SMOKEY'S LAST RIDE:

A SMALL-SCALE APPROACH TO ALTERNATIVE FUELS

Presented to:
Dr. Fred Weber, Department of Chemical Engineering
University of Tennessee-Knoxville
April 28, 2006

Prepared by:
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SENIOR PROJECT - PROSPECTUS
UNIVERSITY HONORS PROGRAM

Name: Christopher Luke Stewart

College: Engineering Department: Chemical Engineering

Faculty Project Advisor: Dr. Fred Weber

PROJECT TITLE: Smokey's Last Ride : A Small Scale Approach to Alternative Fuels

PROJECT DESCRIPTION (Attach not more than one additional page, if necessary):

Every year, the American Institute of Chemical Engineers has a competition in which teams of chemical engineering students from universities around the country compete with a car designed to run solely off of a chemical reaction. This car is set to run from an acid-metal deprotonation with a hydrogen fuel cell. It will also contain several features that are unique chemical engineering processes that will improve both the safety and environmental issues of the car.

Projected completion date: April 10, 2006

Signed: Christopher L. Stewart

I have discussed this research proposal with this student and agree to serve in an advisory role, as faculty project advisor, and to certify the acceptability of the completed project.

Signed: [signature], Faculty Project Advisor

Date: 1/19/06

Return this completed form to The University Honors Program, F101 Melrose Hall.

(January 2006)

SENIOR HONORS PROJECT: ADVISOR PROGRESS REPORT
University Honors Program

Faculty Project Advisor's Name: Dr. Fred Weber

I have met with Christopher Luke Stewart and reviewed the progress being made on her/his Senior Honors Project.

Progress is satisfactory ✓

Progress is unsatisfactory ___

If progress is unsatisfactory, please note here the plans that have been made to move the project forward.

Student's Signature: Christopher L. Stewart Date: 3/16/06

Faculty Advisor's Signature: [signature] Date: 3/16/06

Student should return this form to University Honors by the ninth week of the term.

(January 2006)

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ABSTRACT

The world is an ever-changing place and as more of the world becomes industrialized, our dependency on fuel sources derived from petroleum increases. Petroleum is a non-renewable fuel source, and as our dependency grows, petroleum reserves diminish at an exponential rate. Eventually, the world's supply of petroleum will be depleted, and it is for this reason that we need to start exploring the use of alternative fuel sources. This report will focus on the small-scale development of a car that will run on an alternative fuel that is produced from a chemical reaction.

The University of Tennessee (UT) Chem-E-Car is powered by hydrogen that is produced by the deprotonation of hydrochloric acid (HCl) by magnesium metal (Mg). Hydrogen that is created from this reaction is then used in a hydrogen fuel cell that generates the power needed for the motors on the car. After the calibration and testing of the car was completed, it was entered in a competition between other schools at the American Institute of Chemical Engineers (AIChE) Southern Regional Conference (SRC). The Chem-E-Car teams were given a specific distance that their cars had to traverse while carrying a specific weight load of water. The top five teams that came closest to the given distance qualified for the national competition to be held this fall in San Francisco.

The competition, which was held at Mississippi State University on March 11, 2006, featured 17 teams from colleges throughout the southeastern United States. The required distance was 68 feet and the water load was 220 mL. Each team was given two runs, and their closest finish to the required distance determined their placement in the competition. After the first round, the UT Chem-E-Car team was in first place being 8'8" under the required distance. Over-corrections in the second round placed the UT Chem-E-Car team fourth overall, traveling 7'6" over the required distance.

The chemicals used by the UT Chem-E-Car team are flammable, corrosive, and expensive. While the car proved to be successful at the competition, a larger scale would not be economically feasible. Producing and storing hydrogen should be the main focus of future research into the use of using it as an alternative fuel source. For the national competition in the fall, the team should focus on developing a more detailed calibration and correcting the alignment problem.

INTRODUCTION

Alternative fuels have been the topic of much national attention in the recent few years. On Earth Day 2006, President Bush promoted the use of alternative fuels, particularly fuel cells, as a method to decrease dependency on foreign oil.[1] Several alternative fuel sources are currently being explored, such as hydrogen, ethanol, methanol, liquefied natural gas, electricity, and biodiesel. Of these, hydrogen and methanol both use fuel cells to transfer their chemical potential energy into usable mechanical kinetic energy.

There is currently much research being done on these systems at both the industrial and collegiate levels. Ford, Mazda, Honda, and General Motors have spent millions of dollars in researching fuel cells with the hope of alleviating the use of non-renewable resources as fuel.[2] Each year, the national chapter of the American Institute of Chemical Engineers (AIChE) holds a Chem-E-Car competition at its national conference. This competition is between universities throughout the United States to develop a small car that runs off of a chemical reaction. Specifically, the car cannot produce any harmful exhaust, so effectively, the goal is to research alternative fuels. The top five finishers in each regional conference qualify for competition at the national conference.

