.
Revised September 2000

Solectria AC42-A



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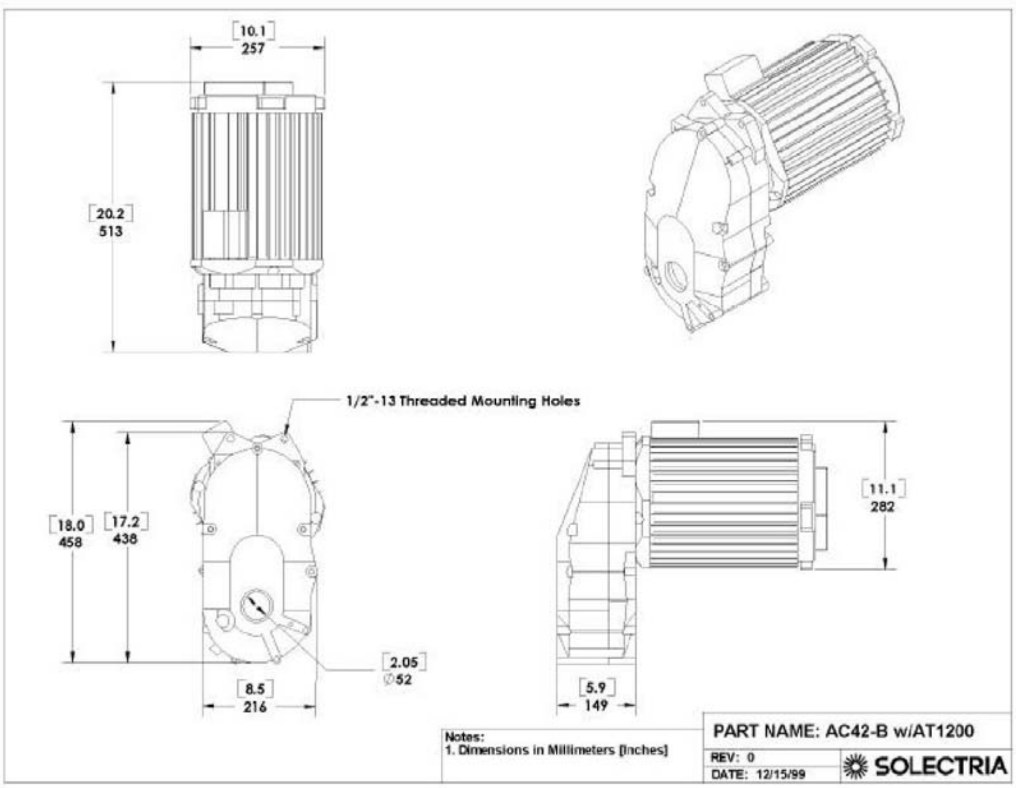
Solectria AC42-B
(Shown with the AT1200 Gearbox)



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SOLECTRIA

Solectria Universal Motor Controllers

UMOC440T and 425T

Overview

The Solectria UMOC is a self-contained, microprocessor controlled, three-phase AC vector control power inverter for AC induction, DC brushless traction drive and auxiliary drive motors. The UMOC utilizes highly reliable IGBT power semiconductor switches.

Applications

Responding to all input sensors and commands, the UMOC provides the power output necessary to operate an over-the-road vehicle. In addition to controlling the main traction motor, the UMOC can send signals to dashboard displays and exterior vehicle signal lights.

Features

- Regenerative braking
- Automatic thermal protection
- Over and under voltage limits for batteries
- Internal contactor
- Self contained operation
- High-speed microprocessor
- Multi-level safety systems
- Lightweight aluminum chassis

Available and Custom Options

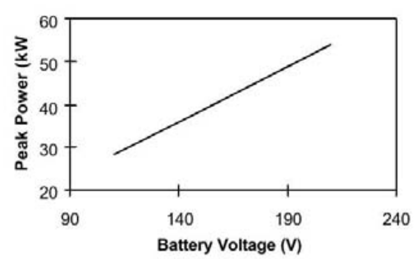
- Interface kit for "plug and play" accessories
- High-power cooling system
- Driver's console can be configured to operate single or multiple controllers
- Factory customized parameter settings

An engineering fee applies to all customized orders.