The University of Tennessee (UT) Department of Chemical Engineering Chem-E-Car Team focused our efforts on utilizing a hydrogen fuel cell to power the car. The 2005 UT Chem-E-Car produced hydrogen from the electrolysis of water, which was fed to a hydrogen fuel cell. The competition rules stipulate that a car must have significant modifications from previous years. The first one that we considered was changing the method of hydrogen production. Other problems with the previous car included an insufficient storage vessel for hydrogen fuel, an inadequate fuel flow system, and an improper gear ratio. Our plans for 2006 were to continue the usage of the hydrogen fuel cell, but alter the method of hydrogen production and address the other issues the previous car had.

BACKGROUND

Since the regional conference is held in the spring, the work on the development of the car begins in the previous fall. This project is taken as a senior design course in chemical engineering. The design of the Chem-E-Car is tailored to meet the needs of the rules that are set by the national chapter of AIChE. The main rules state that the car must: run off of a chemical reaction, traverse between 50-100 feet, carry a water load between 0-500 mL of water, fit in a shoe box with dimensions of 40 x 30 x 18 cm, and expend all fuel and come to a stop in 2 minutes. A diagram of the course layout is shown below in
Figure 1.

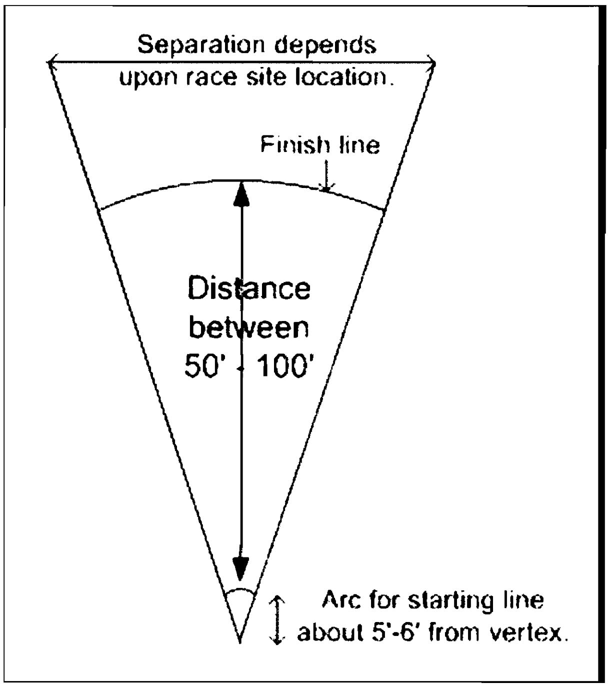

Figure 1 - Course Layout

Chemical Reaction

While the previous team produced pure hydrogen gas (H_2) with the electrolysis of water (splitting water atoms via electrical current), they did not have a sufficient method of storing enough H_2 to traverse the maximum distance while carrying the maximum load. During the development phase of the project, production and storage of H_2 was one of the main focuses of the 2006 UT Chem-E-Car team. We thought back to our high school chemistry lab for a possible simple solution to the problem. In chemistry lab, many high school students get the opportunity to produce H_2 from the deprotonation of hydrochloric acid (HCl) with zinc (Zn) metal. Zn is in the +2 oxidation state, meaning to create a stable molecule, it will accept two electrons, which it does from two moles of HCl. Chlorine has a formal charge of -1, and thus two chlorine atoms bond to one zinc atom to form a stable byproduct of the reaction. This leaves the single hydrogen atom with a charge of +1. Hydrogen only has one proton in its nucleus, and thus since zinc breaks the hydrogen-chlorine bond, this is called a deprotonation. Two hydrogen atoms bond together to form H_2, or diatomic hydrogen, which is in the gas phase. The formal balanced chemical reaction is shown below:

$$Zn_{(s)} + 2HCl_{(l)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$$

Our initial idea was to use this type of H_2 production for our fuel. Zinc can be in mossy form, which are chunks of non-uniform metal for increased surface area. This type of Zn, along with 6M HCl (6 moles of HCl per liter of solution), was obtained from the UT chemistry department. After several trial runs, it was evident that zinc produced enough hydrogen to power the car, but the reaction was too slow for the given time restraints. We thought that this might be due to the large chunks of mossy zinc that were being used. The solution to this problem would be to break up the pieces of mossy zinc to produce a more homogenous mixture. Thus, we obtained powdered zinc, which did give a faster reaction rate, but we had to use almost minute amounts of zinc in the reaction to produce the correct distance. Finally, we obtained magnesium (Mg) in hope of optimizing the reaction rate and required distance given the various loads. This, in fact, did work, and the final reaction is shown below:

$$Mg_{(s)} + 2HCl_{(l)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$$

This reaction eliminates the need for a separate H_2 storage vessel, (which was one of the issues with the 2005 team) since the H_2 is used as soon as it is produced in the on-board reaction vessel.

The Mg used was in ribbon form as shown in Figure 2 below.

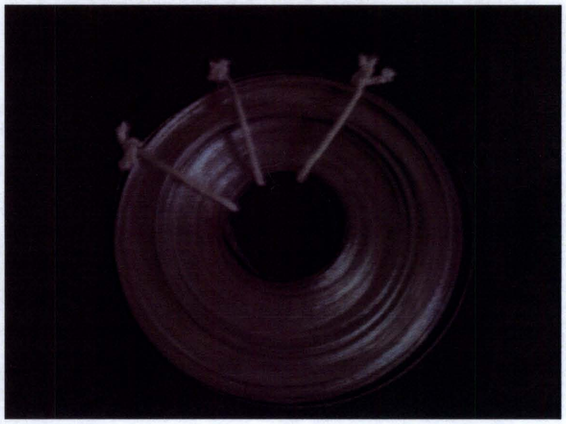

Figure 2 - Magnesium Ribbon

Given that three equivalent lengths of Mg weighed the same, the strips were of constant density, and thus our calibrations could be based on lengths of Mg strips as opposed to weighing particular masses of Mg. The HCl was initially in 6M form, but due to its harmful effects on the fuel cell (discussed later), it was diluted to 2M, shown below in Figure 3.

Figure 3 - 2M Hydrochloric acid

The dilution was carried out via the following equation:

$$M_1V_1 = M_2V_2 \qquad \text{Equation 1}$$

where M represents the given molarity, and V represents the volume of that molarity solution. To obtain a significant amount of constant molarity HCl, we diluted the 6M concentration to close to a full liter of 2M HCl. The actual calculation is shown in the Appendix. This produced 900 mL of solution containing 300 mL of 6M HCl and 600 mL of de-ionized water.

Chassis

In thinking about the chassis for the 2006 car, it was decided to abandon the design from the previous year and start from scratch. Our Professor-In-Charge recommended the use of a Lego Mindstorm™ set due to its flexibility in design and intelligence capability.[3] After researching the opportunities that a Mindstorm™ set would present, the team decided to proceed with the purchasing of a set to use for our chassis design. Some of the opportunities included are: flexibility of design, ability to power individual wheels, and a simple drive system that does not require a gear system. As mentioned previously, the chassis of the 2005 car had an improper gear ratio.

During early chassis development, the team was able to mold the shape of the car to house the different pieces of equipment that are involved in our reaction. The chassis design is shown below in Figure 4.

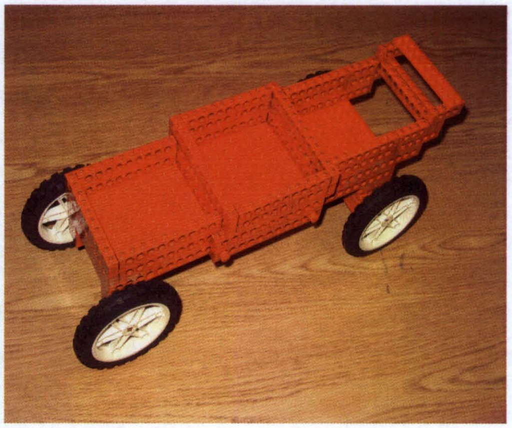

Figure 4 – Chassis

This chassis of the car is used to house the reaction vessel in the front compartment, the water load of hydrogen in the middle compartment, and the hydrogen fuel cell in the rear compartment. Originally, only two motors, one on each of the rear wheels, were used to power the car. However, after testing was done with the maximum water load, it was evident that two motors would not supply sufficient power to move the car. Therefore, due to the design flexibility of the Mindstorm™ set, motors were added to the two front wheels on the chassis. The four motors of the car were wired together in parallel and connected directly to the fuel cell.

One of the reasons that the Mindstorm™ set was chosen was for the intelligence capability that it provided. It was thought that a control system could be added to the car that would aide in controlling the distance that the car would travel. While this is a good idea, this is barred from the competition per the rules. For cosmetics, the body of the car was painted UT orange. After the painting, it was noted that the metal electrical connectors on the motors were covered with paint, which dissipated the electrical current that went to the motors. The paint was scraped off, and the car was retested. This testing revealed a distinct alignment problem that caused the car to pull to the left. Our thoughts are that one of the motors was damaged by paint entering the electrical chamber of the motor. In any event, this alignment problem was not severe enough to warrant buying a new Mindstorm™ set, so we proceeded accordingly.

Hydrogen Fuel Cell

A hydrogen fuel cell, shown in Figure 5 below, is used to convert the produced hydrogen into electrical energy, which is used to power the four motors on the car.