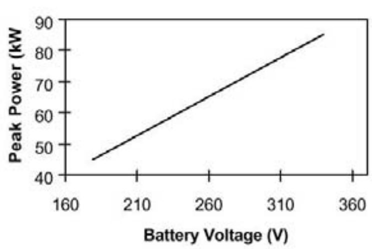
Specifications

	440T	425T
Dimensions	488mm x 225mm x 195mm	
Weight	11.8kg	
Min. Nominal Battery Voltage	216VDC	120VDC
Max. Nominal Battery Voltage	312VDC	192VDC
Min. Operational Voltage	160VDC	90VDC
Max. Operational Voltage	370VDC	240VDC
Unit Efficiency	96-98%	96-98%
Min./Max. Operating Temps.	-40°C to 70°C	-40°C to 70°C
Maximum Current	250A rms	250A rms
Peak Power	78kW@312V	37kW@144V
Continuous Power	34kW@312V	17kW@144V
Max. Voltage "On Charge"	400VDC	240VDC

Battery Voltage vs. Peak Power
UMOC425T



Battery Voltage vs. Peak Power
UMOC440T



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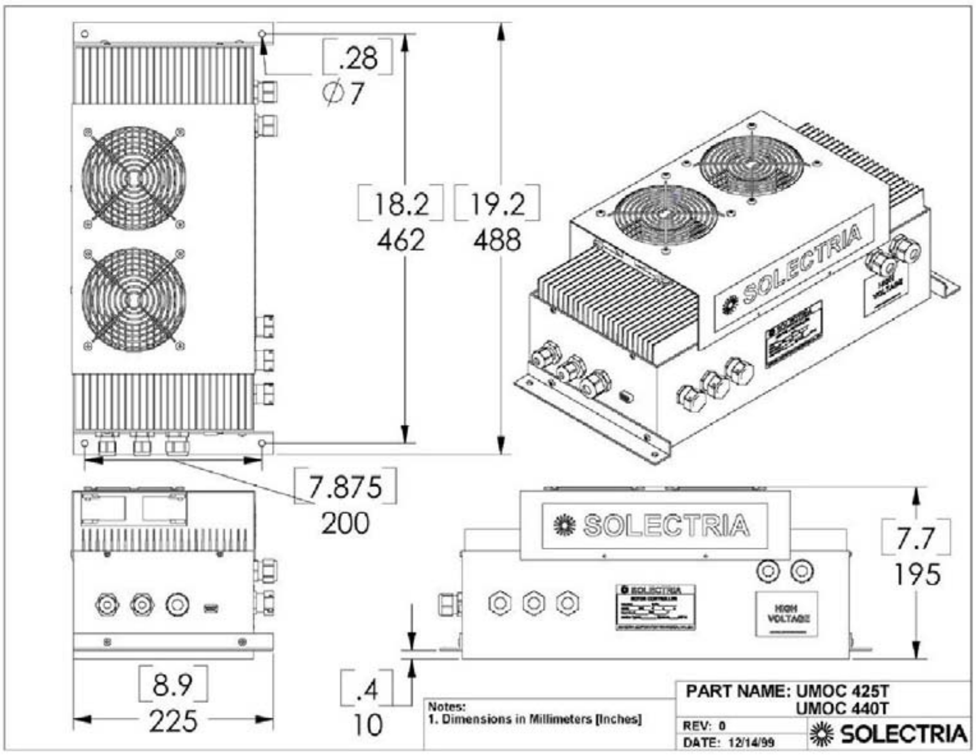

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Revised August 2000

APPENDIX 7 – GOLD PEAK BATTERY SPECIFICATION SHEET [23]

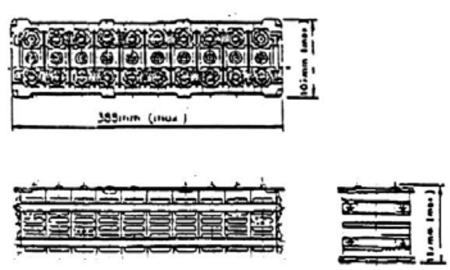
GP® GREEN • CHARGE 10/GP45EVH

Data Sheet for 10/GP45EVH

Specifications :