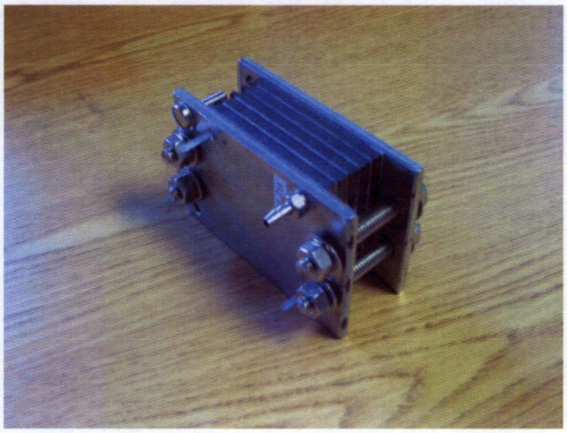

Figure 5 - Typical Hydrogen Fuel Cell

Hydrogen enters the fuel cell through the inlet valve, passes through the membranes in the fuel cell, and reacts with oxygen in air to create water vapor. The reaction between hydrogen and oxygen to form water vapor occurs on a platinum catalyst and is shown below:

$$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(g)}$$

The creation of water vapor is an exothermic reaction, and the energy released is what is converted to electrical energy. As shown from the reaction above, the only by-product of the energy creation is water vapor, which exits via the exit valve on the opposite side of the fuel cell. The motors that power the wheels of the car are wired together in parallel and connected to the metal shell of the fuel cell.

Environmental

The day after initial calibration testing was carried out, the car had significantly less power than when the calibration runs were performed. Upon closer inspection, the exit valve on the fuel cell had significant amounts of solid chlorine accumulation. Thus, we concluded that the fuel cell had been contaminated with HCl entrained in the H_2 gas from the reaction. To verify our thoughts, a litmus test was performed. A sheet of blue litmus paper was held in the product gas as it was released from the reaction vessel. It immediately turned red, indicating that the gas contained an acidic component. The HCl had apparently damaged the platinum catalyst in the fuel cell. Thus, a new fuel cell had to be purchased, and precautionary measures had to be taken to ensure that this would no longer be an issue.

To reduce or eliminate the acid becoming entrained in the products of the reaction, we diluted the HCl from 6M to 2M. In doing so, the reaction between HCl and Mg was not quite as violent. Thus, the hope was that a less violent reaction would not allow the HCl to become entrained in the H_2. This was confirmed by a second litmus test, which suggested the gaseous product contained significantly less acid.

However, as a secondary precaution, a scrubber was added as an intermediate vessel between the reaction vessel and the fuel cell. A scrubber serves to contact product gases with a liquid solvent that absorbs the unwanted component from the gas (i.e., HCl). There are several different types of scrubber setups available. One of which is the packed column, shown below in Figure 6.

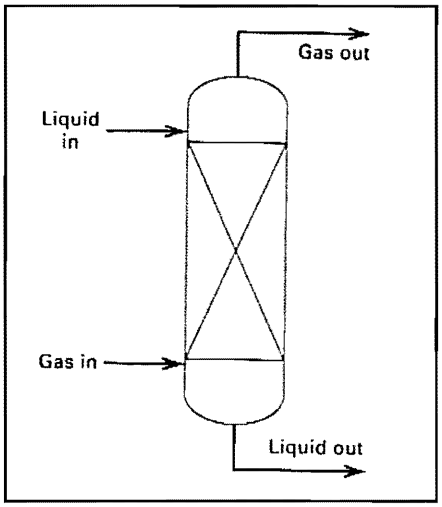

Figure 6 – Packed Column[4]

A packed scrubber allows the product gases to contact a solid packing material, typically made from plastic, ceramic, or metal, in order to allow for a higher surface area for mass transfer. A second type of scrubber is the bubble column, shown in Figure 7 below, which allows the product gases to bubble up through an absorbent liquid. This also allows the gases to contact a higher surface area to increase mass transfer, and thus, effectively remove the acid from them. These two types of columns are widely used in industry due to their high mass transfer capability.[4]

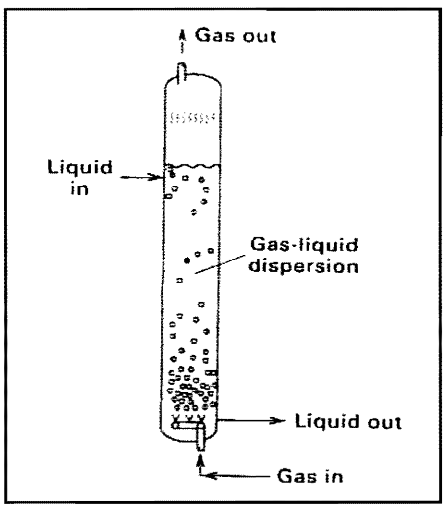

Figure 7 - Bubble Column[4]

The type of scrubber we settled on is a combination of the two previously mentioned. Hydrochloric acid is completely soluble in water. Therefore, de-ionized water was used as the liquid absorbent. Small ceramic saddles and glass wool were chosen as packing materials—the saddles for their high surface area and the glass wool for its demisting capability.[5] The complete scrubber is shown below in Figure 8.

Figure 8 - Scrubber

With the combination of diluting the acid and adding the scrubber, we feel that the gas is less contaminated with HCl. However, adding the scrubber to the middle compartment on the chassis required an addition to the car for the water load. This was facilitated by adding a trailer onto the back of the car, which also added two wheels. These wheels were not motorized but were free turning.

Safety

The personal protective equipment (PPE) required for our chemicals included long sleeves, latex gloves, safety glasses, pants, and non-porous shoes. These precautions were taken to prevent exposure to chemicals. The National AIChE Safety Council requires the use of PPE, and also a detailed analysis of all safety precautions taken during the design of the car. This information is contained in the Job Safety Analysis, which can be found in the Appendix.

The reaction vessel and scrubber are both sealed with a rubber stopper. Since the vessels are closed, internal pressure increases as the reaction proceeds and gas is produced. Per the competition rules, any vessel that contains a pressure greater than that of atmospheric must have a pressure relief device. The stoppers used to seal the vessels serve as pressure relief devices due to the fact they blow in the event of a pressure build-up.

As mentioned previously, the deprotonation of HCl is an exothermic reaction, meaning that it releases heat or energy to the surroundings. When we ran the reaction in the same vessel multiple times, we noticed that the reaction vessel did in fact get quite hot. To avoid melting the paint or the Legos on the chassis, a small piece of Styrofoam was added to the bottom of the reaction vessel. A temperature gradient calculation was carried out in order to determine an approximate temperature rise. In order to complete this, several assumptions had to be made. Those assumptions are: an HCl density of 1 g/mL (since it was a dilute, aqueous solution), a heat capacity of HCl ~ 0.74 cal/g-°C, an average Mg length of about 6 in., a volume of HCl is 20 mL, and an average mass of Mg of 0.02 g/in. The actual temperature gradient was approximated to be 73.5°C. Detailed calculations are shown in the Appendix.[6]

Calibration

The wide range of water loads and required distances that we could have received at the competition facilitated the need to calibrate the car at several different weight loads and distances. Calibration runs were conducted with the water load, distance traveled, and amount of Mg used recorded in an Excel™ spreadsheet. Two variable statistics were performed on the data to generate an equation that would accept water load and distance and return a value for needed Mg length. The calibration plot is shown in Figure 9 below.

As seen in this figure, there is only data for three water loads. To eliminate any error in acid concentration, a large batch (about 1 L) solution of 2M HCl was prepared for both calibration and performance runs. One liter of solution would have been sufficient to run calibrations at multiple water loads, but several calibration runs were done with the old fuel cell. When the fuel cell was damaged, and a new one purchased, the data previously taken had to be discarded. There was only enough solution left to perform calibrations at three water loads and do performance runs. The water loads were chosen at the minimum, maximum, and an intermediate value (0 mL, 500 mL, and 300 mL, respectively). Any water load value given in between these points had to be interpolated.