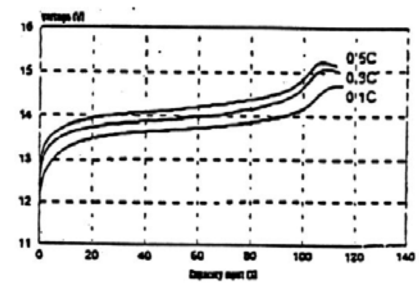
Type	Rechargeable Nickel Metal Hydride Prismatic Cell
Model	10/GP45EVH
Nominal Dimension	388 x 107 x 117 mm
Nominal Voltage	12.5 V
Nominal Capacity	45Ah at 13.5A discharge to 10V/Module or 1.0V/Cell at 20°C
Specific Energy	50 Wh/kg at C/3 discharge
Specific Power	205 W/kg at 80% DOD/30 sec.
Charging Condition (Consult GP for other charging conditions)	-dV : 0mV to 20mV TCO : 50°C Timer : 100% nominal input 15V at 4.5A charging
Max. Charging Temp.	Cell temperature must not exceed 55°C
Service Life	>1500 Cycles
Continuous Overcharge	1.5A maximum No conspicuous deformation and/or leakage.
Weight	11 kg
Internal Resistance	Below 8 mΩ upon fully charged
Ambient Temperature	Charging : 0°C to 55°C Discharging : 0°C to 55°C Storage : 0°C to 55°C
Max. Continuous Discharge Current	225A

Battery Pack:

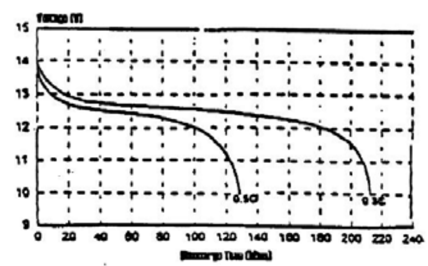


Characteristics :

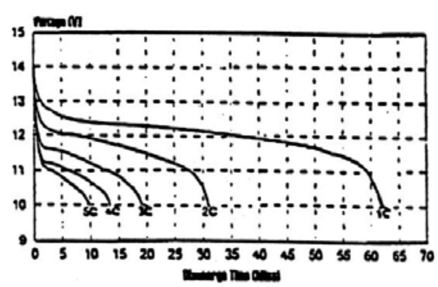
Charge



Low-rate Discharge



High-rate Discharge



* The above information is generally descriptive only and is not intended as guarantee or warranty. Cell and battery specifications are subject to change without notice. All descriptions or warranties are contained solely in specification sheets accompanying formal offers. Please consult GP for conditions of application outside those described in this document.

The Gold Peak Industries Group

Manufacturer reserves the right to alter or amend the design, model and specification without prior notice. 12/99

APPENDIX 8 - ADDITIONAL TECHNICAL PICTORIAL

Figure 36 Millennium Cell, Inc. Hydrogen Generator Model 1 designed to power a 1.2 kW fuel cell.

Figure 37 Millennium Cell, Inc. hydrogen generator test stand used to develop hydrogen generator design prior to installation in the vehicle.

Figure 38 Hydrogen generator test stand condenser water reclamation tank used to develop hydrogen generator design prior to installation in the vehicle.

Figure 39 Fuel cell air compressor assembly.

Figure 40 Custom fuel cell system frame assembly.

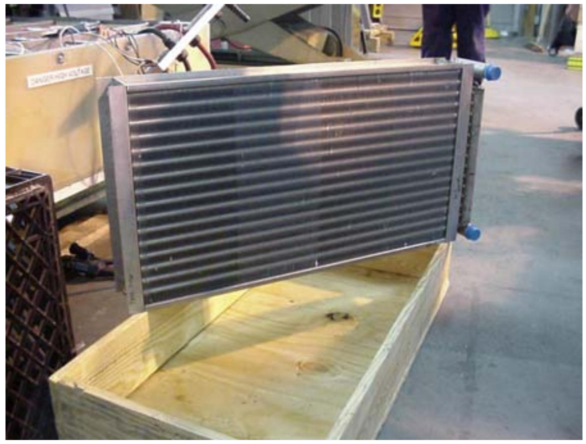


Figure 41 Custom stainless steel radiator to cool fuel cell system.

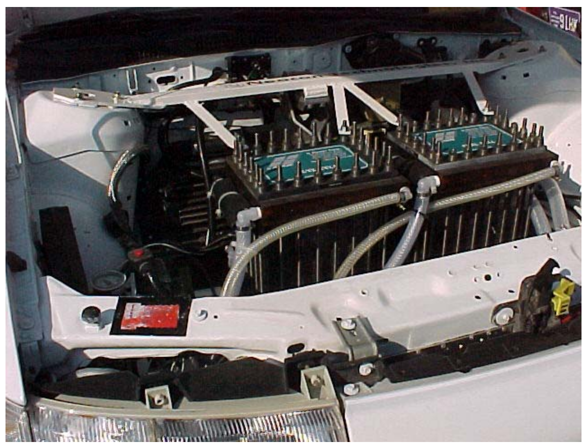


Figure 42 Two 7 kW (gross) fuel cell stacks installed in Genesis vehicle.