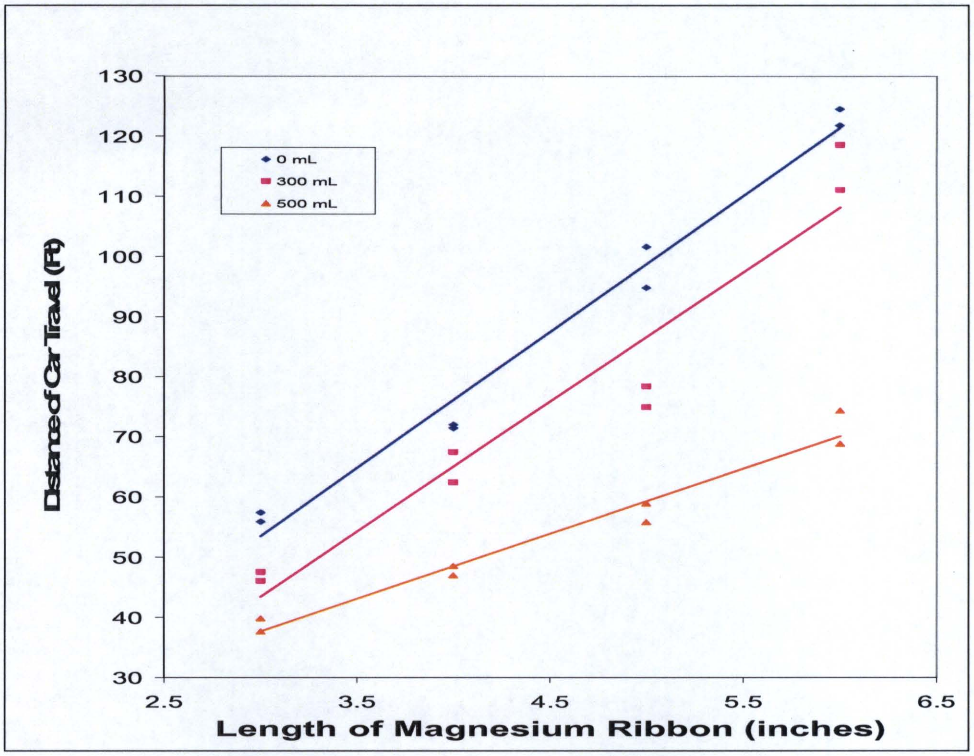

Figure 9 - Calibration Plot for Smokey's Last Ride

Final Design

As mentioned previously, the 2005 UT Chem-E-Car team had an elementary fuel flow system. It consisted of thumb valves used to regulate the flow of H_2 into the fuel cell. Since the valves did not have any gauges or meters on them, it was very difficult to accurately set a flow rate. Therefore, the 2006 team eliminated the use of these valves. Each vessel had completely open flow into them through clear plastic tubing. The reaction vessel was a 50 mL Erlenmeyer flask set inside a 150 mL containment vessel, which was a beaker. The stopper of the reaction vessel was fitted with a burette tip, which was always set to open. The H_2 entered the scrubber via a long glass tube, which was fitted into another rubber stopper. The scrubbed H_2 exited the scrubber via a shorter glass tube also inserted into this stopper. The scrubber itself was a 250 mL Erlenmeyer flask. The final design is shown in Figure 10 below.

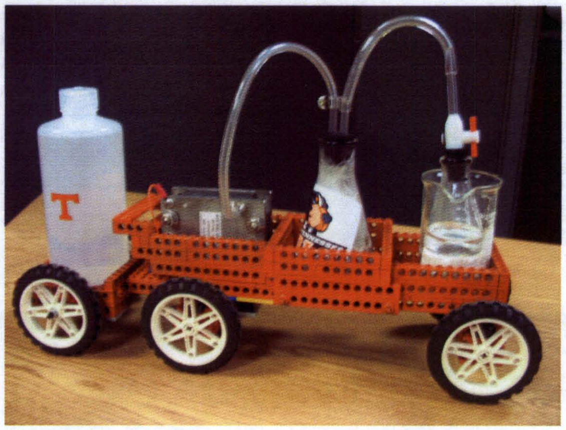

Figure 10 - Smokey's Last Ride

The national rules stipulate that the total cost of the car cannot exceed $1,500. Shown below in Table 1 is the cost analysis. From this table, one can see that the most expensive item was the fuel cell. Other major expenses were the Lego Mindstorm™ set and the roll of magnesium ribbon. However, our total cost of $772 is well within the stated limits.

Table 1 - Cost Analysis

1 Lego Mindstorm™ set	$ 200.00
1 roll Mg	$ 35.00
1 L of 2M HCl	$ 5.00
Paint	$ 10.00
Screws/Bolts	$ 2.00
Beaker	$ 1.00
Flask	$ 1.00
Water Bottle for Weight	$ 5.00
De-I water bottle	$ 5.00
Super glue	$ 4.00
Fuel Cell	$ 475.00
2 stoppers	$ 1.00
Wiring	$ 1.00
Saddles	$ 5.00
Glass wool	$ 5.00
Burette Tip	$ 2.00
Tubing	$ 5.00
Clamp	$ 1.00
Glass tubes	$ 3.00
Stickers/Decals	$ 5.00
Styrofoam	$ 1.00
TOTAL	**$ 772.00**

RESULTS

At the conference, held on March 11, 2006 at Mississippi State University, the distance and water load were given about one hour prior to the competition as 68 feet and 220 mL of water. Based on our Excel™ spreadsheet, the required amount of magnesium was calculated to be 3.83 inches. However, in the practice runs, we were obtaining data with about a 15% error on the long side. Therefore, we reduced the actual amount of Mg to 3.75 inches. Due to the alignment problem, with the car pulling to the left, we aligned the car with the right side of the 20^{o} angle to give it adequate space to pull back to the left. The first round of runs put the UT team in 1st place, being 8'8" short of the required distance. Over-corrections in the second round cost our team a few positions, and we finished 4th overall with a distance of 7'6" over the required distance. Since we finished in the top five, we qualified to compete in the national competition to be held in San Francisco, California in the fall.

CONCLUSIONS

As our car performed well at the regional competition, future work needs to be completed (including more detailed calibrations) to ensure that the car competes well at the national competition in the fall. The alignment problem must also be addressed. The required distance at the regional competition (68 feet) was relatively short given the possible span of 50-100 feet. A longer distance would require the car to be more aligned so there is no risk of deviating off course.

Furthermore, the 2006 Chem-E-Car team was successful in improving upon the previous year's design. Our method of hydrogen production, the deprotonation of HCl by Mg that we obtained from our high school chemistry labs, is sufficiently different than the 2005 team's electrolysis of water, even though we still use the hydrogen fuel cell. The 2005 car had a problem with storing the hydrogen between the time it was created and the time it was used in the fuel cell. Our car, with the continuous reaction occurring during the run, eliminates the need for a storage vessel. The previous team had an elementary fuel flow system with thumb valves, which were nearly impossible to use to regulate the flow of hydrogen. Our car does not require a regulated flow system since the hydrogen generated during the reaction immediately flows into the fuel cell. Finally, the improper gear ratio from the previous car was eliminated by the use of the Lego Mindstorm™ set, which has motors for each wheel and does not need any type of gear system.

Finally, the idea of using a hydrogen fuel cell as an alternative fuel source seems to be feasible. Even though our design placed well in a small-scale competition, it would not be economically feasible on a larger scale. Further research needs to emphasize the method of hydrogen production to reduce costs.

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APPENDIX

HCl Dilution Calculations

$$V_2 = \frac{6\ \text{mol/L} * 300\ \text{mL}}{2\ \text{mol/L}} = 900\ \text{mL}$$

Temperature Gradient Calculations

$$\Delta H_f = \Delta H_{f,MgCl_2} - 2\Delta H_{f,HCl} = (-189.76) - 2(-39.85) = -110.06\frac{kcal}{mol}$$

$\Delta H_{f,Mg}$ and $\Delta H_{f,H2} = 0$ since they are in their standard states

$$0.02\frac{g\ Mg}{in} * 6\ in * \frac{1\ mol\ Mg}{24.31\ g\ Mg} * \frac{2\ mol\ HCl}{1\ mol\ Mg} = 0.00988\ mol\ HCl$$

$$\Delta\text{H}=\text{mC}_\text{p}\Delta\text{T} \rightarrow \Delta\text{T} = \frac{\Delta\text{H}}{\text{mC}_\text{p}} = \frac{110,060\frac{cal}{mol}}{(20g)*\left(0.74\frac{cal}{g^oC}\right)} = 7,436.5\frac{^oC}{mol} * 0.00988\ mol = 73.5^oC$$

Job Safety Analysis for Chem-E-Car Competition

Use this form to identify the potential hazards for the construction and operation of the Chem-E-Car.

Equipment Name: Smokey's Last Ride	**JSA Author:** Dustin Tremaine
Room Number/Building: Dougherty 223	**Faculty Supervisor:** Dr. David Keffer
Revision #: 3	**Revision Date**: 3-7-06

Concept and Major Hazards of the Design: Describe the car design concepts and state the major hazards during the construction and operation of this Chem-E-Car.

The car body and chassis is built from a Lego Mindstorm™ set. The chemical reaction used for the propulsion of the car is the deprotonation of hydrochloric acid with magnesium ribbon. As the reaction proceeds, hydrogen gas is given off. This gas is then scrubbed and sent to a hydrogen fuel cell which will generate electrical power to turn the motors on the car. The car will continue to run until the reaction has come to completion and all hydrogen gas is spent. Hazards are as follows: 1) 2M HCl is corrosive. 2) Magnesium ribbon is flammable. 3) Reaction between the two is exothermic. 4) Hydrogen gas given off is flammable.

Operating Experience: Briefly describe your experience with the design and operation of the Chem-E-Car, including: hours of testing, failures and design corrections, etc.

During the construction of the car, we ran into several problems that had to be corrected and they are as follows: 1) We were going to use the same chassis from last year's competition with adjustments to the motor, gear ratios, axles, and tires. In doing this, we found that this idea was inadequate and decided to use the Lego Mindstorm™ set so that gear ratios were no longer an issue. 2) Originally, mossy zinc was going to be used to deprotonate the HCl. We found that due to inconsistent densities in the pieces of zinc, that calibration was difficult. We then decided to try zinc powder. While the density was more homogenous, the reaction proceeded too slowly. Magnesium ribbon was then tested since it is a more active metal. This reaction proved to proceed at an acceptable rate. 3) The original car design was to have only two motors, one on each of the rear wheels. When calibration runs were done with 500 mL of water, only using two motors provided inadequate power to move the car. Two additional motors were added, one to each of the front wheels, which proved to provide enough power. 4) Initially, we were going to use 6M HCl. Calibration runs with this concentration proved to react too quickly, and large amounts of magnesium were being used. In addition to this problem, hydrogen gas was being generated so quickly that HCL was entrained in the hydrogen gas. It was then decided to dilute the acid to slow down the rate of reaction. It was found that 2M HCl provided the desired rate of reaction. 5) After changing the concentration and amount of metal used for the reaction, evidence of chlorine corrosion became present on the fuel cell. In order to combat this corrosion that in turn decreased performance of the fuel cell, it was decided that a scrubber be used to scrub the entrained HCl from the hydrogen gas. The damage done to the initial fuel cell was to such an extent that a new fuel cell had to be purchased. 6) Numerous hours of testing and calibration were done

on the car. An estimated amount of time that each team member spent on building and calibrating the car is approximately 30 hours.

Personal Protective Equipment (PPE) – Check all PPE worn during fabrication and operation of the equipment.

☒ Long Pants	☒ Safety Glasses	☐ Hard Hat	☐ Apron
☒ Long Sleeves	☐ Splash Goggles	☐ Insulated Gloves	☐ Ear Protection
☒ Non-porous Shoes	☐ Face Shield	☒ Chemical Gloves	☐ Other:

Expected Operating Conditions –

Temperature	**Pressure**
Normal: ambient	Normal: 1 atm
Minimum: 40°F	Minimum: 1 atm
Maximum: 100°F	Maximum: 1 atm

Special Fabrication or Operating Conditions - Check all that apply.

Unattended Operation: ☐	Drying Oven: ☐
Regulated Chemicals: ☐	Class 3b or 4 Lasers: ☐
Pressures Exceeding 2 atm (29.4 psia): ☐	
Temperatures Exceeding 200°C: ☐	

Available Safety Equipment – Provide the location of each item shown below. Show the location of this equipment on an attached floor plan at school and at contest sites. If not available, type "NA" in the field.

Item	**Location**
Fire Extinguisher:	Dougherty 2nd Floor Hall Way
Eyewash:	Dougherty Unit Operations Laboratory
Safety Shower:	Dougherty Unit Operations Laboratory
Telephone:	Dougherty 222
First Aid Kit:	Dougherty Unit Operations Laboratory
Spill Kit:	Dougherty Unit Operations Laboratory
Other:	

Fabrication Hazard Summary – Check all hazards that are likely to be encountered during your Chem.-Car construction. List the major source(s) of the hazard and describe how the hazard(s) will be controlled.

Hazard	Major Source(s) of Hazard	Control Method(s)	PPE Required
☐ Arc welding			
☐ Gas welding			
☐ Lathe			
☐ Milling machine			
☐ Handheld power tools			
☐ Drill press			
☐ Pressure > ambient			
☐ Pressure < ambient			
☐ Electrical			
☐ Other mechanical Hazards			
☐ Hot Surfaces/ High Temp > 150 F			
☐ Cold Surfaces/ Low Temp < 0 F			
☒ Paint spraying	Spray Paint Fumes	Used in well ventilated areas.	Breathing Mask
☒ Flammable materials (Solid, liquid, or gas)	Magnesium Ribbon (metal)	Keep away from open flames.	Fire Extinguisher
☐ Toxic materials (Solid, liquid, or gas)			
☒ Reactive materials (Solid, liquid, or gas)	Magnesium Ribbon (metal) Hydrochloric Acid (liquid)	Keep items out of contact from each other until time for reaction.	Safety Glasses, Long Sleeves, Long Pants, Non Porous Shoes
☐ Ionizing radiation			
☐ Laser radiation			
☐ Asphyxiates			
☐ Open flames, exclusive of welding			
☐ Other: _____			
☐ Other: _____			

Operational Hazard Summary – Check all hazards that are likely to be encountered during the operation of your Chem.-Car. List the major source(s) of the hazard and describe how the hazard(s) will be controlled.

Hazard	Major Source(s) of Hazard	Control Method(s)	PPE Required
☒ Flammable materials (Solid, liquid, or gas)	Magnesium Ribbon (metal) Hydrogen (gas)	Keep away from open flames.	Fire extinguisher
☐ Toxic materials (Solid, liquid, or gas)			
☒ Reactive materials (Solid, liquid, or gas)	Magnesium Ribbon (metal) Hydrochloric Acid (liquid)	Keep hydrochloric acid in excess while using minimal magnesium.	Safety Glasses, Long Sleeves, Long Pants, Non Porous Shoes
☐ Pressure > ambient			
☐ Pressure < ambient			
☐ Electrical			
☐ Rotating equipment			
☐ Pinch points			
☐ Hot Surfaces/ High Temp > 150 F			
☐ Cold Surfaces/ Cold Temp < 0 F			
☐ Biohazard			
☐ Laser radiation			
☐ Ionizing radiation			
☐ Asphyxiates			
☐ Steam			
☐ Open flames			
☐ Other: _____			
☐ Other: _____			

Notice: Attach the relief valve calculations to this documentation and display on Poster Board.